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Predicting ship machinery system condition through analytical reliability tools and artificial neural networks

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ABSTRACT

Inadequate ship machinery maintenance can increase equipment failure posing a threat to the environment, affecting performance, having a great impact in terms of business losses by reducing ship availability, increasing downtime and moreover increasing the potential of major accidents occurring and endangering lives on-board. This paper aims to provide a systematic approach for identifying critical ship machinery systems/components and to analyse their physical parameters. Critical ship main engine systems/components are used as input in a dynamic time series neural network, in order to monitor and predict future values of physical parameters related to ship critical systems. The critical main engine systems/components and their relevant parameters to be monitored are identified though the combination of Fault Tree Analysis (FTA) and Failure Mode and Effects Analysis (FMEA). A case study of a Panamax size container ship is presented in which Artificial Neural Networks (ANN) are used to predict the upcoming values of all main engine cylinders exhaust gas temperatures. The forecasted results were validated through comparison with actual observations recorded on board the ship. The proposed hybrid methodology successfully presents a systematic approach for initially identifying critical systems/components through reliability modelling and tools and subsequently monitoring their physical parameters through neural networks.

1. Introduction

Maintenance tasks affect the reliability and availability levels of the shipping industry and are important factors in the lifecycle of a ship that can minimize down-time and reduce operating costs as is accounts for 20%–30% of a ship's operational expenses (Stopford, 2009). Also, due to the impact of shipping on the environment and the importance of the safe operation of ships; ship owners and operators pursue to adopt a maintenance plan and procedures that will reduce costs and promote the lifecycle integrity of the ship. Although the maritime industry is responsible for the massive transportation of goods worldwide, it is only recently that new approaches investigating the enhancement of ship's reliability, availability and profitability have been considered according to Lazakis and Ölçer (2015). Though the industry is still predominantly reliant on a time-based, prescriptive approach to maintenance, there are a number of factors challenging the long-held norm. The increasing complexity of shipboard systems, heightened expectation and competitive needs as to ship and plant availability and efficiency and the influence of the data revolution on vessel operations, favour a properly structured Condition Based Maintenance (CBM) regime. This may not replace all planned maintenance, but it can possibly reduce downtime, inspection and unnecessary servicing work. The advocates of change argue that a move from scheduled, rule-based maintenance to a data-driven, risk-based approach can lead to more accurate and timely maintenance, resulting in lower costs, greater availability of ship systems and increased safety (Tinsley, 2016).

In this respect, according to British Standard (2012), CBM is defined as the maintenance policy carried out in response to a significant deterioration in a machine as indicated by a change in a monitored parameter of the machine condition. The heart of CBM is condition monitoring which aims in collecting data regarding equipment conditions. Condition monitoring technologies are applied through various tools by recording and evaluating different measureable parameters. Data can include vibration, acoustic, temperature, current signal, oil and lubricant measurements (Pascual, 2015). Compared to other industrial applications, in the shipping industry data pooling is not always possible as similar equipment in different conditions may have different failure patterns. Another issue is the constant appearance of new equipment, which makes

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historical records obsolete. Moreover, data is not collected in a standardised way so that it can lead to more informed and successful decision making (Dekker, 1996). Technological advances and high cost of ownership have resulted in considerable interest in advanced maintenance techniques. Raza and Liyanage (2009) stated that there has been an increasing demand for testing and implementing intelligent techniques as a subsidiary to existing condition monitoring programs and that ANNs have emerged as one of the most promising techniques in this regard.

The question of how much data, which data, and how often this should be collected and how has also risen; as although companies adopt CBM schemes, there seems to be an issue in processing, analysing and utilising the recorded operational data. This paper aims to identify critical systems of a ship's main engine through the combination of the FTA and FMEA tools and to further examine them through monitoring their physical parameters. The physical parameters are used as input for time series analysis and forecasting using artificial neural networks.

The present research paper is organized as follows: Section 2 presents the maintenance overview and status in the maritime industry alongside the methodologies/tools implemented in detail. In Section 3 the suggested methodology is demonstrated and explained. Section 4 presents the case study application through which the methodology is applied alongside the obtained results. Finally, the discussion and conclusion of this research study is presented in Section 5.

2. Research background/literature

The evolution of maintenance was based not solely on technical but rather on techno-economic considerations according to Pintelon and Parodi-Herz (2008). Furthermore, according to Arunraj and Maiti (2007), maintenance policies can be categorised into four generations as seen in Fig. 1. The fourth generation is the most recent one, which focuses on condition based maintenance, condition monitoring and failure eliminations. It concentrates on reducing the proportion of equipment failures and overall levels of failure probability through various tools and strategies, based on preventive and predictive maintenance approaches.

Examining Fig. 1 and associating it with maintenance in the shipping industry, it can be observed that maintenance was initially treated as a necessary evil and has now started to be considered an important factor in the operational management and lifecycle of ships. Lloyds Register (2013) published a report regarding machinery planned maintenance and condition monitoring which was revised in order to add machinery condition based maintenance procedures and describe how a machinery planned maintenance scheme can be accepted as an integral part of the continuous survey machinery cycle. Class NK introduced the concept of PrimeShip-Total Ship Care (2013) which has been designed to prevent pollution of the marine environment and ensure safety of ships at every stage of a ships life including maintenance. The product contributes to improved reliability and increased efficiency of hull structure analysis, machinery shaft alignment and torsional vibrations and maintenance management amongst others. DNV-GL also published a paper in 2014 regarding condition monitoring in the shipping industry reviewing existing condition monitoring technologies and methods for implementing such technologies (Knutsen et al., 2014). The American Bureau of Shipping (ABS) introduced the NS5 Entreprise software (2015b) aiming to handle the primary functions of operational management-maintenance, supply chain, workforce, environmental and safety. Classification Societies encourage condition monitoring techniques on board ships, offer guidelines but do not oblige ship operators or owners to implement such techniques in their operation and maintenance. Furthermore, Lazakis and Ölçer (2015) introduced a Reliability and Criticality Based Maintenance (RCBM) strategy by utilising a fuzzy multiple attributive group decision-making technique, which is further enhanced with the employment of Analytical Hierarchy Process (AHP). The outcome of this study indicated that preventive maintenance is still the preferred maintenance approach by ship operators, closely followed by predictive maintenance; hence, avoiding the ship corrective maintenance framework and increasing overall ship reliability and availability. However, most shipping companies still follow the so called Planned Maintenance System (PMS) based on ISM code (IMO, 1993) which is centred on the preventive maintenance scheme, in which machinery items are maintained based on operating hours or calendar intervals. A brief discussion of the methods applied in this paper is presented below, while the specifics of how they were applied to the case study are given in detail in Section 3.

2.1. Failure modes and effects analysis (FMEA)

FMEA provides a systematic method for organizing the study of a particular system or process in terms of failure analysis. The aim of FMEA is to review the system in order to provide details on how to identify failures and their causes as well as determine the end results of the failures occurring. Thus, FMEA is a formalized method to consider all components, their functions, failure modes and system failures (Isermann, 2006). It involves reviewing as many components, assemblies and subsystems as possible to identify possible failures modes and causes and effects of such failures. FMEA can be applied in a bottom-up approach which assists in mapping the overall failure potential of the system. This

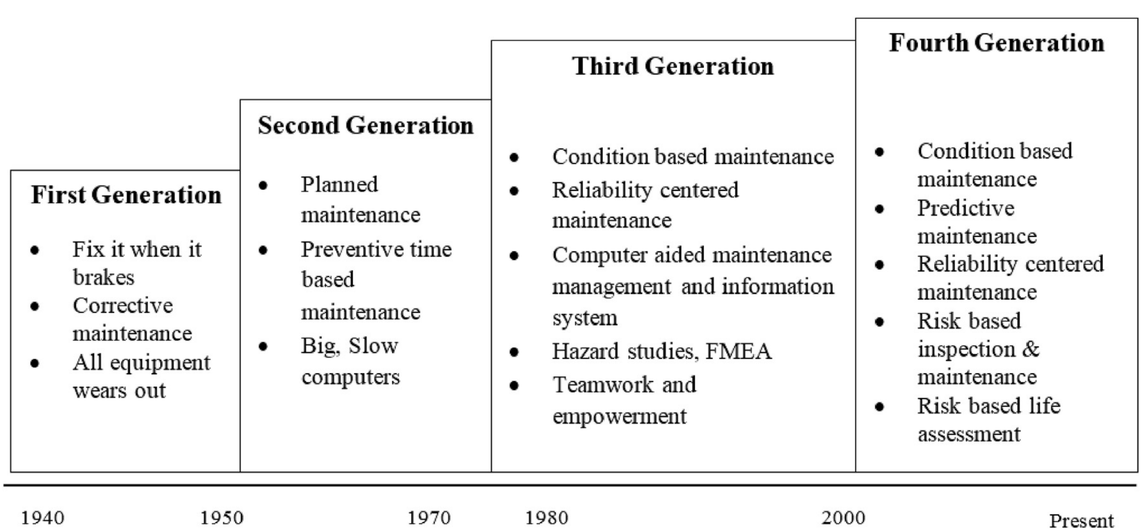

Fig. 1. Evolution of maintenance (Adapted by Arunraj and Maiti, 2007).