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Modeling Effective Maintenance Strategy using Reliability Centered Maintenance with Risk Maintenance

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Abstract
This study was done with the aim of modeling effective maintenance strategy using reliability centered maintenance with risk maintenance. The primary data obtained were analyzed partly in the MS excel and MATLAB computational environment in line with the modeled equations of reliabilityand maintainability condition of a selected rotodynamic system (pump) of a selected petrochemical firm in Rivers State. The maintenance strategies were selected from scheduled maintenance (SM), condition-based maintenance (CbM), Proactive Maintenance (PrM) and design-out modification (DoM) maintenance alternatives. The analyses for ranking of the maintenancealternatives for eachcomponent of the pump showed that, the best alternative for bearing is scheduled maintenance (SM), the best alternative maintenance strategy for impeller condition-based maintenance (CbM), the best maintenance alternative strategy for mechanical seal is proactive maintenance (PrM), and the best maintenance strategy for shaft is proactive maintenance (PrM).

Keywords: **Modeling, Effective maintenance, Reliability centered maintenance, Risk maintenance**

1. Introduction

Reliability, operation, and maintainability of process plant are what determine its performance. Maintenance improves and reconditions equipment for productivity enhancement at reduced production cost. Equipment cannot maintain it efficiency over long period of time without propermaintenance intervention in place. Sustaining or improving equipment efficiency over time through maintenance will sustain productivity.Maintenance approach can be used to mitigate this impact of failure. When Maintenance approach or strategy is not proper or appropriate for the plant, it can lead to increase cost and without justifiable improvement in equipment reliability. Maintenance must be synchronized with production requirement and demand to ensure optimum equipment availability, minimal downtime, and production loss. Equipment with high production demand will require more maintenance attention than equipment with less production demand. Organization seeks and adopts effective maintenance strategy to minimize the rate of machinery deterioration thereby minimizing the associated losses. The maintenance strategy helps to preserve safety, reliability and availability of plant, the plant thereby operates smoothly. Maintenance is all actions or activities done on an asset either technically or administratively or the combination to ensure the asset will be available to perform its intended function at optimal cost. Maintenance helps asset to realize its mission, it keeps or restore asset to acceptable operating condition. Maintenance is done to either prevent or correct failure. When maintenance is done before failure occur, it is often to prevent failure and to keep asset in acceptable operating condition. Maintenance done after item has failed tends to restore the item to its acceptable operating condition. Many literatures have been studied in the modeling effective maintenance strategy using Reliability Centered Maintenance with risk maintenance and some of them are stated: US Department of Energy classes maintenance as reactive, preventive, predictive and RCM; German Standard D1N131051 classified maintenance as preventive, inspection and repair while European Standard EN13306 has its classification as corrective and preventive Khazrei and Deuse, (2011);Different authors categorize maintenance into three types which are preventive, corrective and predictive maintenance (Mondal and Srivastava, 2013; Perajapati*et al*., 2012; Sharma *et al*., 2005; Moayed and Shell, 2009; Gebauer *et al*., 2008);Preventive maintenance is in common use in petroleum and petrochemical industry Zaim *et al*., (2012); The processing plant is put out of service to perform maintenance, overhaul and repair operations and to inspect, test and replace process materials and equipment (Duffua and Ben-Daya, 2004; Lawrence, 2012); Planned shutdown is classified into total and partial shutdown (Hameed, 2016); Selvik and Aven, (2011), developed structure for reliability and risk centered maintenance which suggested extension of RCM to incorporate risk which is not adequately covered in conventional Reliability Centered Maintenance, they took uncertainties, likely events and its consequences as key components of risk; Cheng *et al*., (2008) introduced artificial intelligence into RCM analysis, this involves carrying outReliability Centered Maintenanceanalysis on new equipment using guide from previous similar equipment RCM analysis records; Wang and Gao, (2012), developed Reliability Centered Maintenance based system for decision-making that combines risk evaluation, condition monitoring and performance check, to d up process of RCM analysis. There is serious challenge of implementing a maintenance strategy which ensure equipment availability at optimum level and equipment/system efficiency, decrease the deterioration rate of components, ensure safety and environmentally friendly operation, and reduces total cost of operation.This research work therefore model effective maintenance strategy using RCM with risk base Maintenance. The objectives are: Perform reliability audit and analysis using information obtained from the history file; perform risk base criticality analysis to obtain critical equipment and select appropriate maintenance strategy.

2. Material and Methods

2.1Materials

RCM diagram with modifications sketch to accommodate analytic hierarchy with risk maintenance process when deciding appropriate maintenance strategy for particular component of the system

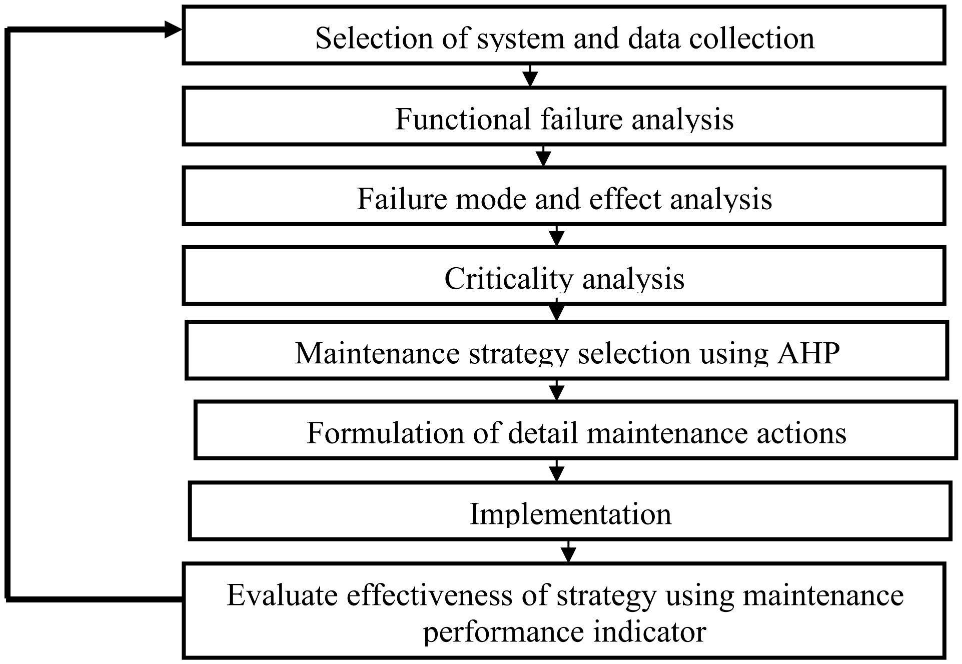

Figure 1: Model Algorithm (Chin *et al*., 1999).

System Selection and Data Collection

A centrifugal pump from petrochemical process plant in Rivers state, Nigeria is selected for case study. The pump takes its suction from butane 1 plant reactor and discharges into the pump around pump coolers and from there back to the reactor inlet at the top. The primary data for this research is obtained from the equipment history file and other data are obtained through professional discussion and questionnaire with plant personnel

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2.2 Methods

The Applied AHP Model

The methodology is applied to all equipment, and it produces appropriate maintenance strategies

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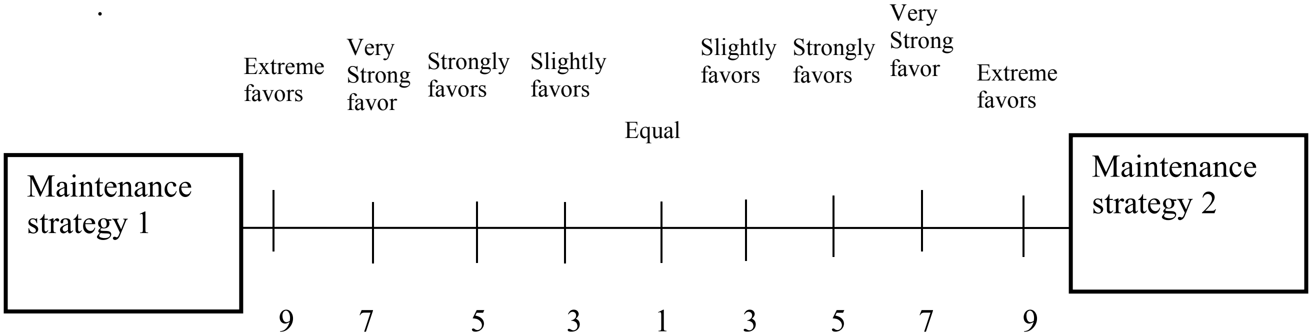

Figure 2: Criteria Ranking Scale

The AHP model applied herein is formulated by considering a general equation:

$$C * x = \lambda_{\max} * x \quad (1)$$

Where:

C is the comparison matrix of size n * n, for n criteria also known as the priority matrix, x is the eigenvector (or priority vector) of size n * 1 and λ_{max} is the eigenvalue.

The actual AHP process is applied sequentially as itemized from steps 1 through 8.

Step 1: List the Overall Goal, Criteria and Decision Alternative

The major goal which is to select the most effective maintenance task is given as the Level 1 element, and then lastly alternatives maintenance strategies are given in Level 3.

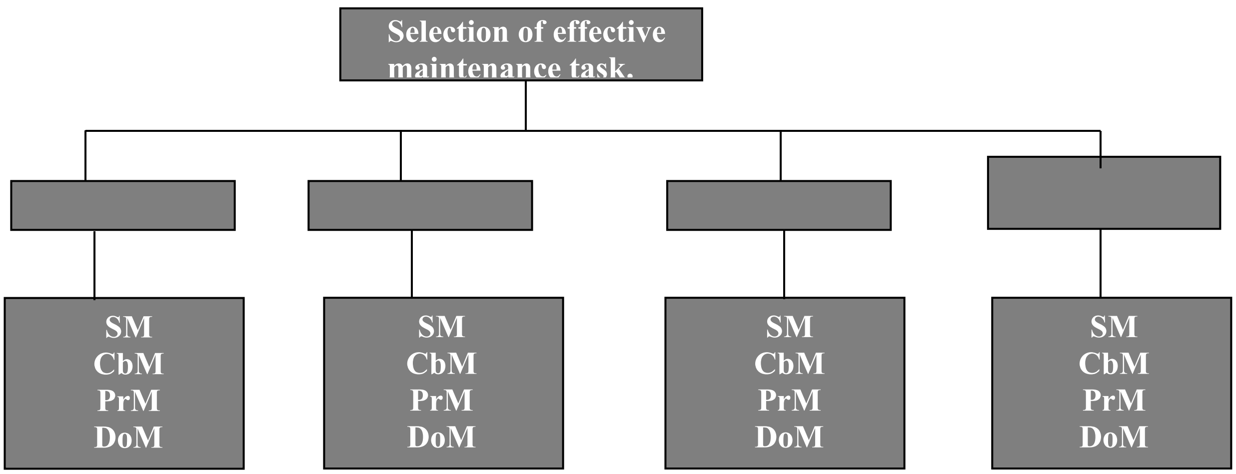

Figure 3: The AHP Schematic Model.

Step 2: Development of Pairwise Comparison Matrix

Each pair of decision alternatives are rated based on relative importance. The alternative is placed horizontally and vertically in matrix form and the matrix has numerical ratings comparing alternative in horizontal (first) with the alternative in vertical (second).

Table 1: The relative pairwise rating of importance alternatives

Relative Importance Pairwise Comparison	Numerical Rating
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	3
Equally preferred	1

Even numeric ratings of 8,6,4,2 can also be assigned. A reciprocal rating the numerical rating is assigned when the second alternative is judge better than the first. The value of I is always allotted when comparing an alternative with same alternative.

Pairwise comparison matrix:

$$C = \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{23} & C_{33} \end{bmatrix} \quad (2)$$

Step 3: Normalized Matrix Development

Each number in a column of the pairwise comparison matrix is divided by its column sum.

Sum of the values in each column:

$$C_{ij} = \sum_{i=1}^{n} C_{ij} \quad (3)$$

Normalized Pair-wise matrix:

$$X = \frac{C}{\sum_{i=1}^{n} C_{ij}} = \begin{bmatrix} X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{23} & X_{33} \end{bmatrix} \quad (4)$$

Step 4: The Priority Vector Development

Thepriority vector of each normalized matrix row is averaged. The averaged rows form the priority vector of alternative preferences with respect to the particular criterion. The values in the priority vector sum to 1.

Weighted Matrix:

$$W = \frac{\sum_{j}^{n} = 1 X_{ij}}{n} = \begin{bmatrix} W_{11} \\ W_{12} \\ W_{13} \end{bmatrix} \quad (5)$$

Step 5: Calculate a Consistency Ratio

The consistency ratio is used to measure consistency of the inputted subjective pairwise comparison matrix. When the consistency ratio is less than 0.1, then the consistency is good. When the ratios are greater than 0.1, the input have to be re-evaluated.

Consistency Vector:

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{23} & C_{33} \end{bmatrix} * \begin{bmatrix} W_{11} \\ W_{12} \\ W_{13} \end{bmatrix} = \begin{bmatrix} Cv_{11} \\ Cv_{12} \\ Cv_{13} \end{bmatrix} \quad (6)$$

$$Cv_{11} = \frac{1}{W_{11}} \left[C_{11}W_{11} + C_{12}W_{12} + C_{13}W_{13} \right] \quad (7)$$

$$Cv_{12} = \frac{1}{W_{21}} \left[C_{21}W_{21} + C_{22}W_{22} + C_{23}W_{23} \right] \quad (8)$$

$$Cv_{13} = \frac{1}{W_{31}} \left[C_{31}W_{31} + C_{32}W_{32} + C_{33}W_{33} \right] \quad (9)$$

Step 7: Development Criteria Pairwise Matrix

The criteria are subjected to pairwise comparison by using subjective ratings and matrix is form.

The matrix normalized as in (step 3) and a criteria priority vector is formed as in (step 4).

Step 8: Development of Overall Priority Vector

The criteria priority vector in step 7 is multiplied by the priority matrix in step 6.

Determining the Consistency Ratio

Step 1: In each row of the pairwise comparison matrix, the weighted sum is of the multiples of the entries by the priority of its corresponding (column) alternative.

Step 2: In each row, divide its weighted sum by the priority of its corresponding (row) alternative.

Step 3: The average λ_{max} of the results of step 2 determined.

Step 4: The consistency index, CI, of the n alternatives computed by Equation (10)

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (10)$$

Step 5: Determine the Random Index (RI) from the standard RI tables as given in Table 2.

Table 2: Random Index Values for n Alternatives.

Alternative (n)	3	4	5	6	7	8
Random Index (RI) Value	0.58	0.90	1.12	1.24	1.32	1.41

Step 6: Determine the consistency ratio, **CR** as given by Equation (9).

3. Results and Discussion

3.1 Results

AHP Results of Equipment Criticality (EC) Sub-criteria for Pump Bearing

Figure 3 shows AHP process and results for pump bearing based equipment criticality criteria.

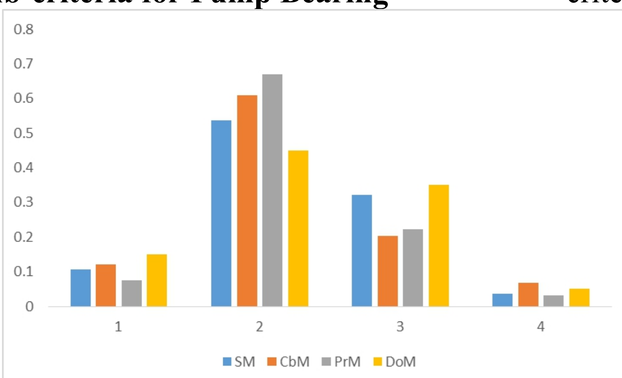

Figure 3: Weights Ratios for EC sub-criteria of Bearing

Figure 3 shows the ranking of maintenance alternative for the bearing based on equipment criticality criteria alone. It can be seen from the graph that the ranking of the maintenance alternative based on equipment criticality for the bearing as seen in the figure is as follow: Proactive Maintenance (PrM) is first with 55.79%, followed by Condition based Maintenance 13%, then Scheduled Maintenance (SM) at 12.19% and Design - out Modification least ranked at 5.69%.

AHP Results of Mean Time to Fail (MTTF) Sub-criteria for Pump Bearing

Figure 4 represents AHP process and results for bearing based on the MTTF criteria.

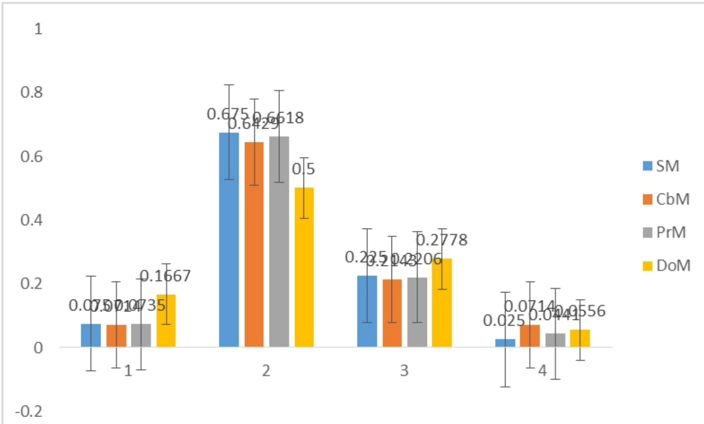

Figure 4: MTTF Alternatives Relationship for Bearing

Figure 4 shows the Analytic Hierarchy of the - criteria of bearing. From the plot, it is seen thatCbM ranked highest in bearing maintenance methods with a weight of 6l.99%, followed by PrM at a weight of 23.44%, where the least two were SM and DoM at weights of 9.67% and 4.90% respectively. Based on weightage of each alternative, the best bearing maintenance technique to be applied, with respect to MTTF criteria, is CbM method.

AHP Results of Mean Time to Repair (MTTR) Sub-criteria for Pump Bearing

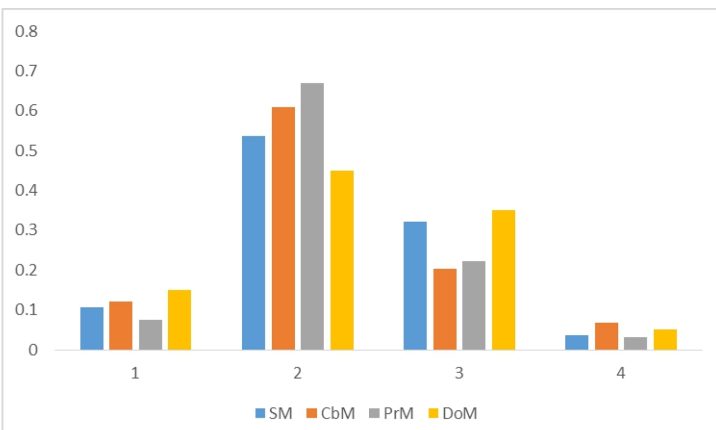

Figure 5: MTTR Alternatives Relationship for Bearing

Figure 5 shows the AHP ranking of maintenance alternative for the bearing based on MTTR criteria alone. From the plot, it is seen that CbM ranked highest in bearing maintenance methods with a' at a weight of 27.44%, where SM and DoM at weights of 11.33% and 4.63% respectively were the least. Based on weightage of each alternative, the best bearing maintenance technique to be applied, with respect to MTTR criteria, is CbM method

AHP Results of Applicability Sub-criteria for Pump Bearing

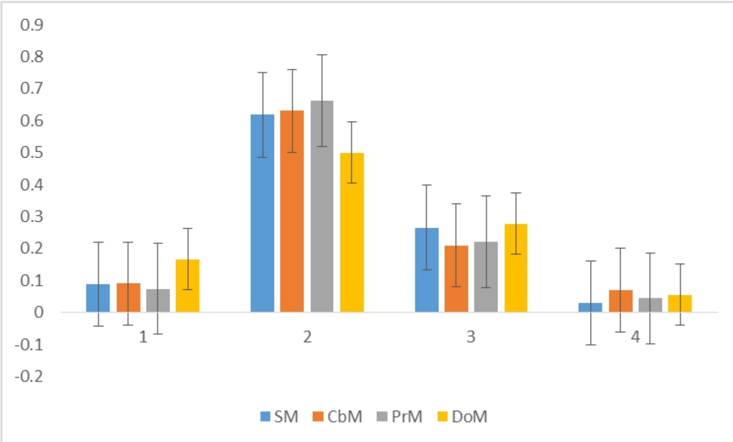

Figure 6: Applicability Alternatives Relationship for Bearing

Figure 6 shows the AHP ranking of maintenance alternative for the bearing based on applicability criteria alone. As can be seen from the plot it is obvious that the maintenance ranking can be given from highest to lowest as SM>CbM>PrM>DoM at rates of (59.20% >26.20%> 10.07%> 4.53%).

AHP Results of Equipment Criticality (EC) Sub-criteria for Pump Impeller

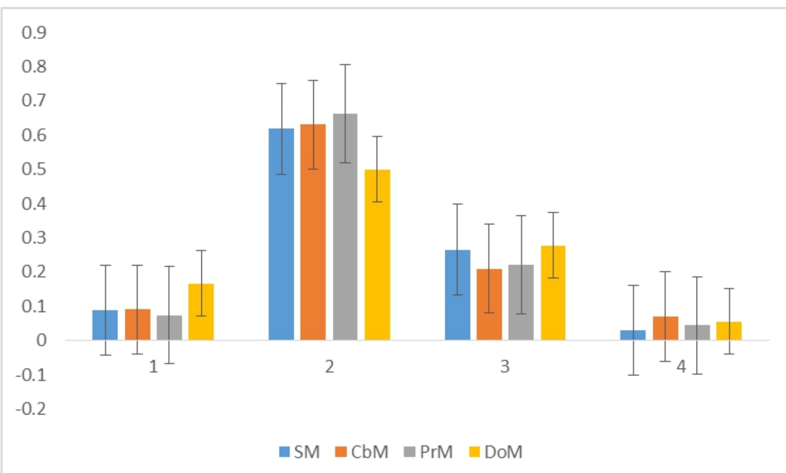

Figure 7: EC Alternatives Relationship for Impeller

Figure 7 shows the AHP ranking of maintenance alternative for the impeller based on equipment criticality criteria alone. The ranking of the different maintenance alternatives from highest to lowest is seen as CbM>PrM> SM>DoM at weighed percentages of 6024%, 24.33% 10.46% and 4.98% respectively.

AHP Results of Mean Time to Fail (MTTF) Sub-criteria for Pump Impeller

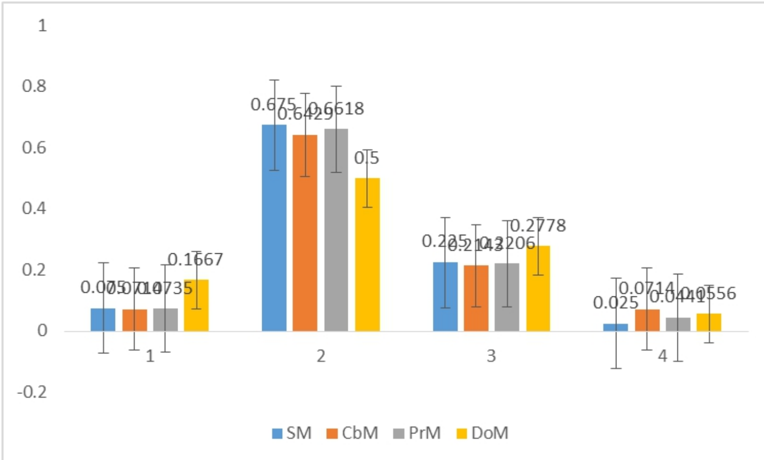

Figure 8: MTTF Alternatives Relationship for Impeller

Figure 8 shows the AHP ranking of maintenance alternative for the impeller based on MTTF criteria alone. It is seen from the plot that the ranking of the different maintenance alternatives from highest to lowest was given as CbM>PrM>SM>DoM at weighed percentages of 61.99%, 23.44%, 9.67% and 4.90% respectively.

AHP Results of Mean Time to Repair (MTTR) Sub-criteria for Pump Impeller

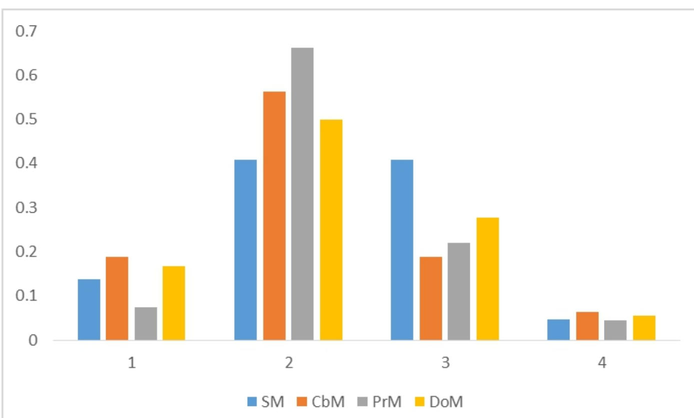

Figure 9: MTTR Alternatives Relationship for Impeller

Figure 9 shows the AHP ranking of maintenance alternative for the impeller based on MTTR criteria alone. It is seen from the plot that, the ranking of the different maintenance alternatives from highest to lowest was given as CbM>PrM> SM >DoM at weighed percentages of 53.33%, 27.37%, 14.10% and 5.19% respectively.

AHP Results of Applicability Sub-criteria for Pump Impeller

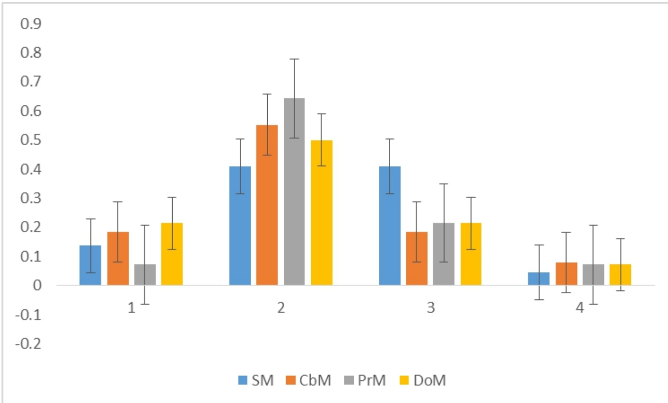

Figure 10: Applicability Alternatives Relationship for Impeller

Figure 10 shows the ranking of maintenance alternative for the impeller based on applicabilitycriteria alone. It is seen from the plot that the ranking of the different maintenance alternatives from highest to lowest was given as CbM>PrM> SM >DoM at weighed percentages of 52.61%, 25.55%, 15.16% and 6.68% respectively. This clearly indicates that the best maintenance method for the impeller with respect to applicability criteria is the CbM method.

AHP Results of Equipment Criticality (EC) Sub-criteria for Pump Mechanical Seal

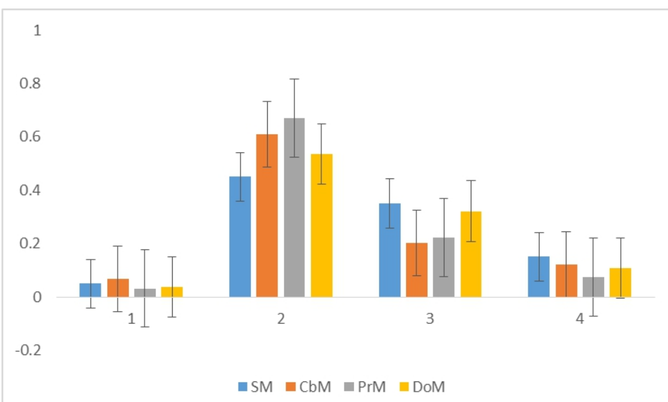

Figure 11: EC Alternatives Relationship for Mechanical Seal

Figure 11 shows the ranking of maintenance of alternative methods for the mechanical seal based on Equipment Criticality (EC) criteria alone. It is seen from the plot that the ranking of the different maintenance alternatives from highest to lowest is given as CbM>PrM>DoM> SM at weighted percentages of 56.60%, 27.44%, 11.33% and 4.63% respectively.

AHP Results of Mean Time to Fail (MTTF) Sub-criteria for Pump Seal

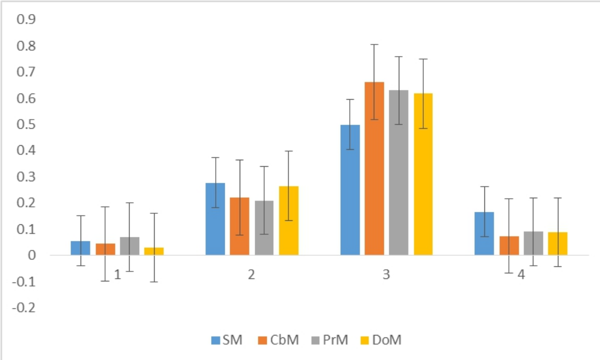

Figure 12: MTTF Alternatives Relationship for Mechanical Seal

Figure 12 shows the AHP ranking of maintenance alternative for the mechanical seal based on MTTF criteria alone. It is seen from the plot that the ranking ofthe different maintenance alternatives from highest to lowest is given as PrM>CbM> SM>DoM at weighed percentages of 60.24%, 24.33%, 10.46% and 4.98% respectively. This ranking indicates that the PrM method is the best maintenance method for the seal in relation with the MTTF criteria.

AHP Results of Mean Time to Repair (MTTR) Sub-criteria for Pump Seal

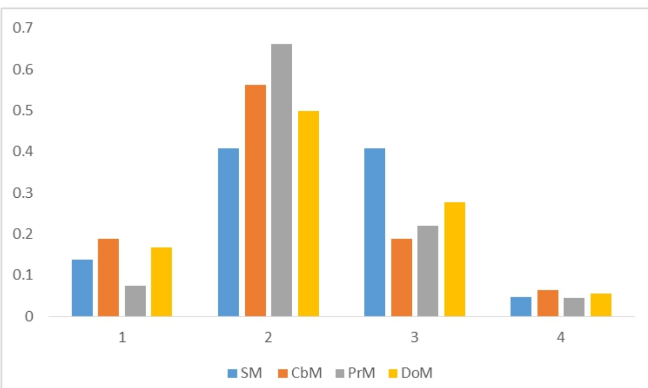

Figure 13: MTTR Alternatives Relationship for Mechanical Seal

Figure 13 shows the AHP ranking of maintenance alternativefor the mechanical seal based on MTTR criteria alone. It is seen from the plot that the ranking of the different maintenance alternatives from highest to lowest is given as CbM>PrM> SM >DoM at weighed percentages of 53.33%, 27.37%, 14.10% and 5.19% respectively. This ranking indicates that the PrM method is the best maintenance method for the seal in relation with the MTTF criteria.

AHP Results of Applicability Sub-criteria for Pump Mechanical Seal

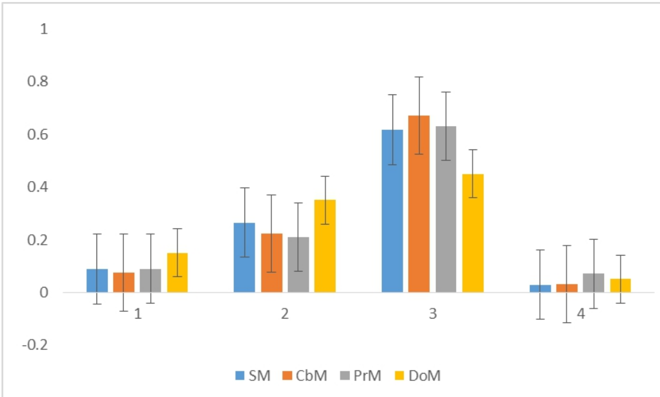

Figure 14: Applicability Alternatives Relationship for Mechanical Seal

Figure 14 shows the AHP ranking of maintenance alternative for the Mechanical seal based on applicability criteria alone. It is seen from the plot that the ranking of the different maintenance alternatives from highest to lowest was given as PrM>CbM> SM >DoM at weighed percentages of 59.20%, 26.20%, 10.07% and 4.53% respectively. This percentage ranking indicates that the best maintenance method for the seal is the PrM method.

AHP Results of Equipment Criticality (EC) Sub-criteria for Pump Shaft

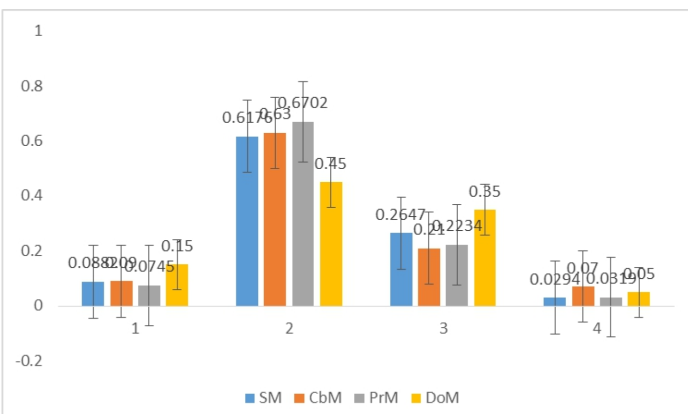

Figure 15: EC Alternatives Relationship for Shaft

Figure 15 shows the AHP ranking of maintenance alternative for the shaft based on Equipment Criticality criteria alone. It is seen from the plot that the ranking of the different maintenance alternatives from highest to lowest is given as CbM>PrM> SM>DoM at weighed percentages of 59.20%, 26.20%, 10.07% and 4.53% respectively.

AHP Results of Mean Time to Fail (MTTF) Sub-criteria for Pump Shaft

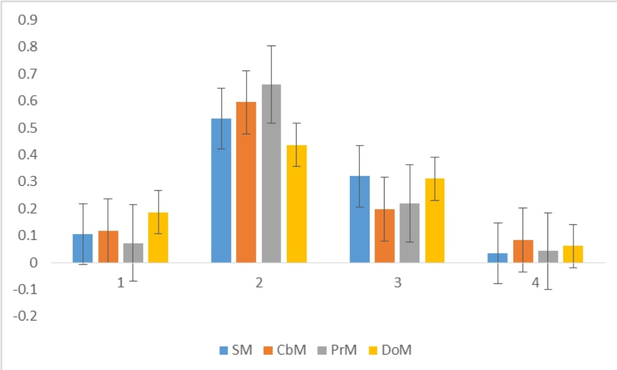

Figure 16: MTTF Alternatives Relationship for Shaft

Figure 16 shows the AHP ranking of maintenance alternative for the shaft based on MTTF criteria alone. From the graph, the ranking of the different maintenance alternatives from highest to lowest is given as: OM >PiN> SM>DoM at weighed percentages of 55.79%, 26.33%, 12.19% and 5.69% respectively. This ranking indicates that the CbM method is the best maintenance method for the Shaft in relation with the MTTF criteria.

AHP Results of Mean Time to Repair (MTTR) Sub-criteria for Pump Shaft

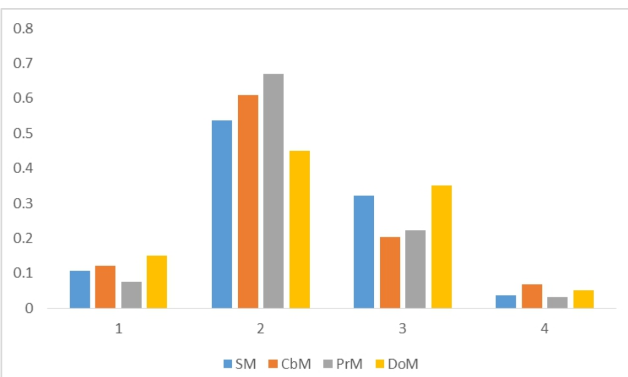

Figure 17: MTTF Alternatives Relationship for Shaft

Figure 17 shows the AHP ranking of maintenance alternative for the shaft based on MTTR criteria alone. It is seen from the graph that the ranking of the different maintenancealternatives from highest to lowest is given as CbM>PrM> SM>DoM at weighed percentages of 56.60%, 27.44%, 11.33% and 4.63% respectively. This ranking indicates that the CbM method is the best maintenance method for the Shaft in relation with the MTTF criteria.

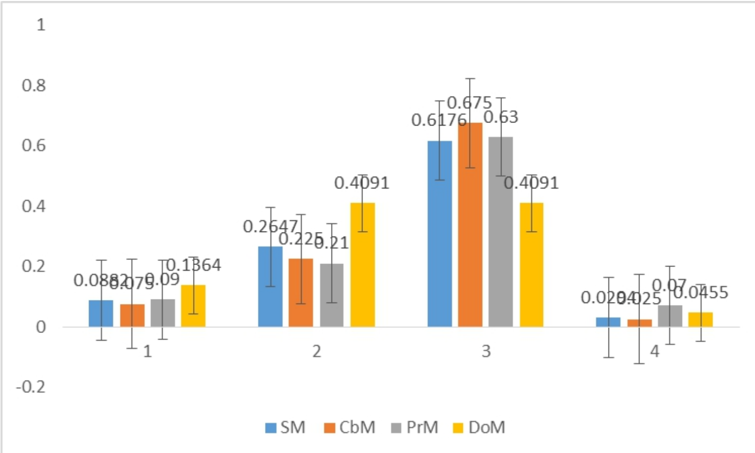

Figure 18: Applicability Alternatives Relationship for Shaft

Figure 18 shows the AHP ranking of maintenance alternative for the shaft based on applicability criteria alone. It can be seen from the graphthat the ranking of the different maintenance alternatives from highest to lowest was given as PrM>CbM> SM>DoM at weighed percentages of 58.29%, 27.72%, 9.74% and 4.25% respectively. This percentage ranking indicates that the best maintenance method for the Shaft respect to' applicability criteria is the PrM method.

Combination of Weight Vectors Obtained from Pairwise Comparison

Table 3 represents the overall priority score and ranking of different maintenance alternative for bearing.

Table 3: AHP Results overall priority matrix (overall weightage).

	Criteria weight	EC	MTTF	MTTR	APPLICABILITY	Overall priority matrix	Ranking
		0.1084	0.2809	0.0607	0.5501		
Bearing							
	SM	0.5579	0.0967	0.1133	0.5920	**0.43019269**	1
Alternative	**CbM**	0.2633	0.6199	0.5660	0.2620	**0.37369114**	2
	PrM	0.1219	0.2344	0.2744	0.1007	**0.14837102**	3
	DoM	0.0569	0.0490	0.0463	0.0453	**0.04774515**	4
Impeller							
	SM	0.1046	0.0967	0.141	0.1516	**0.13081239**	3
Alternative	**CbM**	0.6024	0.6199	0.5333	0.5261	**0.56050819**	1
	PrM	0.2433	0.2344	0.2737	0.2555	**0.2494277**	2
	DoM	0.0498	0.049	0.0519	0.0668	**0.05919315**	4

Mechanical Seal							
	SM	0.0463	0.0498	0.141	0.1007	**0.08295974**	3
Alternative	**CbM**	0.566	0.2433	0.5333	0.262	**0.30957086**	2
	PrM	0.2744	0.6024	0.2737	0.592	**0.53791161**	1
	DoM	0.1133	0.1046	0.0519	0.0453	**0.06957843**	4
Shaft							
	SM	0.1007	0.1219	0.1133	0.0974	**0.10515783**	3
Alternative	**CbM**	0.592	0.5579	0.566	0.2772	**0.40591515**	2
	PrM	0.262	0.2633	0.2744	0.5829	**0.44207796**	1
	DoM	0.0453	0.0596	0.0463	0.0425	**0.04684906**	4

3.2 Discussion

Figure 3 shows that relationship between the distributed although a close look at the chart that the different sub - criteria have different spread in terms of their ranking but at Point 2 it is clearly seen that if equipment criticality is the only selection criteria, the most optimal maintenance method to be adopted would be CbM follow PrM

Figure 4 gives the relationship of the different maintenance methods applicable for bearing maintenance with respect to MTTF selection criteria and this shows positive skewness in terms of the different methods with respect to criteria weights. The criteria weight trend clearly shows that the best maintenance method to be applied for the bearing is the PrM. This also shows that a mix of maintenance alternatives can be applied following the overlapping. When introducing error bars to justify this result, it was shown by the overlapping bars that the best maintenance mix would be an optimal blend of SM, CbM and PrM.

Figure 5 gives the relationship of the different mean square applicable for bearing maintenance and this shows positive skewness in terms of the different methods with respect to their criteria weights. The criteria weight trend clearly shows that with respect to MTTR as only selection criteria, the best maintenance method to be applied for the bearing is the CbM followed by PrM.

Figure 6 shows that to obtain the most optimal maintenance method with respect to equipment criticality criteria alone for the impeller, there is need to carry out further analysis to find the best mix with the right combination of all four alternatives considered in this study. The error bars show that though the highest average maintenance method is CbM as seen in the figure but there is an overlap between the four methods.

Figure 7 shows a positive skewness which could mean the weights are not uniformly spread. However, the important information given by the chart is that there could be a better alternative which is obtainable by properly combining the SM, CbM and PrM alternatives at the right mix rather than using the CbM alone.

Figure 8 shows a positive skewness which could mean the weights are not uniformly spread. However, the important information given by the chart is that there could be a better alternative which is obtainable by properly combining the SM, CbM and PrM alternatives at the right mix rather than using the CbM alone.

Figure 9 shows that the best alternative maintenance strategy considering applicability selection criteria is not solely the CbM rather there can be proper mix of SM, CbM and PrM in formulation of appropriate maintenance task. However, there is need to concentrate the mix between the CbM and the PrM alternatives to get the best alternative for the impeller because judging from the error bars, it is seen the significant overlap between DoM, SM and the other two alternatives the best maintenance alternative, the CbM and PrM should be properly combined.

Figure 10 shows that the best alternative maintenance strategy considering equipment criticality criteria is not solely the CbM rather there can be a mix of CbM, PrM and DoM in formulation of appropriate maintenance task.

Figure 11 shows that there is a possible mix of SM, CbM and PrM that would behave better compared to the PrM acting alone, therefore, it is necessary to apply the necessary measures to find the proper mix for the best alternative.

Figure 12 shows that there is a possible mix of CbM and PrM that would behave better compared to the CbM acting alone, therefore, it is necessary to apply the necessary measures to find the proper mix for the best alternative.

Figure 13 shows a negative skewness which indicates that the average value of the alternatives is less than their middle value, as well as smaller than their most frequent value. There is a possible mix of CbM and PrM that would behave better compared to the PrM acting alone, therefore, it is necessary to apply the necessary measures to find the proper mix for the best alternative.

Considering the overlapping error bars of the different alternatives, Figure 12 therefore, shows that there can be mix of the maintenance alternatives for the shaft maintenance. Considering the overlapping error bars, it is proper to infer that there is a maintenance mix for all the four alternatives that will provide better maintenance and reliability results than just considering the CbM alone.

From Figure 15, we can see that it is inclusive to say that CbM is the best alternative on its own. However, we can judge from the overlapping error bars that to obtain the most optimal alternative would mean having the different alternatives in the right mix. The chart also clearly shows that more concentration should be given to finding the right mix between SM, CbM and PrM while DoM has very negligible effect on finding the best mix of alternatives.

From Figure 16, we can judge from the overlapping error bars that to obtain the most optimal alternative would mean having the different alternatives in the right mix. The chart also clearly shows that more concentration should be given to finding the right mix between SM, CbM and PrM while DoM has very negligible effect on finding the best mix of alternative.

Figure 17 show's that though PrM is best single maintenance strategy for the shaft with respect to applicability criteria there can be mix of the maintenance alternatives. However, the error bars also show that while considering the best alternatives mix, it would not be necessary to consider the DoM maintenance alternative since it has no significant effect in respect.

Table 3 shows that the overall best maintenance strategy for pump bearing with of the four selection criteria is scheduled maintenance (SM), the next alternative Based Maintenance (CbM), then Proactive Maintenance (PrM), the last is Design out maintenance (DoM), the overall best maintenance strategy for pump impeller with consideration of the four selection criteria is Condition-Based Maintenance (CbM), the next alternative is Proactive Maintenance (PrM), then, scheduled maintenance(SM), the last is Design out Maintenance (DoM), the overall best maintenance strategy for pump mechanical seal with consideration of the four selection criteria is Proactive Maintenance (PrM), the next alternative is Condition-Based Maintenance (CbM), then scheduled maintenance(SM), the last is Design out Maintenance (DoM) and the best maintenance strategy for pump Shaft with consideration of the four selection criteria is Condition-Based Maintenance (CbM), the next alternative is maintenance (PrM), then scheduled maintenance(SM), the last is Design out Maintenance (DoM).

Conclusion

The selection criteria used are Equipment criticality (EC), Mean Time to Failure (MTTF), Mean Time to Repair (MTTR) and Applicability. Scheduled Maintenance (SM), Condition based Maintenance (CbM), Proactive Maintenance (PrM) and Design-Modification (DoM) were considered maintenance alternatives for maintenance significant items. The analyses on the ranking of the alternatives showed that by considering the overall priority weights, the best alternative maintenance strategy for bearing is scheduled maintenance (SM), the best alternative maintenance strategy for impeller is Condition-Based Maintenance (CbM), the best maintenance alternative strategy for mechanical seal is Proactive Maintenance (PrM), and the best maintenance strategy for shaft is Proactive Maintenance (PrM).

The RCM Integrated Multi-decision Analytic Hierarchy Process and Risk- Based Maintenance model should be applied in oil and gas sector in order to evaluate performance index of their rotodynamic units and thereby create effective maintenance strategy. This model should be further tested with other firms and its behavior can be used to improve the model for wider application in different sectors.

Nomenclature

Symbol	Meaning	Unit
AHP	Analytical Hierarchy Process	-
CBM	Condition Based Maintenance	-
CI	Consistency Index	-
CR	Consistency Ratio	-
DoM	Design-out Modification	-
EC	Equipment Criticality	-
MATLAB	Matrix Laboratory	-
MTTF	Mean Time to Fail	year
MTTR	Mean Time to Repair	year
n	Alternative	-
PrM	Proactive Maintenance	-
RCM	Reliability Centered Maintenance	-
RI	Random Index	-
SM	Scheduled Maintenance	-
W	Weight Matrix	-

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