Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Reliability-centered maintenance and cost optimization for offshore oil and gas components

To cite this article: A H Nithin *et al* 2021 *J. Phys.: Conf. Ser.* **1730** 012007

Journal of Physics: Conference Series **1730** (2021) 012007 doi:10.1088/1742-6596/1730/1/012007

Reliability-centered maintenance and cost optimization for offshore oil and gas components

A H Nithin[1,2], S Sriramula[1], T Ebinum[2]

[1]University of Aberdeen, School of Engineering, Aberdeen, AB24 3UE, United Kingdom
[2]Optimal, 15 Carden Place, AB10 1UR, Aberdeen, United Kingdom

Email:anu.hanishnithin@abdn.ac.uk

Abstract. Reliability-Centered Maintenance (RCM) is widely used for enterprise asset management in the Oil and Gas sector. The traditional RCM process encompasses the development of equipment hierarchy, the determination of the functional failure of assets, identification of the critical failure modes and the development of suitable maintenance strategies for these failure modes through RCM logic tree analysis. However, the current industry standards and conditions call for greater strides of production availability and reliability of the assets. The aim of the paper is to deliver RCM oriented cost optimization framework for the assets through the implementation of probabilistic and statistical analysis. Probabilistic analysis of the most critical components predicts the failure over time. The mean time to failure, mean time between failure and mean time to repair parameters are determined from the failure history. The parameters of the probability distribution, for instance, the shape and scale parameters of Weibull distribution determine the failure pattern of the failure mode over time. The cost optimization modules allow the analyst to determine the optimum intervals for maintenance or replacement of the maintainable items. The integrated RCM methodology, therefore, provides quantitative and cost-effective solutions for asset maintenance and management. A case study of an equipment in the Oil and Gas sector will be presented to illustrate the optimization framework.

1. Introduction

Reliability-Centered Maintenance (RCM) techniques have gained popularity since they were first developed by the aeronautical industry during the early 1960s. RCM analysis involves preserving the function of an asset by looking at the inherent functions and functional failure of the asset. The maintenance strategies of the assets are determined based on criteria such as failure, cost, reliability, and safety. This type of analysis forms a decision-making tool for the operators to choose the right maintenance strategy while optimizing the operation and maintenance costs and resources while minimizing the downtime of asset failure. The decisions related to maintenance strategies involve choosing the right approach for corrective maintenance, preventive maintenance comprising of fixed time intervals, condition-based inspections and monitoring, predictive maintenance and run to failure and re-design events [1, 2].

The traditional methods of RCM usually encompass the steps of building an equipment hierarchy by identifying the maintainable items, understanding the operating context of the assets, functions, and functional failures as shown in Figure 1. The asset criticality analysis prioritizes the assets based on criticality. Failure Modes and Effect Analysis (FMEA) is performed for the most critical assets. FMEA processes rank the failure modes pertaining to each maintainable item by analysing the failure mechanism, causes and effects or consequences at local and system levels. This forms the basis of further RCM study of logic tree analysis which considers the feasibility of conducting the maintenance tasks in terms of the failure behavior, costs of inspections and monitoring and the useful life of the maintainable items. This is done by allocating the resources in terms of labor, materials, task equipment and tools which would facilitate the development of maintenance strategies of the assets [1].

Maintenance techniques and the possible opportunities have evolved over four generations with higher expectations of attaining better availability, reliability, cost effectiveness and safety. The RCM and other reliability-based techniques gained popularity towards the middle of second and third generation of maintenance techniques. The current fourth generation calls out for innovative techniques comprising of predictive analytics, internet of things, and continuous monitoring with emphasis on interconnectivity [1]. There is a greater need for improving traditional reliability-based techniques through integration of fourth generation techniques. A new framework for RCM is proposed in this paper based on probabilistic and statistical optimization techniques, with the advantage of being quantitative and comprehensive.

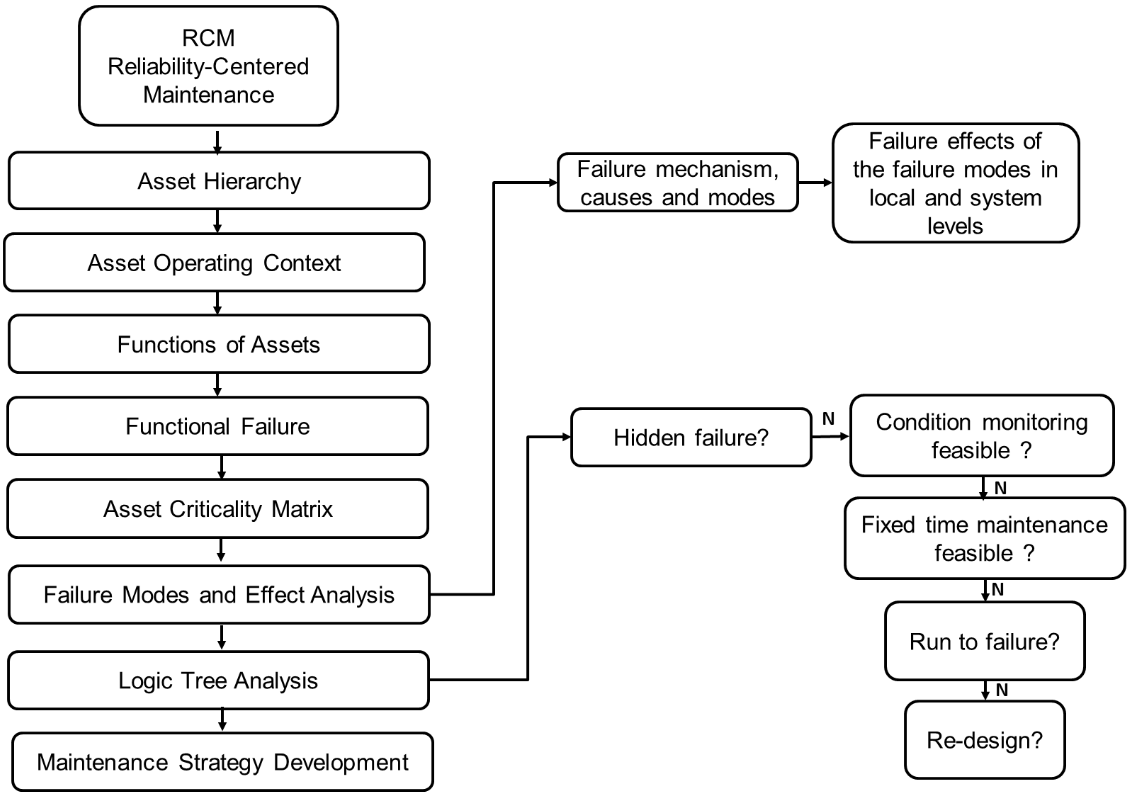

Figure 1. Process of Reliability-Centered Maintenance (RCM).

2. Reliability-Centered Maintenance Optimization Framework

A recent survey conducted by the authors received responses from asset managers, maintenance and operation managers, manufacturing directors and reliability engineers across industries from all over the world. According to the survey, RCM was found to be the most preferred technique for development of asset maintenance strategies but also highlighted the disadvantages of RCM process to be time-consuming, qualitative, and based on human judgement. This paper addresses some of these aspects by including probability-based uncertainty quantification.

The equipment hierarchy considered in this paper is based on ISO 14224 [3] which provides a taxonomical level starting from industry, business category, and installation. The equipment is classified and sub-divided into equipment unit, subunit, component, and part of the maintainable item. Based on the criticality analysis and FMEA, a component would be identified as critical.

Pareto analysis on the topsides equipment is performed to determine the criticality based on the mean failure rates of the equipment. Pareto principle [4] is also known as 80-20 rule or the law of vital few, implying that around 80% of the effects come from 20% of the causes. In the case of equipment reliability, it means that 80% of the failure effects arise from 20% of the equipment population. This would help in the identification of critical equipment which would fail more often, so detailed RCM analysis could be adopted for the critical equipment.

Weibull analysis is then performed on this critical component to determine the failure pattern over time. Weibull probability distribution [5] is commonly used to model the data related to component life since it can acquire different shapes and has the flexibility to represent other probability distributions such as exponential, lognormal etc. The cumulative probability distribution function of a two-parameter Weibull distribution is given as:

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right] \tag{1}$$

where β is the parameter denoting the shape of the distribution and η is the scale parameter or the characteristic life of the distribution. The shape parameter determines the time at which the failure occurs, for example, $\beta<1$ corresponds to early failures due to installation or design related errors, $\beta=1$ corresponds to random failures in useful life which are independent of time and $\beta>1$ corresponds to age-related failures. The characteristic life or scale parameter states the time at which 63.2% of the population would have failed [5].

Following the Weibull analysis, if the failure rate is said to be increasing or in the wear-out phase, the preventive replacement of the component could be estimated through cost optimization techniques. The product of unplanned failure and failure probabilities and the cost of planned replacements are calculated and minimized to determine the optimum replacement interval. Two maintenance replacements are considered – age and block replacement. The age replacement scenario considers the time interval that starts at time t =0 to T and failure could occur within the time interval. On the contrary, the block replacement always occurs at time T, ignoring the fact that the failure may or may not occur before time T [6].

The data and the results of the paper are based on OREDA Offshore Reliability Database [7] and in accordance with the ISO14224 Standards [3]. The OREDA data records the failure information of equipment in the Oil and Gas installations whereas the ISO14224 standards give a framework for the collection and exchange of reliability and maintenance data.

3. Numerical Illustration

A pareto analysis of topside equipment, based on the mean failure rate per year based on OREDA data [7], on typical Oil and Gas installations is shown in Figure 2. The pareto analysis follows 80/20 rule which states that 80% of the total failure effects arise from the first 20% of the components. It is noted that the centrifugal gas compressor comes within the first 20% and hence, was chosen as an example to illustrate the optimization framework.

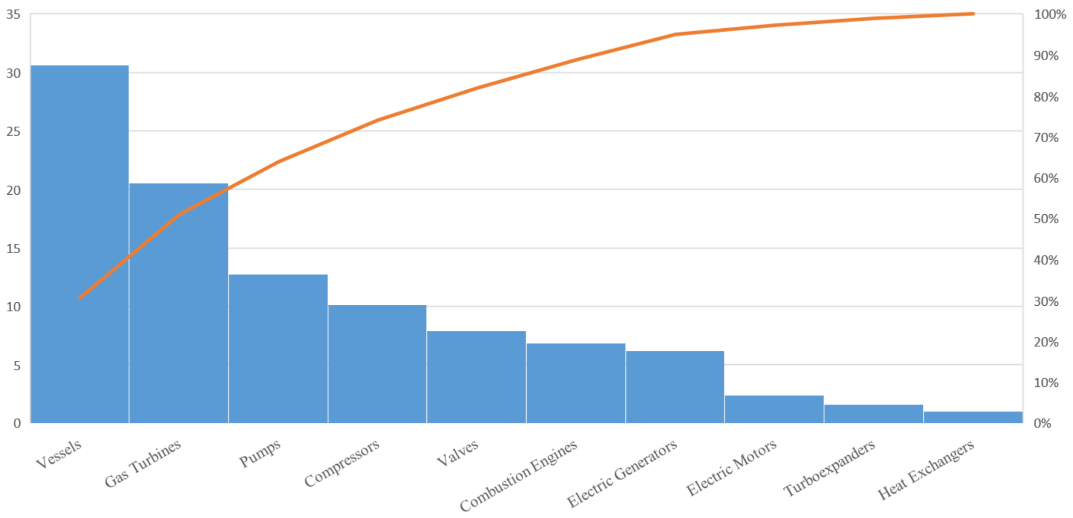

Figure 2. Pareto analysis of equipment in the topsides.

A centrifugal compressor helps in increasing the pressure of a compressible fluid such as gas which would facilitate the export of the gas through the pipeline. Gas enters the compressor through the inlet and transforms to axial flow and directs to the impeller. The kinetic and potential energy of the gas is increased by the impeller. The shaft which is rotated by a driver provides the torque to the impeller. The high velocity gas leaving the impeller slows down in the diffuser which will lead to the build-up of pressure and temperature due to the heat generated due to compression [8]. An example of equipment hierarchy for valves as maintainable items in accordance with the ISO 14224 Standards is shown in Figure 3.

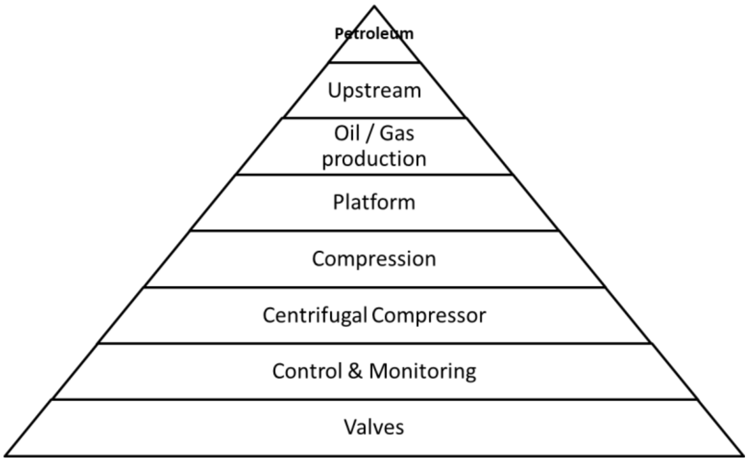

Figure 3. Equipment hierarchy of a centrifugal compressor.

The boundaries of the centrifugal compressor as per ISO 14224 are given in Figure 4. The subunits are power transmission, lubrication system, control and monitoring, shaft seal system, compressor unit and recycle system. The power transmission subunit transmits the input power to the compressor unit by varying the process parameters to adapt to the operating conditions. The lubrication system consists of a reservoir to store oil and provides clean and cool oil to the components at an acceptable pressure and flowrate. The typical measurable parameters of the instrumentation for the control and monitoring are the speed, rotor vibration and position, bearing metal temperatures, lube oil pressure and temperature, suction and discharge pressure and flow rates. The shaft seal systems are crucial in containing the process gas through the use of dry gas [8]. The subunits and maintainable items of the centrifugal compressor within the equipment boundary are given in Table 1.

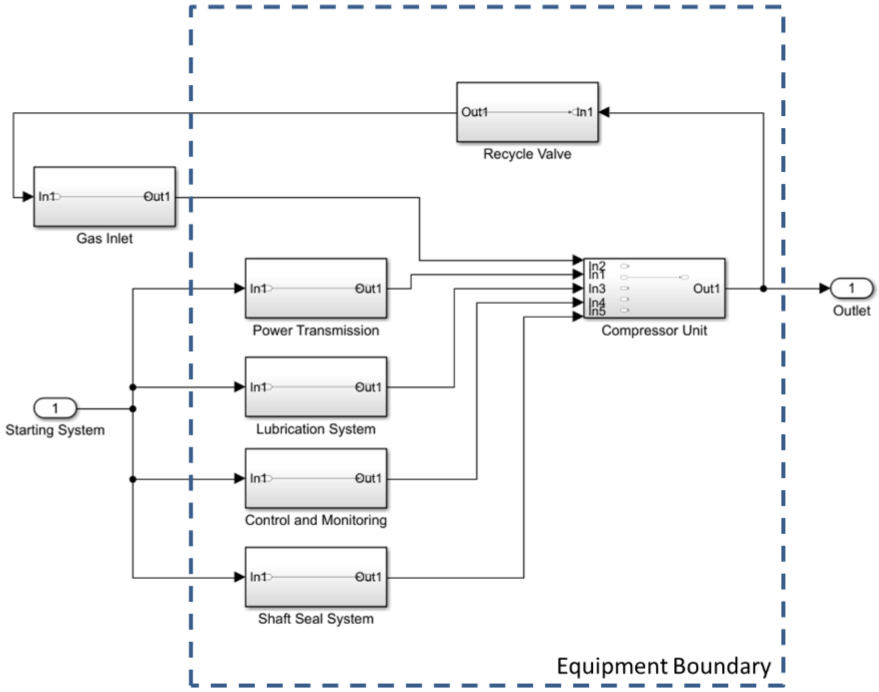

Figure 4. Equipment boundary of a centrifugal compressor (Based on [3]).

Table 1. Subunits and maintainable items of a centrifugal compressor [3]

Subunits	Maintainable items
Power transmission	Gearbox/ variable drive, bearings, belt/ sheave, coupling to the driver, coupling to the driven unit, lubrication, seals
Compressor	Casing, rotor with impellers, balance piston, inter-stage seals, radial bearing, thrust bearing, shaft seals, internal piping, valves, anti-surge system, piston, cylinder liner, packing
Control and monitoring	Actuating device, control unit, cables and junction boxes, internal power supply, monitoring, sensors, valves, wiring, piping, seals
Lubrication system	Oil tank with heating system, pump, motor, check valves, coolers, filters, piping, valves, lube oil
Shaft seal system	Oil tank with heating, reservoir, pump, motor, gear, filters, valves, seal oil, dry gas seal, mechanical seal, scrubber
Miscellaneous	Base frame, piping, pipe support and bellows, control valves, isolation valves, check valves, coolers, silencers, purge air, magnetic bearing control system, flange joints

Weibull analysis is conducted for selected failure modes for valves as shown in Figure 5. One of the causes of the failure modes of valve failing to start may be due to early design-related or installation failure with shape parameter less than one. A valve may fail due to random degradation failures in the useful life and the shape parameter is one. A valve may leak due to age-related factors such as wear and tear with the shape parameter greater than one.

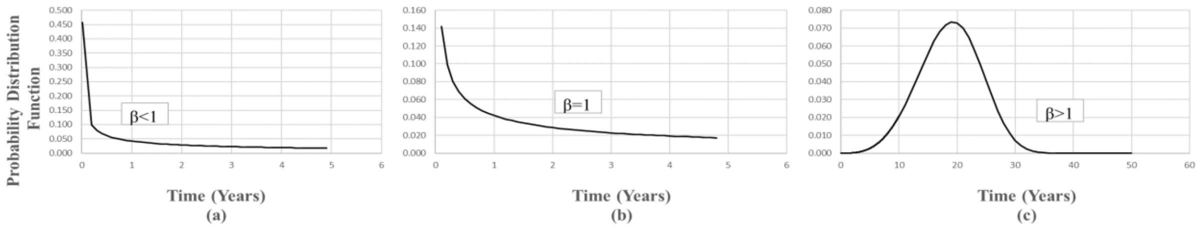

Figure 5. Weibull analysis for each failure mode for a valve (a) early or infant-mortality failures (b) random failures (c) age-related failures

The parameters, β and η, are estimated from the instance of failure causes and from the mean failure rate as provided in OREDA. To determine the cost optimization for optimum replacement interval, β>1 and cost of unscheduled failure must be greater than the cost of planned replacement as shown in Table 2. The cost of failures and replacement are shown for illustrative purposes only. The cost per unit time is shown in Figure 6.

Table 2. Parameters for optimization of age-related failure

Parameter	Value
β	4
η	20.7 years
Cost of unscheduled failure	£30000
Cost of planned replacement	£10000

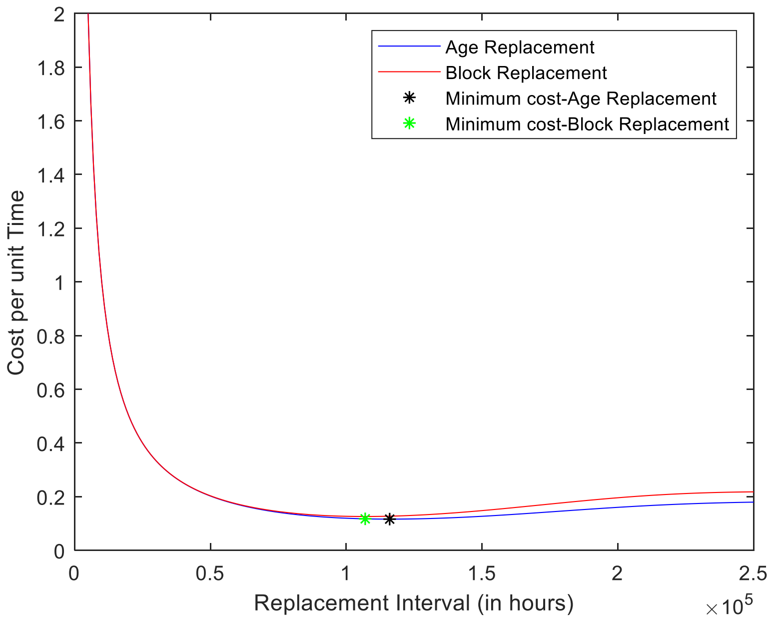

Figure 6. Cost optimization for optimum age and block replacement of valves.

The optimum age replacement time for the valves due to the age-related wear out failure mode is determined to be 116000 operating hours and for optimum block replacement for the valves is determined to be 107000 hours. This means that if a failure occurs before 116000 hours for age replacement case, the valve should be replaced and then replace it again only after the completion of another 116000 hours. In block replacement scenario, if the failure occurs before 107000 hours, say at 7000 hours, the valve needs to be replaced and then again replaced at 107000 hours. Age replacement would ideally be suited for expensive components whereas block replacements occur at regular intervals and mainly for inexpensive components.

4. Conclusion

This paper reviewed the traditional RCM processes and the associated advantages and disadvantages. An integrated approach with statistical and optimization techniques would facilitate the validation of the traditional RCM processes and makes it quantitative and comprehensive. The paper illustrated the optimization approach using the example of centrifugal compressor in the Oil and Gas installations. Weibull analysis and cost optimization procedures are performed for selected failure modes to determine the optimum replacement intervals for the components. Future research work is planned to determine the overall system reliability of the equipment by considering the failure modes of a component that are considered in series or parallel configuration.

Acknowledgements

This research project has been funded and supported by Innovate UK and Optimal as part of Knowledge Transfer Partnerships Scheme.

References

[1] Basson M 2018 RCM3 *Risk-Based Reliability Centered Maintenance* (Industrial Press)

[2] Selvik J T and Aven T 2011 A framework for reliability and risk centered maintenance *Reliability Engineering & System Safety* **96** 2

[3] BSI Standards Publication 2016 *Petroleum, petrochemical and natural gas industries - collection and exchange of reliability and maintenance data for equipment* Report No. ISO 14224:2016.

[4] Kiran D R 2017 *Total Quality Management* (Butterworth-Heinemann)

[5] Walpole R, Myers R, Myers S and Ye K 2014 *Probability and Statistics for Engineers and Scientists* (Pearson New International Edition)

[6] Smith D J 2011 *Reliability, Maintainability and Risk* (Butterworth-Heinemann)

[7] SINTEF 2009 *OREDA, Offshore Reliability Data, Volume 1 - Topside Equipment* (OREDA Participants)

[8] Wilkes J, Pettinato B, Kurz R, Hollingsworth J, Zhang D, Taher M, Kulhanek C, Werdecker F, Büche D and Talabisco G 2019 *Compression Machinery for Oil and Gas* (Gulf Professional Publishing)