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Human error assessment during maintenance operations of marine systems – What are the effective environmental factors?

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ABSTRACT

Human errors during maintenance operations are one of the most prevalent causes of marine accidents. Seafarers conduct marine system maintenance on-board in a challenging environment, which makes maintenance prone to un-intentional errors. To address this concern, the study of human performance during maintenance operations on ships is necessary as a part of maritime quantitative risk assessment. However, there is a significant lack of appropriate field data and information relating to human performance on-board ships. This study attempts to fill this important data and knowledge gap. It presents a data collection and analysis procedures for maintenance operations of marine systems. Data related to performance-affecting factors is collected from a total of 235 experienced seafarers from Engine Departments (ED) and Deck Departments (DD) through a structured questionnaire. The collected data is then analysed for normality and also for a pairwise significance test. It helps to study the generalization of the data and also to identify the relative importance of the performance-affecting factors. Collected data will help in developing human error assessment techniques for more accurate Human Error Probability (HEP) estimation in marine environmental conditions. Additionally, this study is useful for identifying the relative importance of performance-affecting factors for the maintenance operations of marine systems. Based on the results of this study, workload and stress, and ship motion (roll and pitch) are identified as critical factors affecting seafarers' performance during maintenance operations. These identified high important performance-affecting factors will assist in future human reliability analysis and risk mitigation strategies for improving the safety and reliability of maintenance operations for the marine industry.

1. Introduction

Maintenance operations of marine systems are essential to avoid unexpected downtime, to minimize the number of mishaps, and furthermore to increase the life of the machinery. Over the past two decades, numerous accidents have occurred during the maintenance operations of marine systems due to human-induced errors (Kuehmayer, 2008; MARS, 2010; MD, 2011; TSB, 2013). Some of the examples of these accidents are fishing vessel Erika, and "RALI II", and a passenger ferry Al-Salam (DMA, 2011; El-Ladan and Turan, 2012; TSB, 2013). Another example of accident due to human error is the Exxon Valdez oil tanker at Prince William Sound, Alaska in 1989 (Wickens and Huey, 1993). Researchers Islam et al. (2016) explained more detail of human error causation and its impact on the maintenance operation of marine systems.

There are several types of factors affecting human error during maintenance operations of marine systems (Abaei et al., 2017; Noroozi et al., 2010). These factors can be classified into two broad categories, being internal and external factors (Wu et al., 2006). The internal factors can be further categorized as a seafarer's ability, mental state and physical state. Additionally, external factors can be further categorized as environmental and operational factors. This study focuses on environmental factors affecting seafarers' performance only. There are many environmental factors affecting seafarers' performance during the maintenance operations on-board ship (Islam et al., 2017a). Some of these environmental factors are weather conditions, workplace temperature, ship motion, noise and vibration, workload and stress (Hetherington et al., 2006; Li and Ng, 2002; Sillitoe et al., 2010; Stevens and Parsons, 2002; Xhelilaj and Lapa, 2010).

Weather conditions significantly affect seafarers' maintenance activities in marine operations due to the hostile marine environment. An extreme weather condition has a major impact on seafarers' maintenance activities. Because extreme weather produces significant wave heights, the level of ship motion, noise and vibration, and workload and

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stress increases. Due to the increased intensity of these factors, seafarers' performance decreases significantly and influences maintenance activities which in turn leads to human error (Arslan and Er, 2008; Berg, 2013; Kristiansen, 2013). Similar results were found in the various studies by Christiansen and Hovmand (2017); Parker et al. (1997); Tupper (2013). Parker et al. (1997) found results by conducting a survey among Australian seafarers, Tupper (2013) by analysing numerous accidents data, and Christiansen and Hovmand (2017) by investigating the reason for accidents in Nordic fishing vessels.

Workplace temperature is another environmental factor lowering seafarers' performance during maintenance operations. Extreme workplace temperature (hot or cold) can negatively affect seafarers' performance in different ways. It may cause fatigue and increase or decrease body temperature. Fatigue decreases the ability to concentrate on maintenance activities, high temperature leads to heat stroke, and low temperature leads to health and operational consequences (Parsons, 2014). Moreover, mental abilities and perception are also significantly affected by extremely cold temperature, hence the rate of perceptual error is increased. Furthermore, cold weather ultimately affects physical performance due to the decrease in flexibility and the inability to identify external elements. Thus the chances of error increase (Parsons, 2014). Hancock et al. (2007) used Meta-analytic methods to analyse 291 collected reference data. Analyses of the data confirmed a substantial negative effect on performance associated with extreme temperature.

Ship motion is also a reason for seafarers' performance reduction prompting seafarers to make errors. Stevens and Parsons (2002) conducted a survey to ascertain the effects of ship motion on seafarers' performance. The survey results demonstrated that ship motion significantly affected the seafarers' performance. Moreover, Colwell (2005) studied the effect of ship motion on seafarers' task performance for a virtual naval platform and found similar results.

Sensitivity to motion sickness differs for each individual and can develop slowly or quickly (Wertheim, 1998). Due to excessive ship motion, seafarers feel uncomfortable, degrading their performance both mentally and physically. Moreover, it makes seafarers less efficient, creates task difficulty and sometimes even makes it impossible to conduct the task (Tupper, 2013). Furthermore, a study by Bos (2004) found that seafarers' performance is significantly affected even with mild motion sickness and the degradation becomes more noticeable as motion sickness increases.

Noise and vibration is another environmental factor that has a negative effect on seafarers' performance which leading to increasing likelihoods of human errors. Jepsen et al. (2015) conducted a review of seafarers' fatigue and found similar results. Moreover, Hystad and Eid (2016) collected survey data from a sample of 340 seafarers working on-board ships in order to identify the impact of noise and vibration on seafarers' performance and deduced similar results. Noise and vibration can degrade stamina and alertness, which affects both productivity and the safety of operations. They can also lead to strain and fatigue and are responsible for seafarers' hearing damage, sleep disturbance, irritability and decreased performance. Researchers Cohen and Weinstein (1981); Fahy and Walker (1998); Stansfeld and Matheson (2003) believe that noise and vibration have a significant impact on human performance initiating the lack of attentiveness, fatigue, annoyance, hearing hazards etc. Persistent exposure to noise causes fatigue and confusion. This may significantly affect maintenance procedures on-board ship (Ross, 2009).

Finally, workload and stress are additional important environmental factors in decreasing seafarers' performance. When the seafarers' workload increases, their performance consequently decreases. Smith et al. (2006) performed a study to identify the most important factor responsible for causing seafarers' fatigue. He observed that workload and stress is the most important factor of all other factors (i.e. noise and vibration) leading to fatigue which negatively impact on seafarers' performance. Recently Jepsen et al. (2015) conducted a review of seafarers' fatigue due to workload and stress and identified similar results. Managing work overload is a very common problem for seafarers during maintenance operations. It is initiated by too much effort to overcome the demand being placed upon them. Work underload can also be a problem due to the low level of exertion and stimulation. Extreme overload and underload both lead to human error (Yerkes and Dodson, 1968). If the seafarers are not focused or are bored, this may lead to errors. After a lengthy period of time, the work overload may lead to sleep loss and fatigue. Fatigue is an example of a chronological unproductive team response in a transitional workload situation. The Exxon Valdez accident is one of the best examples of this type of situation (Wickens and Huey, 1993). Work overload can be increased by seafarers' lack of experience, lack of sleep, insufficient personnel, and perceived danger, time constraints and task difficulty, all of which distract and force the seafarers to focus more closely on the task at hand (Embrey et al., 2006b). In these circumstances, it is very hard for seafarers to stay focussed on the maintenance activity (Embrey et al., 2006b).

The above description of the performance-affecting factors and the consequences clearly demonstrate that environmental factors (e.g. weather conditions, workplace temperature, ship motion, noise and vibration and workload and stress) significantly impact on the seafarers' performance and effect the likelihood of error. Therefore, it is necessary to systematically address this concern. In order to minimize human error due to environmental conditions, it is essential to develop HEP assessment technique to quantify human error. Developing the human error assessment techniques in quantitative risk assessments requires numerical data (Abbassi et al., 2015; Islam et al., 2016; Islam et al., 2017b; Noroozi et al., 2013). Currently, there is a lack of appropriate human error data to allow the maintenance operation of marine systems to be applied by the industry and for researchers to develop an accurate technique for human error assessment. Therefore, collecting the relevant quantitative data on human errors which have occurred in maritime operations, is unavoidable. The data available in the literature on performance-affecting factors is not collected in a structured way to develop HEP assessment technique. Moreover, most of the data are collected from studies with specific regional case studies. Furthermore, available data in the public domain by Blanco and Lewko (2002); Montewka et al. (2014); Ritmiller (1998), specifically on the key factors affecting the human performance during maintenance operation in shipping, are qualitative and subjective in nature. Therefore, in these studies, the lack of appropriate data on human performance is identified as a key knowledge gap. This knowledge gap limits the usability of any engineering approach to better understand and improve human performance.

Islam et al. (2018) and Islam et al. (2017a) studied the influential factors on seafarers' performance considering experienced seafarers' feedback and by analysing the available literature. For the data collection, the experienced seafarers' feedback could have conflicting interests. Therefore, it is essential to measure the responses and the difference in the feedback on a consistent scale. It is also to be noted that to develop a broader human error assessment technique, the appropriate supposition principles need to be used.

To meet the scientific rigour and enable generalization of the data and its interpretation, various sources of data and modes of feedback, such as interviews with experienced seafarers' on-board, review of existing documentation, and a direct questionnaire method, can be used. The direct interview is generally conducted face to face. It offers a wide range of data some of which is unwanted (Patton, 2005; Stanton et al., 2013; Styśko-Kunkowska, 2014). However, this is time-consuming. Furthermore, undesirable additional information may distract from the focus of the study and may be time costly. Therefore, as noted by Witkin and Altschuld (1995) in many circumstances, respondents may be hesitant to put a number to a question, and the researchers may not come up with a result. Due to the respondent's hesitation to apply a number, the interview objective is affected which will be costly in time and difficult to find another suitable respondent. Thus, a direct