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A dynamic model for the hull inspection of ships: The analysis and results

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ABSTRACT

Risk Based Inspection in the maritime sector is an approach that involves the quantitative estimation of the probability of failure and the respective consequences concerning either an equipment item or the hull structure of the vessel. The proper risk based inspection plan has great significance on balancing the safe operation requirements and the inspection costs. This paper deals with the ageing and the breakdown of the fore part of a ship due to different degradation and failure mechanisms (corrosion, fatigue, deformation) and the emerged risks that are related to the property, the personnel and the environment. The developed model evaluates several probable inspection schemes, which diversify based on the inspection effectiveness, the time intervals and the corresponding costs.

1. Introduction

The ships are designed in such a way as to ensure an economically profitable operation throughout their expected lifecycle, always in harmony with the conditions and the acceptance criteria set by the rules from the legislator bodies. This can be efficiently accomplished through the Risk Based Inspection (RBI) planning. RBI planning aims to the optimization of inspection frequency in order to avoid possible unacceptable risks from under inspections of structural components or from over inspections to functional items. The main object of RBI methodology is to identify either structural elements or mechanical equipment, which have the highest probability of failure, and to organise a plan so as the risk levels will be controlled at reasonable cost (Chang et al., 2005).

A Dynamic Bayesian Network (DBN) is developed for the evaluation of different inspection schemes for the fore part of the vessel in terms of risk and cost by examining different degradation and failure mechanisms. The model integrates corrosion, fatigue (crack initiation) and deformation and analyses the probability of occurrence of these damage types for a time period of 15 years and their subsequent consequences for multiple inspection plans with variable effectiveness and implementation time. Corrosion and fatigue can be regarded as degradation processes with the potential of causing failure of nearly all components of ship. Furthermore, these three mechanisms may lead to lowering the load bearing capacity of the hull structure of the ship and hence overall ship safety.

The paper is structured as follows: a literature review with respect to the applications of RBI in the maritime sector and the offshore industry is presented. The next section of the paper consists of a brief description of the different stakeholders that are performing inspections and surveys, their key characteristics as well as the identified differences on the implementation of the inspection process. This section is followed by the description of the selected methodology, the developed model and the quantification process of the model. The subsequent section presents the assessment of proposed inspection plans. Finally, the paper concludes with important results and observations derived by the presented analysis.

2. Literature review

The American Society of Mechanical Engineers (ASME) had developed RBI methodology since 1941 but it became common during the 90's decade (Tan et al., 2011). The earliest application of risk based inspection appeared in the nuclear industry in the 1970's and by the years it have been implemented into other industries, such as the petrochemical industry in the 1980's and 1990's, and subsequently it extended to rails, aircraft and shipping industries (Conachey et al., 2008). The concept of risk-based in-service inspection was published in early 1990s (ASME, 1991). The cooperation between Det Norske Veritas (DNV) and the American Petroleum Institute (API) in the early 90′, led to the birth of the RBI methodology for the oil industry. The cooperation involved also a sponsor group of the largest oil companies like Amoco, Dow, Exxon, Shell etc. The result was the publication of the Base Resource Document, which later was published as API 581. RBI, as defined by the API 581,

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Table 1
Categories of deficiencies (Randic et al., 2015).

Number of Category	Category of deficiencies
01	Certificates & Documentation
02	Structural condition of the hull
03	Water/Weather condition
04	Emergency systems
05	Radio communication appliances
06	Cargo operations including equipment
07	Fire safety
08	Different alarms
09	Working and living conditions
10	Safety of navigation appliances
11	Life saving appliances
12	Dangerous goods appliances
13	Propulsion and auxiliary machinery
14	Sea pollution prevention appliances
15	International Safety Management Code for the safe management and operation of ships and for pollution prevention (ISM Code)
16	The International Ship and Port Facility Security Code (ISPS Code)
17	Other
18	Regulations and Code of the Maritime Labour Convention (MLC Code)

constitutes a pioneer approach for inspection planning, a theory that establishes as the main targets the safety and integrity of the operating facilities/equipment. RBI is based on the risk and focuses specifically on the equipment and the corresponding degradation mechanisms. It provides a connection between the mechanisms that lead a structural element to failure and the inspection approaches that can successfully mitigate the corresponding risks.

Inspection procedures of marine vessels containing structural elements, which are composed of sub-elements and components, can be enhanced by implementing risk based approaches. In a highly complex environment like sea, the integrity of the above-mentioned systems constitutes a significant role, in both their design and operation. Consequences of a possible failure of a ship may contain human injuries, as well as losses, economic damages, and environmental pollution (Ayyub et al., 2002). On 1st January 2011, the Port State Control Committee (PSCC) of Paris Memorandum (Paris MoU) adopted the New Inspection Regime (NIR). The major target of the NIR was to insert the risk based approach to selecting vessels for inspection. In other words, NIR reward the well maintained ships by reducing aimless inspections, while ships of high risk profile are inspected more frequent and detailed. Moreover, the elaborated statistical analysis of Knapp and van de Velden (2011) on the investigation of ship risk profiles, as well as the susceptible areas to general safety, conclude that older general cargo ships are highly prone to risk and two regions, the Caribbean and the Gulf of Mexico, verify the need of port state control inspection because their international legislations does not include smaller ships. Heij and Knapp (2012) provide suggestions for estimating risk at an individual ship by rating various risk factors, such as the type of ship, the nature of companies and managers, historical information on previous accidents, inspections, detentions, etc.. Concerning the seawater ballast tanks, Paik et al. (2004)attempted to estimate the depth of corrosion as a function of time by using a mathematician model which provided the appropriate statistical characteristics. Their study focused on the prediction of corrosion wastage on low alloy carbon steel plates into seawater ballast tank structures of vessels. A study for the calculation of corrosion wastage in ballast tanks of a ship was also considered by Gudze and Melchers (2008). Their model had taken into consideration the operational profile of the examining vessel, as well as the several temperatures of the geographical areas where the ship used to operate. Soares et al. (2009) examined further the influence of temperature and marine environment to the corrosion rate on vessels. They demonstrated that corrosion is mainly influenced by moisture in marine environments, and subsequently the period of exposure to wetness.

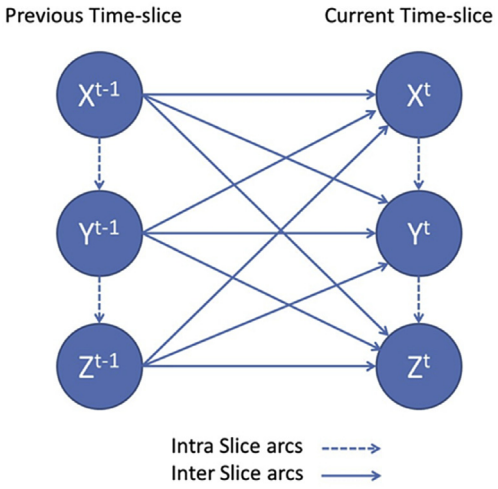

Fig. 1. Typical structure of a DBN.

In offshore industry, several studied have been performed analysing various risk based approaches. Offshore platforms are steel structures responsible for extracting and processing oil and natural gas. Due to the hazardous nature of the extracting products, offshore platforms are considered of high risk procedures. The attention of risk management is relied on the safety of the crew, the integrity of structure, the prevention of environmental pollution and the regularity of production (Brandsaeter, 2002). Furthermore, it should be highlighted that regardless of the harsh environment, the platform should maintain its integrity by means of Inspection, Maintenance and Repair (IMR) plans. The optimization of these plans is to inspect by using the right tool, at the right place, at the right time, and at the lowest cost (Rouhan and Schoefs, 2003). The risk based approaches in offshore industry are more targeted to components which may cause disastrous consequences. Specifically, Goyet et al. (2002) applied a risk based inspection plan for a welded joint in the hull structure of a Floating Production, Storage and Offloading facilities. Furthermore, Straub et al. (2006) focused on the economical benefits of adapting risk based inspection planning to offshore platforms. Their study compared the costs of risk based inspection strategy with the traditional fixed inspection intervals for all possible critical elements. IMO, 2010, DNV distributed a detailed description of risk based inspection on offshore platforms. The recommended practice of DNV refers to topside mechanical equipment including similar characteristics to Formal Safety Assessment. The study of Kawsar et al. (2015) was based on the subsea pipeline systems of offshore platforms. The proposed probabilistic model was applied to several accidental scenarios to confirm the safety of subsea pipelines under different environmental conditions. Over the past decade oil and gas operators of floating offshore installations (FOIs) such as FPSOs, FPUs and FLNG units have been slowly pushing for a risk-based approach to be applied to these asset types in order to fit better with their operational goals. Farias and Netto (2012) studied the impact of the corrosion on the structural integrity of the hulls of floating production storage and offloading (FPSO) units. The traditional class surveys which are based on a periodic class regime, encompasses local regulations, class society rules and industry standards and practices, however, the example of oil and gas industry that has long applied risked-based methodologies and technology for integrity management, shows the extreme capabilities of this approach (Goyet et al., 2010; Ku et al., 2012; Lanquetin et al., 2007).

3. Types of inspections, surveys and audits

One of the major concerns of ship managers and ship owners is the safety of vessels. The main aim of the shipping companies is to validate the strength structure and the equipment systems remain operational in a satisfactory condition. Inspections, as a process, assist these companies to