INTERNATIONAL JOURNAL OF ENGINEERING, INFORMATION SCIENCE AND APPLIED SCIENCES (IJEIS-AS)
e-ISSN: 2615-1693 *Vol. 2 No. 1, February 2019*

Maintenance Of Decision Engineering Programs In The Distribution Of Sea Water Pump In PT. KMI With The RCM-II Approach

Taiyeb Ibrahim [1], Rosmiati [2]
Universitas Trunajaya Bontang
taiyeb.ibrahimm@gmail.com[1], hanafi.rosmiati@gmail.com[2]

Keywords :
Availability; FMEA; framework; LTA; maintenance profit; MTTR; RCM II; Reliability and Weibull

ABSTRACT
During World War II, demand for goods and aspects of logistics speed began to increase while the availability of workers dropped dramatically. This creates the mechanization and automation of the production of goods so that the industry begins to depend on machinery and causes engine downtime to be a major concern. Similarly, if the assets fail not only the economic aspect which adversely affected but the environmental aspects and safety of life threatened. This condition causes the maintenance program to be planned with the preventive maintenance concept being the flagship program. But this condition creates additional operational costs for the industry which are often considered not as profit producers. Until now, the field of maintenance management experienced rapid development compared to other management fields. The global industrial movement with just-in-time (JIT) concepts, efficient logistics, customer satisfaction and others forces industries in the world not to mention Indonesia to keep physical assets working according to the expectations above. So that a strategic framework is created to ensure that physical assets continue to operate in accordance with these goals and expectations. This framework started from the aviation industry known as MSG3 and then spread to industries outside of airlines known as Reliability-Centered Maintenance (RCM), Moubray 2011. The success of applying RCM in the industry has been widely reported by previous research, including: Singh and Suhane, 2010: In RCM journal, Availability of Centrifugal Pump on the Base of Weibull Analysis: produces motivation and teamwork and with the Weibull approach in RCM, maintenance tasks can save material costs 35% - 65%. Ogaji and Robert, 2006: "Improving a culture of improvement work that focuses on proactive maintenance". Oyj and Ekholm, 2009 in the journal "Feasibility Study of Reliability Centered Maintenance Process", RCM produces a database for numerical format statistical purposes. Petrovic, et al., 2014: Pump failure can be prevented by up to 61% in selecting maintenance

tasks based on the mode level. Afefy, 2010 in the Reliability-Centered Maintenance Methodology and Application case study produced: RCM approach Maintenance costs decreased from $ 295,200 / year to $ 220,800 / year, reduced total labor costs 25.8%, PM savings 80% of total downtime and Savings of 22.17% for spare parts costs. Makwana and Pancholi, 2014 in the case study "Implementation of Reliability Centered Maintenance (RCM) and design out for Reliability" concluded: 12% -15% uptime increase and setup and failure time reduction.

INTRODUCTION

Reliability-Centered Maintenance Framework

RCM is: A process used to determine what must be done to ensure that a physical asset can continue to work on what its users want to do according to the current operational context to achieve relibility, availability, efficiency and profit, Moubray (2011). Basically RCM offers a methodological framework with several key issues that are not handled by reactive, predictive and preventive maintenance techniques with the framework process RCM asks seven questions on assets or systems that are being reviewed, Moubray 2011, namely:

1. Are the functions of assets and performance standards related to that function appropriate to the current context of their operations? (Function & performance standard)
2. How can the asset fail to fulfill its functions? (Function failure)
3. What is the mode / cause of each failure of the function? (Mode)
4. What happens if the mode / cause of failure arises? (Failure effect, RPN, P-F diagram, Waibull Analysis, Reliability, Availability, MTTF, MTTR, maintenance profit & FMEA)
5. How do these failures affect? (Consequences & LTA)
6. What actions can be taken to predict or prevent any failure? (Maintenance task)
7. What if no proactive or appropriate action is found? (Default action)

Risk Priority Number (RPN)

RPN is a measure used when assessing risk to help identify critical failure modes related to design or process with interview techniques and credible discussions with reference to Liu et al., 2013: Suggested rating for Occurrance, Saverity and Detection of a failure mode.

$$RPN = O \times S \times D \quad (1)$$

Potential Failure (P-F) Diagram

The P-F diagram is one of the common methods used to determine the time interval for task maintenance, by processing historical data signs of the start of a malfunction. Task maintenance interval:

$$\frac{1}{2}\, P\text{-}F \quad (2)$$

Weibull Failure Data Analysis

Treatment history data was processed using plot graph weibull and weibull formula, median Bernard rank F (t)%, then can be determined: reliability function R (t), Probability density function (PDF) or reliability index f (t), rate failure λ (t), and MTTF.

$$F(t) = \left(\frac{t-0{,}3}{n+0{,}4}\right) 100\% \quad (3)$$

t: time between failure (day) and n: number of cycles Probability density function (pdf) weibull for 3 parameters:

$$f(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} exp\left[-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right] \quad 4)$$

Where β> 0 and η> 0, Shape Parameter (β) and scale parameter or characteristic life (η) are estimated, both of these values are obtained from the plot graph of the magic parameters 3, Warwick Manufacturing Group 2004. e: 2.718 (natural number). Reliability, R (t):

$$R(t) = \int_t^{\infty} \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} exp\left[-\frac{t-\gamma}{\eta}\right]^{\beta} dt \quad (5)$$

Failure rate,

$$\lambda(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\beta}\right)^{\beta-1} \quad (6)$$

Mean time to failure

$$MTTF = \gamma + \eta\Gamma\left[\left(\frac{1}{\beta}\right)+1\right] \quad (7)$$

MTTR = Maintenance activity, the time needed to maintain an asset until it is declared feasible to run. The value is obtained from the estimated experienced team handle it.

Availability),

$$A = \left[\frac{MTTF}{MTTF+MTTR}\right] 100\% \quad (8)$$

Cost efficiency,

$$= \frac{Total\ cost\ standard}{Total\ cost\ actual}\ 100\% \quad (9)$$

Maintenance profit,

$$Mp = \left[\frac{Mcs-Mcp}{Mcs}\right] 100\% \quad (10)$$

Mcs: Current maintenance costs
Mcp: Maintenance cost after repair analysis

METHOD

The systematic in this research and writing thesis uses a method based on classification: Applied research, Creswell (2004), Empirical, Sangadji and Sopiah (2010), Case and field study, Sangadji and Sopiah (2010), Combined qualitative & quantitative, Cooper & Emory (2007) and Library, Fowler FJ (2004). To overcome the problems that occur in the treatment of sea water pumps at PT. KMI is carried out based on the RCM framework with the following systematic steps:

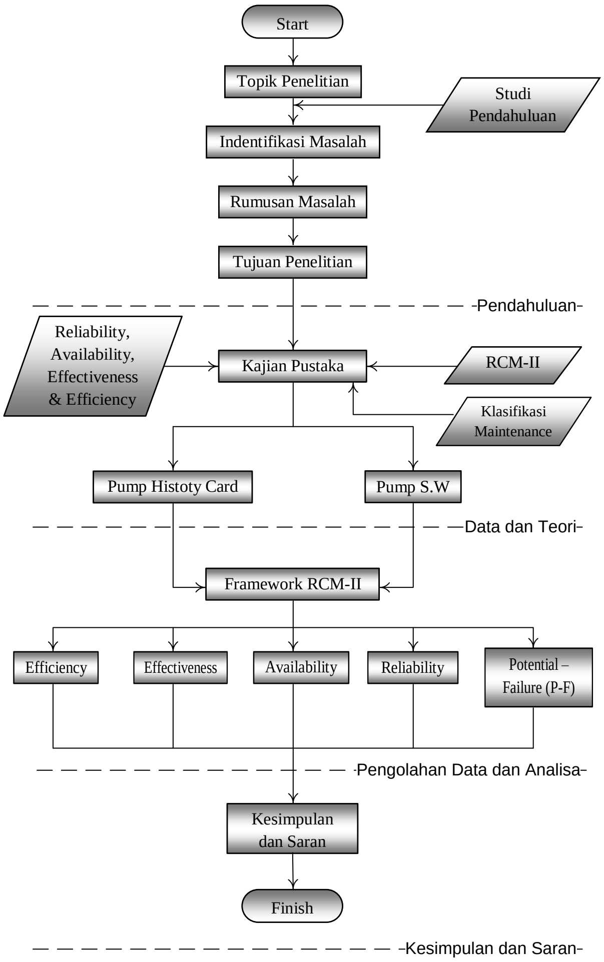

Fig 1. *The Flowchart of RCM framework*

RESULTS AND DISCUSSIONS

The RPN value is a measure used when assessing risk to help identify critical failure modes associated with the design or process then determine the appropriate program maintenance, Puthillath & Sasikumar 2012. The following are the results of the RPN on pump parts, Table 1.

Tabel 1. Risk priority number & maintenance program

No.	Component	S	O	D	RPN	Maintenance task
1	Radial bearing (321)	8	8	9	576	Predictive (BCM)
2	Thrust bearing (324)	8	8	9	576	Predictive (BCM)
3	Bearing bush (301)	8	8	9	576	Predictive (BCM)
4	Rubber bearing (310)	8	8	9	576	Predictive (BCM)
5	Shaft sleeve (529.1)	3	9	9	243	Preventive (PM)
6	Packing (461)	3	9	9	243	Preventive (PM)

Source: Data processed, 2017

From the historical summary table data, pump maintenance is used to find Weibull parameter values, the results are: (β = 1.06) shape parameter (slope), (η = 627) scale parameter (characteristic life) and location parameter (failure free life) . By using plot graph weibull, weibull formula, median rank Bernard F (t)% was obtained: reliability function R (t) = 36.79%, availability 98.94% and failure rate λ (t) = 0.0016 / day, MTTF = 794.24 days, MTTR = 8 days, 1 / 2P-F = 1125 days and Maintenance cost efficiency = 78.93%.

Failure mode and effects analysis (FMEA) or answer the first to fourth questions of RCM-II and analyze is a methodology for analyzing potential reliability problems at the beginning of the maintenance program development process, the reason is that it is easier to take action if the problem is detected early and improve reliability through the design of maintenance programs. Based on the results of discussions and interviews with credible sources, PT. KMI. The FMEA results are then carried out with logic tree analysis (LTA), the result is maintenance decision on several components of the sea water pump, and the results of the RPN, Table 2.

Tabel 2 *Maintenance task decision worksheet*

RCM -II Decision Worksheet	**System:** *Sea Water Distribution*	**No.:** 001	**Complied by:** Taiyeb	**Date:** 1/01/17	**Sheet:** 1 *of* 5	MERCU BUANA
	Sub-system: *Sea Water Pump 065-G01*	**Ref.:** *Eng.*	**Reviewed by:** Setiawan	**Date:** 4/01/17		

Information Refrence			***Conseguence Evaluation***				***H1 S1 O1 N1***	***H2 S2 O2 N2***	***H3 S3 O3 N3***	***Default Tasks***			***Proposed Task***	***Initial Interval***	***Can be done by***
F	***FF***	***FM***	***H***	***S***	***E***	***O***				***H4***	***H5***	***S4***			
1	A	1	✔	x	x	✔	✔						Lakukan *On Condition Task (predictive)* pada *interval <1/2 P-F & proactive scheduled dischard task* per 2 thn & alternatif 3 thn.	7,5 bln, 2 dan 3 thn.	*Inpction & Mekanik*
1	B	1	✔	x	x	✔	✔						Lakukan *On Condition Task (predictive)* pada *interval <1/2 P-F & proactive scheduled dischard task* per 2 thn & alternatif 3 thn.	7,5 bln, 2 dan 3 thn.	*Inpction & Mekanik*
2	A	1	✔	x	x	✔	✔						Lakukan *On Condition Task (predictive)* pada *interval <1/2 P-F & proactive scheduled dischard task* per 2 thn & alternatif 3 thn.	7,5 bln, 2 dan 3 thn.	*Inpction & Mekanik*
2	B	1	✔	x	x	✔	✔						Lakukan *On Condition Task (predictive)* pada *interval <1/2 P-F & proactive scheduled dischard task* per 2 thn & alternatif 3 thn.	7,5 bln, 2 dan 3 thn.	*Inpction & Mekanik*
3	A	1	✔	x	x	✔	✔						Lakukan *On Condition Task (predictive)* pada *interval <1/2 P-F & proactive scheduled dischard task* per 2 thn & alternatif 3 thn.	7,5 bln, 2 dan 3 thn.	*Inpction & Mekanik*
3	A	2	✔	x	x	✔	✔						Lakukan *On Condition Task (predictive)* pada *interval <1/2 P-F & proactive scheduled dischard task* per 2 thn & alternatif 3 thn.	7,5 bln, 2 dan 3 thn.	*Inpction & Mekanik*
4	A	1	✔	x	x	✔	✔						Lakukan *On Condition Task (predictive)* pada *interval <1/2 P-F & proactive scheduled dischard task* per 2 thn & alternatif 3 thn.	7,5 bln, 2 dan 3 thn.	*Inpction & Mekanik*
4	A	2	✔	x	x	✔	✔						Lakukan *On Condition Task (predictive)* pada *interval <1/2 P-F & proactive scheduled dischard task* per 2 thn & alternatif 3 thn.	7,5 bln, 2 dan 3 thn.	*Inpction & Mekanik*
4	A	4	✔	x	x	✔	✔						Lakukan *On Condition Task (predictive)* pada *interval <1/2 P-F & proactive scheduled dischard task* per 2 thn & alternatif 3 thn.	7,5 bln, 2 dan 3 thn.	*Inpction & Mekanik*
5	A	1	✔	x	x	✔	x	x	x				*No scheduled maintenance (reactive)*	x	*Mekanik*
5	A	2	✔	x	x	✔	x	x	x				*No scheduled maintenance (reactive)*	x	*Mekanik*
6	A	1	✔	x	x	✔	x	x	x				*No scheduled maintenance (reactive)*	x	*Mekanik*

Source: Data processed, 2017

Note: - F: function; FF: failure facntion; FM: failure mode; H: consequences of hidden failure; S - E: consequences of safety and environment; O: operational consequences and N: non-operational consequences.

The 3-year interval is an alternative, if within 2 years the operation does not show symptoms of damage, for example: vibration, temperature, amperes and others.

Through the RCM-II framework by answering the first question (function), the second question (malfunction) and the third question (failure mode) found the cause of pump function failure, namely: From the FMEA results it was found that the main cause of failure in assets is starting from bearing part thirst bush 301 which is directly in contact with the shaft so that over time it creates increased vibrations. the initial condition of the emergence of vibrations as a reference for based condition monitoring maintenance to be declared a failure at the vibration limit of 9-11 mm / s. If you see this kind of maintenance practice, it means run to failure. The effect of this event is that there are a number of parts that experience failure (which should have been avoided) such as shaft bending, wearing rings that are heavily scratched and impellers affected by unbalance as reported by Nozal PT. KMI 2016. This is what makes the cost inefficient. This condition can be resolved immediately if a proper maintenance program is carried out. The causes of malfunction in pump parts are caused by failure mode: Erosion, part dimensions less or exceeding those specified by manufacturing telecommunication, mechanical damage (wear out), imitation material selection (out original manufacture), part shift from its position, reduced part elasticity (wear), eroded wear, wrong assembly, incoming foreign objects, error round out and repair methods.

Decision on Program for Maintenance of Sea Water Pump

From the results of historical treatment data processing pumps 065 G01 sea water pump A, B, C and S (identical) found reliability level of 36.79% availability 98.94%, maintenance cost efficiency 21% and MTTF = 749.24 days or 2 , 05 years during the operational period of 1997 - 2016. Maintenance cost efficiency was 21% very low. Furthermore, if this is not done by the RCM II approach, the organization does not know whether the maintenance policy that has been carried out has been running efficiently. During this time the organization feels a recurring fatigue about the performance of assets and the large costs that are being reviewed.

In this study, the format of data from the maintenance history cards from 1997 to 2016 is still manual, which is registered in non-standard forms and sentence terms so that the data must be reformatted and ask the meaning of sentences in crew maintenance and inspection, so it takes 2 week to perfect it. In the future it is hoped that standards can be made on other assets. Prior to the application of RCM II in FMEA analysis an understanding of asset function, type of failure, mode and effect arising from assets that are being reviewed from each section has various interests, so that it is not standardized how to deal with assets and performance standards desired by the user.

This thesis research results in the same teamwork and understanding of assets being reviewed, asset functions, types of failures, modes and effects if they fail, the result is standardized task decision worksheet maintenance SOP, Table 2. From the analysis of 3 parameter plot graph weibull method β, γ and η obtained characteristic life interval preventive maintenance 749.24 days (2 years) as the basis for determining proactive - scheduled discard the main task in the form of replacing part 301 for reasons as stated in the paragraph above.

PF diagram analysis from the Weibull 1 / 2P-F plot produces a maintenance decision in the form of scheduled on-condition task-condition based monitoring (CBM) 1125-749.24 = 375.76 days or 1.03 years and this is considered a supplement to support proactive scheduled scheduled main task. When 1.03 years is used to monitor pump performance if within 2 years of operation it does not show clear signs that a failure is in progress (failure), it can be decided to do CBM. P-F vibration diagram analysis, 1/2 P-F 7.5 months was used as a reference for predictive CBM after the pump operated 2 years and it was decided not to carry out maintenance. The trip remains 1.03 years if there are clear signs that an increase in failure is taking place (vibration increases) then predictive-BCM is done at an interval of 7.5 months, see illustration (Figure 2).

Analysis of risk priority number is found> 500, this value is one of the ways to determine maintenance tasks, namely predictive maintenance category and 2 components of RPN 243 in preventive maintenance categories, Puthillath and Sasikumar (2012). So that it generally goes into predictive maintenance (condition monitoring). These results are also concluded from the results of the weibull analysis in the paragraph above.

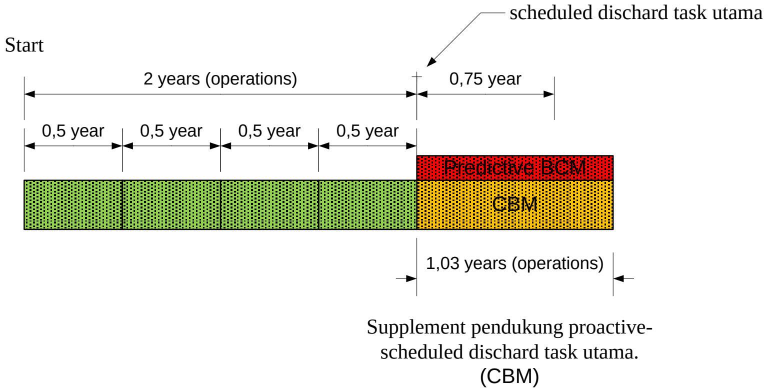

Fig 2. *Task maintenance illustrations resulting from data analysis and processing*

Source: Data processed, 2017

Maintenance cost efficiency analysis before Weibull analysis is carried out at an average of 21%, this value is very low. After Weibull analysis and damage analysis based on Nozal's report, PT. KMI (2016), as explained in the paragraph in this chapter, obtained maintenance cost efficiency of 78.98%, which meant an increase of 79.98% - 21% = 57.93%.

Previous Research Study

From the results of the RCM II FMEA analysis of the assets under review (sea water pump 065-G01 A, B, C and S) resulting in the same understanding between all sections concerned about asset function, type of failure, mode and effects of assets which is being reviewed so as to produce teamwork, work culture of asset repair and produce a team agreement on standardization of ways to deal with if assets want to fail (planning) and desired performance by the user (function statement). This is also stated by Singh and Suhane, 2010 in the RCM journal, Availability of Centrifugal Pump on the Base of Weibull Analysis: generating motivation and teamwork. And also by Ogaji and Robert, 2006: "Improving a culture of improvement work that focuses on proactive maintenance".

RCM II implies the importance of neatly registered treatment history data for the needs of task maintenance analysis and weibull statistical analysis. Hi, this is also raised by Oyj and Ekholm, (2009) in the journal "Feasibility Study of Reliability Centered Maintenance Process", RCM produces a database for numerical format statistical purposes.

RCM II in FMEA generally does not only analyze components per component but chain effects if one component fails so that it focuses on the main cause (at the mode level) to be the main reason for improvement as stated in this study only 301 bearing bushing components are replaced each interval 3 years to avoid the failure of other components that are very expensive. This is also stated by Petrovic, et al., 2014: pump failure can be prevented by up to 61% in selecting maintenance tasks based on the mode level.

From the results of 3 parameter plot graph weibull analysis β, η and γ obtained preventive maintenance intervals 749.24 hours (2 years), reliability 36.79%, availability 98.94%, and cost efficiency increased by 57.93% from the standard part replacement is only bearing bush 301). Likewise from the results of the P-F diagram analysis, proactive task-condition monitoring was obtained with time intervals per 225 days or per 7.5 months from the previous one per month (increasing by 86.7%). From previous studies also reported the success of RCM in increasing reliability, availability and cost savings. Singh and Suhane (2010) report: With the Weibull approach in RCM, maintenance tasks can save material costs 35% to 65% and increase teamwork. Abid, et al., 2014, in the case study concluded: the RCM approach can improve system reliability and cost savings. Afefy, 2010 in the Reliability-Centered Maintenance Methodology and Application case study produced: The RCM approach to maintenance costs decreased from $ 295,200 / year to $ 220,800 / year, reducing the total cost of labor by 25.8%, saving PM 80% of total downtime and savings of

22.17% on spare parts costs. Makwana and Pancholi, 2014 in the case study "Implementation of Reliability Centered Maintenance (RCM) and design out for Reliability" concluded: 12% to 15% uptime increase and setup and failure time reduction.

CONCLUSION AND SUGGESTION

Conclusion

From the results of the RCM II framework approach: FMEA, RPN, LTA and processing of 3 parameter weibull statistics on assets under review of the 065-G01 A, B, C and S sea water pump can be summarized as follows:

1. From the RCM-II framework data processing to the first question (function), the second question (malfunction) and the third question (failure mode) found the cause of the failure of the pump function and pump parts are: Overall failure of the pump function caused by failure mode maintenance implementation policies that tend to run to failure patterns. Current types of run to failure maintenance have been abandoned because they are considered to be less profitable in terms of cost, availability and reliability. Failure of pump parts is caused by failure mode: Erosion, part dimensions are less or exceed those specified by manufacturing telephones, mechanical damage (wear out), imitation material selection (out original manufacture), part shift from position, reduced part elasticity (wear) , wear eroded, wrong assembly, the presence of foreign objects entering, error method round out and repair.
2. The RCM II framework approach on the assets being reviewed results in a proactive-scheduled decision maintenance main dischard task at the characteristic life (η) or MT9 749.24 days or 2 years, scheduled on-condition task (condition based monitoring) 1125- 749.24 = 375.76 days or 1.03 years and this is considered as a supplement to support the main pump proactive-scheduled discard task if within 2 years of operation it does not show clear signs that failure is in progress It can be decided to do CBM and predictive-BCM at a 7.5 month interval, maintenance cost efficiency of 57.93%, maintenance profit of Rp. 3.17 billion / year, saving proactive task condition monitoring with a time interval per 225 days or per 7.5 months from the previous one per month (86.7% increase), availability level of 98.94% in the 98.00 reliability range % to the point of failure 36.79% and encourage the formation of teamwork in designing maintenance tasks.

Suggestion

From the results of this research, further research is needed if an asset that is being reviewed after preventive maintenance is proposed at a 2-year interval whether availability and reliability levels can still be determined in the next 10 years interval?

REFERENCES

Abid, M., Ayub, S., Wali, H., and Tariq, M. N. (2014). Reliability Centered Maintenance Plan for the Utility Section of a Fertilize Industry: A Case Study. The International Study. *The International Journal of Science and Advanced Technology*, 4(3), 9-16.

Afefy, I. H. (2010). Reliability - centered maintenance methodology and application: a case study. *Engineering Journal*, 2(11), 863-872.

Allen, B. J. (2004) . *The Use Of Weibull In Defect Data Analysis*. Warwick Group Publishing.

Alwi, R. (2016). Reliability Centered Maintenance Dalam Perawatan FO Service Pump Sistem Pump Sistem Bahan Bakar Kapal Ikan. *Jurnal Riset Teknologi kelautan*, 14(1), 77-86.

Dantes, N. (2012). *Metode Penelitian*. Andi Jogyakarta.

Dhillon, B.S. (2006). *Maintainability, Maintenance, and Reliability for Engineers*. Bacon Raton, Florida: CRC Press

Eti, M. C., Ogaji, S. O. T., & Probert, S. D. (2006). Reducing the cost of preventive maintenance (PM) through adopting a proactive reliability focused culture. *Applied energy*, 83(11), 1235-1248.

Kołodziejski, M. (2011). Failure Finding Tasks in Reliability Centred Maintenance. *Scientific Journals*, 28(100), 53-59.

Lindley R. & Keith M. (2002). *Maintenance Enginering Handbook*, Sixth Edition. McGraw-Hill Publishing.

Makwana, R., & Pancholi, N. (2014). Implementation of Reliability centered maintenance (RCM) and design out for reliability (DOFR) approaches to milk powder drying unit of dairy plant – a case study. *International Journal for Scientific Research & Development*. 2(4), 217-221.

Moubray, J. (2011). Reliability - centered maintenance (RCM-II). PT. Relogica Indonesia.

Mudiastuti, R. D. (2014). Maintenance Activity Planning on Cenrtifugal Pump System With Failure Modes and Effects Analysis (Fmea) Method Based on Fuzzy Cost Estimation and Reliability Centered Maintenance II Method. *Australian Journal of Basic and Applied Sciences*, 8(13), 34-40.

Naik, B. D., & Soni, P. K. (2016). Application of Reliability Centered Maintenance on Horizontal Boring Machine - A Case Study. *International Journal of Advanced Engineering Research and Science*, 3(7), 17-34.

Nilsson, J., Wojciechowski, A., Stromberg, A. B., Patriksson, M., & Bertling, L. (2009). An maintenance optimization model for shaft seals in feed-water pump systems in nuclear power plants. *In PowerTech, IEEE Bucharest* (pp. 1-8).

Nosal, N. P. (2016). High Vibration Problem On Sea Water pump. *Turn Around Specialty Report PT. KMI*. 1(1) 1-12.

Peters, R. (2014). *Reliable maintenance planning, estimating, and scheduling*. Gulf Professional Publishing.

Petrovic, Z., Car, Z., Radicevic, B., Sikulec, L., & Grkovic, V. (2014) Implementation of the RCM Methodology on the Example of City Waterworks. *The International Journal Heavy Machinery*, 7(3), 38-47.

Puthillath, B., & Sasikumar, R. (2012). Selection of maintenance strategy using failure mode effect and criticality analysis. *International Journal of Engineering and Innovative Technology*, 1(6), 73-79.

Rausand, M., & Arnljot, H. (2004). *System reliability theory: models, statistical methods, and applications* (Vol. 396). John Wiley & Sons.

Saravanan, Altaf, M., & Udaiappan, M. (2014). Profitable Condition Monitoring And Conditions Apply. *International Journal Condotion Monitoring*, 15(54), 133-142.

Sari, W., & Prasetyawan, Y. (2012). Perancangan Kebijakan Perawatan dan Penentuan Persediaan Spare Parr di Sub Sistem Evaporasi Pabrik Urea Kaltim - 3 PT. Pupuk Kalimantan Timur. *Jurnal Teknik ITS*, 1(1), 141-146.

Singh, D., & Suhane, A. (2015). Study of Centrifugal Pump sing Failure Mode Effect & Critical Analysis Based on Fuzzy Cost Estimation: A Case Study. *International Journal of Scientific Research (IJSR)*, 4(7), 19-22.

Yam, R. C. M., Tse, P. W., Li, L., & Tu, P. (2001). Intelligent predictive decision support system for condition-based maintenance. *The International Journal of Advanced Manufacturing Technology*, 17(5), 383-391.