Design of a Maintenance Optimisation Approach for Offshore Oil and Gas Production Systems

Chanan S. Syan and Geeta G. Ramsoobag

Abstract The expediency of production in the Offshore Oil and Gas Industry is dependent upon high asset integrity levels as a result of well organised maintenance practices. There arises a need for a structured approach to maintenance optimisation for such a complex system. This paper outlines a process for designing an approach for maintenance optimisation of an Offshore Oil and Gas Production System. A detailed literature research on maintenance optimisation is performed to highlight the key tools, techniques and strategies applicable to this industry. In addition, further research was conducted on past optimisation frameworks in the area. The findings highlighted several key stages which were used to design the proposed framework however some stages were modified to accommodate specific elements relating to the industry of interest. This would serve to guide users on achieving effective optimisation for a range of assets. Although the initial stages have been tested future work will attempt to validate the complete framework with a practical case and perhaps extend it to include multi-criteria optimisation techniques.

Keywords Maintenance optimisation · Preventative maintenance · Risk based maintenance

1 Introduction

With current oil prices at around US$50 a barrel, the Oil and Gas industry needs to reduce its operating costs to remain competitive (Meenagh 2015). A significant portion of these operating costs are maintenance related. World Offshore Maintenance Modifications and Operations Market Forecast 2014–2018 reports a total cost of US$112 billion in maintenance, modifications and operations for the

C.S. Syan (✉) · G.G. Ramsoobag
Department of Mechanical and Manufacturing Engineering, The University of the West Indies, St. Augustine, Trinidad
e-mail: chanan.syan@sta.uwi.edu

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global Oil and Gas industry (PR Newswire 2014). The complex nature of assets, remote location for operations and harsh environmental conditions magnifies the risks associated with equipment failure. This industry must ensure high levels of uninterrupted production to meet its demands and thus remain profitable. Implementation of effective asset management through optimised maintenance practices is one avenue to aid in maximising return on investment and provides a strategic function for creating a competitive advantage. Maintenance must be performed in a timely manner accounting for high production levels at low costs. Thus, there arises a requirement for an approach which guides researchers on performing maintenance optimisation for this industry.

Although past literature research has revealed many generic approaches to optimisation, due to the variation in complexity of various systems tailoring is often required before success becomes a reality (Waeyenbergh and Pintelon 2002). A case which requires an industry-specific approach involves Oil and Gas offshore production. This should serve to holistically achieve maintenance optimisation by targeting the particular maintenance practices associated with this industry. Hence the following research questions for this paper are formulated:

(1) What maintenance optimisation approaches, techniques and strategies are most applicable to an Offshore Oil and Gas Production setting?
(2) How can these approaches, techniques and strategies be utilised effectively to achieve maintenance optimisation for an Offshore Oil and Gas Production System?

2 Review of Maintenance Optimisation Approaches

The literature research process encompassed a review of 136 papers in total. This facilitated both the familiarisation with tools and techniques applicable to maintenance optimisation and framework development.

Publications consisting of several approaches have been proposed and some applied to achieve maintenance optimisation. The findings of eleven review papers illustrated certain general classifications which are compiled and illustrated in Fig. 1. Dekker (1996) has segmented these approaches as either Qualitative including Reliability Centred Maintenance (RCM) and Total Productive Maintenance (TPM) or Quantitative which are data driven rather than expert based. Jardine and Tsang (2013) further classified Quantitative approaches as either Deterministic or Stochastic. The classification has shown that a myriad of factors such as maintenance strategy, replacement or inspection decisions and multi-component or single component cases also affects the optimisation approach that could be employed (Van Horenbeek et al. 2010 and Vasili et al. 2011). A further twenty-two papers were reviewed which have targeted optimisation efforts to the Oil and Gas Industry to allow for further investigation into the most relevant techniques and strategies. Applications to numerous aspects of this

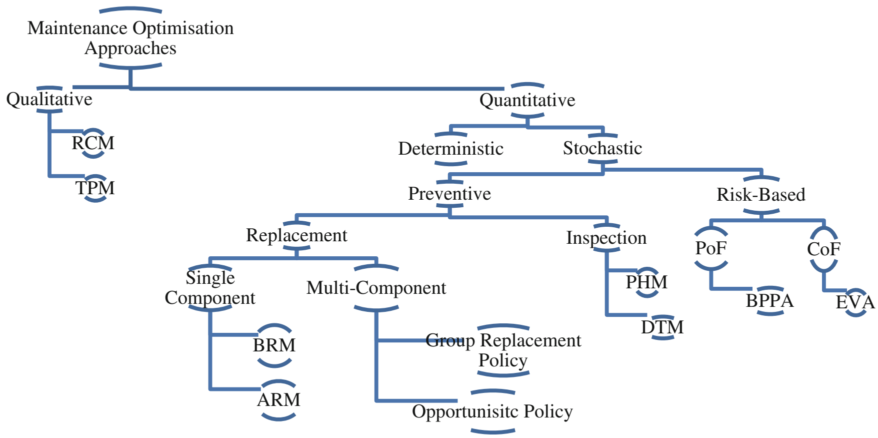

Fig. 1 The classification of maintenance optimisation approaches

industry including static assets such as pipelines and pressure vessels (Dawotola et al. 2011) and rotating assets such pumping systems, certain topside process components and fuel systems (Gowid et al. 2014) were noticed. Increasing use of maintenance strategies such as Condition Based Maintenance (CBM) (Telford et al. 2011) for rotating elements and Risk Based Inspections (RBI) for static assets highlighted a need for techniques in optimisation with the capability to handle variances.

Eighty-six papers were studied which have effectively utilised tools and techniques to treat with varying maintenance strategies. The page limit of the current paper prohibits the display of the complete list of reviewed papers however Table 1 shows extracts of how the publications were reviewed highlighting categories such as year, maintenance strategy, application, optimisation criteria and techniques used for each.. Authors such as Thodi (2011) and Topalis et al. (2012) attempted to optimise the risk criterion which was evaluated to an equivalent cost in terms of Probability of Failure (PoF) and Consequences of Failure (CoF). Techniques such as Bayesian Prior-Posterior Analysis (BPPA), Fault Tress Aanalysis (FTA) and Rate Models were shown as effective in modelling the Pof while Economic Value Analysis (EVA) was the most popular means of analysing CoF. In addition several authors such as Tian and Liao (2011) and Wang et al. (2010) optimised CBM inspections using techniques such as Proportional Hazards Modelling (PHM) and Delay Time Modelling (DTM), both of which proved successful. Since cost was the most popular optimisation criterion the research also focused on certain papers which have attempted Availability optimisation as this is another important criterion in the industry of interest (Chan and Asgarpour 2006). Jardine and Tsang (2013) have detailed the concept of Age and Block Replacement Models (ARM and BRM) for optimising Preventive Replacements.

Also reviewed were techniques utilised for assessment of maintenance strategies. Analytical Hierarchy Process (AHP) is a flexible, multi-criteria decision making tool which has been utilised significantly in this context (Ahmadi et al. 2010). Authors such as Rashidpour (2013) have applied AHP to aid in maintenance strategy selection. Andrawus (2008) has expounded on a combined Reliability Centred Maintenance (RCM) and Asset Life-Cycle Analysis (ALCA) approach to maintenance strategy selection to assess the economic viability of a particular strategy. The above research findings provide a comprehensive basis of tools and techniques to facilitate the maintenance optimisation process. However, to be able to effectively achieve results a structured approach must be formulated which directs users on applying such tools and techniques. As a result, the following section details further review of past frameworks utilised to achieve optimisation and explains the design of one such framework targeted towards the Oil and Gas industry.

3 Optimisation Framework Review

The work done in this publication follows the definition of a framework as "*a guideline, procedure or step by step process used to plan or decide for something*" (Ahmad et al. 2011). A framework which provides a guideline for planning decisions to achieve maintenance optimisation would prove tremendously beneficial. (Tam and Price 2006). Asset intensive industries such as Oil and Gas require such a framework to ensure proper operations and high levels of continuous production. Although numerous frameworks have been proposed in the past success is often non-materialistic due to the lack of specificity. To fully realise optimisation benefits technical factors and clear system details must be incorporated into the framework. A total of seventeen further publications were analysed to gain an understanding of the key stages which must be included in such a framework. A limitation encountered in many past approaches is the apparent disconnect between maintenance targets and organisational objectives (Vasili et al. 2011). As a result, a promising framework should provide allowance for maintenance performance targets to directly relate to the company objectives. Mishra et al. (2006) discusses the concept of World Class Maintenance, which emphasises the need for integration between corporate strategy and maintenance management. Parida and Chattopadhyay (2007) comment on the challenge experienced when combining these company goals and maintenance objectives through top-down or bottom- up approaches. The authors have indicated an increase in subjectivity when using a bottom up approach. Marquez et al. (2009) developed a Maintenance Management framework which utilises a Balanced Scorecard (BSC) technique to establish the system key performance indicators allowing for alignment with the organisational strategic objectives.

Offshore Oil and Gas production systems are amongst the most complex, multi-dimensional systems. Maintenance performance targets realised should be represented in terms of different sub-level performance evaluations. A publication by Gowid et al. (2014) has looked at performance evaluation through system

Table 1 Publications showing techniques utilised based on maintenance strategy and optimisation criteria

Author/year	Maintenance strategy	Criteria optimised	Application	Technique(s) used
Thodi (2011)	Replacement	Risk (cost)	Offshore process components (pipelines)	BPPA, EVA
Topalis et al. (2012)	Inspections	Risk (cost)	Atmospheric storage tanks	EVA, modified failure frequency
Jardine and Tsang (2013)	PM replacements	Cost and availability	Bearing replacement age	ARM/BRM
Tian and Liao (2011)	CBM inspections	Cost and reliability	Shear pump bearings of food processing plant	PHM and EXAKT software
Jardine et al. (2001)	CBM oil analysis	Cost	Haul truck wheel motors	PHM and EXAKT software
Wang et al. (2010)	CBM inspections	Cost	Numerical example	DTM
Andrawus (2008)	CBM inspections	Cost	Offshore wind turbine components	DTM
Chan and Asgarpour (2006)	Preventative maintenance	Availability	Numerical example	Markov model
Sachdeva et al. (2008)	PM replacements	Cost, availability life cycle costs	Paper production system (forming dryer units)	Genetic algorithms and monte-carlo optimisation
Dawotola et al. (2011)	Inspections	Risk (cost)	Petroleum pipelines	AHP

Availability assessment. The analysis has evaluated system parameters methodically throughout different levels of asset systems. Furthermore, Seifeddine (2003) presented a maintenance program which has targeted risk evaluation through the product of failure consequences and probability of failure categorising risk as low, medium and high and treatment is assigned accordingly. Seratella et al. (2007) outline a combined Risk and Reliability approach to optimisation for offshore in-service ships. These authors have noted benefits projected from RBI analyses and thus sought to combine Risk and Reliability. The integrated approach addressed safety and environmental concerns, increased integrity and facilitates optimisation of both strategy types. The analysed papers have shown variations in the number of stages utilised to achieve the end objective however, several similar key principles which should be included in the framework were noted. These principles alongside additional steps which would guide optimisation in the industry of interest were studied and developed into a logical framework shown in Fig. 2.

Stage 1 seeks to develop a link between maintenance and business level objectives. Consider an offshore production case in which business objectives include high uninterrupted production levels to ensure customer satisfaction. This objective can be translated to a maintenance target such as percentage availability. The segmentation of the overall system into various levels and identification of

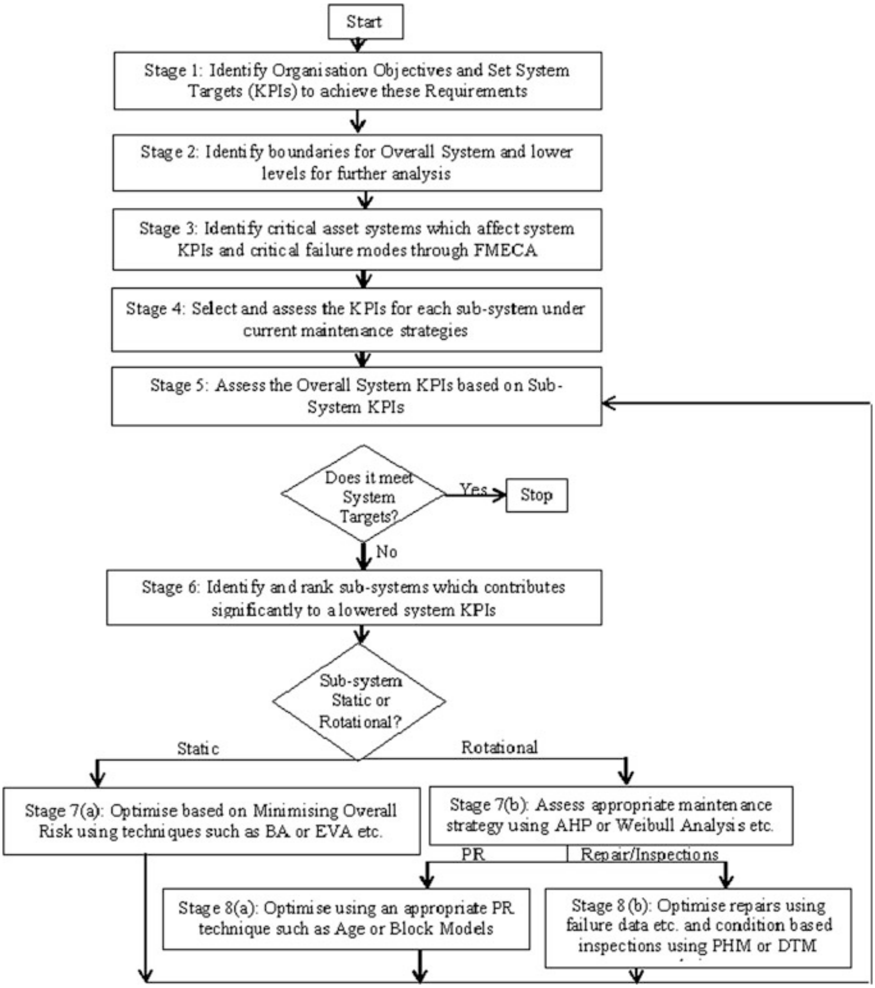

Fig. 2 Designed approach for maintenance optimisation in the oil and gas industry

boundaries allows for performance evaluations to be assessed in such a manner that the overall system is shown as a function of lower sub level systems. Further analysis then follows to allow for critical assets and failure modes to be determined and the system KPI assessed. The outcome of step 5 would identify assets or systems for which maintenance optimisation efforts would greatly impact the overall system.

The final stages of the framework categorise static and rotational assets and in this manner allows for simple application of the relevant tools and techniques for optimisation. If a static asset is selected which after evaluation impacts the performance criteria significantly risk methods can be implemented to optimise the inspection interval. On the contrary, if the asset is rotational an appropriate maintenance strategy must first be validated and the appropriate optimisation technique employed. In this manner the tools and techniques outlined above can simply be fitted at the appropriate stage and implemented to achieve results. The first five steps in Fig. 1 have been tested for an offshore gas production system using a qualitative FMECA for asset criticality analysis and a hybrid Markov and Reliability theory approach for determining system Availability. OREDA (2002) handbook was the main data source.

4 Conclusion and Future Recommendations

In conclusion, an approach which acts as a tool for maintenance optimisation is designed for the Offshore Oil and Gas Industry. It allows for practitioners and academics in the field to further attempt optimisation for such an industry taking into consideration the complexities in asset size and varying maintenance strategies. Furthermore, although the first few steps of the framework have been tested continued validation is required through complete application to a practical case. The framework can be extended to include multi-criteria optimisation techniques and thus present a wider range of achievable targets for the organisation.

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