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A methodological extension to human reliability analysis for cargo tank cleaning operation on board chemical tanker ships

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ABSTRACT

This is an article that conducts an empirical human reliability analysis for tank cleaning process on-board chemical tanker ship to enhance safety and operational reliability in maritime industry, providing a methodological extension through the integration of the AHP technique into the HEART approach. The paper provides a methodological development on decision making and human factors via extending a new approach to weight the proportion of the effect for calculating error producing conditions through operations. The model demonstration illustrates that cleaning of residues from hazardous cargoes such as acetic acid has required performing various critical tasks supported with recovery solutions. This research also provides practical insights along with reliability monitoring in ship operational level.

1. Introduction

In recent years, human factors have significantly increased in the marine industry since most of accidents have been widely caused by within shipboard hierarchy (Fortland, 2004). There have been various attempts proposed to tackle with human errors in order to enhance maritime safety. One of the most important attempts have been governed by IMO (International Maritime Organisation) whose aim is to establish a regulatory framework including safety, security, and pollution prevention in order to enhance maritime safety. In addition, maritime safety can be improved if the international regulatory requirements are effectively and systematically adopted by ship owners and shore-based management organisations continuously. Furthermore, majority of hazardous occurrences and marine accident caused by human error can seriously be reduced. In this sense, human performance and relevant conditions on-board ship play critical role to prevent marine accident particularly in tanker ships which are carrying dangerous cargo on-board.

The chemical tanker is special type of ships designed to carry petrochemical product cargoes in bulky condition. Since the petrochemical commodities shipping has been increasing enormously in marine transportation, their carriage requires extra attention due to the inherently hazardous content such as being poisonous, explosive, corrosive, and toxic (IMDG Code, 1996). These noxious products might have potential hazards for human life and marine environment whose control is required advance operating procedures supported with innovative marine technologies. Therefore, the carriage of the petrochemical substances is quite critical process includes serious tasks for responsible crew on-board ship. Particular attention has been given by ship crew during cargo operations such as loading, discharging, gas inerting, tank cleaning and gas freeing in shipboard platform engaged in the carriage of chemical cargoes. The IMO has recently adopted significant amendments for SOLAS (International Convention for the Safety of Life at Sea) convention which proposed new mandatory requirements for cargo tank cleaning and inerting. While carriage of chemical cargoes require excessively attentions, the crew must be well trained and qualified in both theoretical and practical manner as well as be aware of the potential hazards. Therefore, crew/human reliability on-board ship has been a serious concern in marine industry. The expectation from the crew is to perform system-required task without any misperception or violations which might cause an operational failure. So that, chemical tanker organisations should proactively control and prevent the possible catastrophe using advance techniques and smart procedures.

With this insight, this paper proposes a hybrid methodology to conduct HRA upon cargo tank cleaning operations on-board chemical tanker. The paper introduces a new approach by combining Analytic Hierarchy Process (AHP) methodology into HEART in order to provide comprehensive and rational framework for HRA.

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To achieve reasonable improvement in HEART approach, the paper is organized as follows; this section emphasized the role of the HRA in maritime safety. The next section provides literature review upon HRA. The third section identifies proposed methodology. Furthermore, an application on cargo tank cleaning operation onboard chemical tanker is presented to demonstrate the specific application of the proposed methodology in section four. The final sections give the discussion and conclusion as well as original contribution of the study.

2. Literature review

Human reliability is one of the significant aspects of shipboard operations since they have potential impacts on maritime safety. The consequences of human reliability directly affect marine environment, ship and commodity. The statistics show that human error is the most contributory factor to system failure and accident (Kirwan, 1987). In recent days, investigation of the human performance has been conducted as a core topic to minimise fatal accident in marine industry. Particularly, human reliability analysis has been a prominent subject for safety and reliability engineers, quality assurance specialists and ship operators since the shipboard organisations should have limited tolerance to operational and technical mistakes at sea.

Human reliability is defined as the probability that the person/operator performed system-required task without failure in a certain time period (Swain and Guttmann, 1983). The present HRA covers a couple of stages such as identifying human act, modelling of significant human action and evaluating human action probabilities. However, these methods have fundamental limitations to introduce all of the significant aspects of human performance due to insufficient data, subjectivity of analysis and uncertainty (Konstandinidou et al., 2006). The HRA utilises human error probability (HEP) values which is always difficult to find out. Therefore, the human reliability techniques focused on to solve HEP values with variety of applications.

Although the HRA is quite new disciplinary research, there have been numerous methods developed to quantify the human performance and calculate human error probability. The first generation HRA methods are covering the date between 1970–1990 years. The second generation is between 1990–2005 years. Consequently, the third generation HRA methods have been presented since 2005. As the human reliability has direct correlation with human factors, performance shaping factors (PSF) for human error came up to improve or reduce human performance (Blackman et al., 2008). In addition, PSF is sometimes called as common performance condition (CPC) or error producing conditions (EPC). The contribution of PSF into accident prevention leaded to emerge various HRA methods in literature.

The first HRA techniques were developed after the Second World War due to the substantial acceleration in military equipment such as weapon systems (Swain, 1990). Thereafter, numerous HRA approaches started to evolve in order to assess human error and reliability such as THERP (Technique for Human Error Rate Prediction). The method is hybrid and it combines the dependency and recovery (Swain, 1963). The purpose of the paper is to evaluate human reliability dealing with task analysis, failure definition and quantification of HEP values. To assess human failure in task or action sequences, SLIM (Success Likelihood Index Methodology), presented by Embrey et al. (1984), has been used to evaluate HEP occurring along the specific task. The method successfully applied in nuclear industry. Furthermore, Williams (1988) introduced a useful tool namely called HEART (Human Error Assessment and Reduction Technique) in order to analyse human tasks with identify HEP value by applying weighting factors. The HEART has been successfully modified and applied in numerous disciplines such as petrochemical industry (Noroozi et al., 2014), road transportation (Castiglia and Giardina, 2013), healthcare (Chadwick and Fallon, 2012) and nuclear energy (Kirwan, 1997). Furthermore, another HRA method, ATHEANA (A Technique for Human Error Analysis), was introduced as second generation technique in order to define human actions in nuclear industry (Cooper et al., 1996).

CREAM (Cognitive Reliability and Error Analysis Method) is another HRA technique introduced by Hollnagel (1998). This technique consists of basic and extended version. The basic version provides initial screening of human interaction while extended version utilises the findings of it in order to perform elaborative analysis. Likewise, Konstandinidou et al. (2006) proposed a different approach that combined the CREAM into a fuzzy logic in order to determine the human error actions probability. The paper offers a pilot model, which is successfully translating CREAM methodology into fuzzy logic. The authors use fuzzy logic in order to design CPC including nine input variables and one output variable. Another paper in which some developments were carried out in the fuzzy quantification of HEP in the light of the CREAM framework was presented by Marseguerra et al. (2006). The paper applied the proposed model into an emergency response to a steam generator tube rupture scenario in NPP (nuclear power plant).

SPAR-H (Standardized Plant Analysis Risk-Human reliability) technique was introduced by US Nuclear Regulatory Commission (NRC) in 1994. The purpose of this method is to define HEP values based on human performance influences. Thereafter, Bayesian network (Almond, 1992) method has been introduced as a new perspective (Jensen and Nielsen, 2007). Unlike traditional HRA approach, this approach contains the dependency between the different PSF and related actions in a direct way.

The HEART approach has numerous succeeded methodological extensions in the literature such as NARA (Nuclear Action Reliability Assessment), CARA (Controller Action Reliability Assessment) and RARA (Railway Action Reliability Assessment). These have recently been introduced as specific HRA methods. The NARA was introduced by Kirwan et al. (2004) as powerful tool to monitor human reliability performance in NPP. Likewise, the CARA was proposed by Kirwan and Gibson (2008) to assess HEP in aviation industry. A similar method RARA was developed by Gibson et al. (2012) for a specific approach to human error quantification in railway industry. Since those methods were derived from HEART, their unique parameters such as generic task type and error-producing conditions were re-defined in accordance with nuclear, aviation and railway industry respectively. Therefore, NARA, CARA and RARA methodologies have their own specific parameters.

Since HEART approach has successfully tailored in various disciplines, applications upon marine industry are scarce. For instance, Deacon et al. (2013) was introduced human error analysis to enhance offshore evacuation procedures. In the paper, authors utilize HEART methodology in order to determine HEP values for critical steps in the escape, evacuation and rescue process in offshore units. A similar methodological approach has been presented in recent days (Noroozi et al., 2014). In this paper, a condenser pump installed in single buoy moorings (SBM) in offshore platform has been analysed and HEP values have been evaluated during maintenance process. Furthermore, Montewka et al. (2010) introduced a new approach for collision probability modelling. The authors integrate Monte Carlo and generic models in order to conduct risk assessment for the case of collision at sea. Another HRA application on marine industry was a hybrid method combining APJE and SLIM (Xi and Guo, 2011). The aim of the paper is to predict marine HEP during ship to ship collision. Moreover, an illustrative example analysing cargo oil pump shut down scenario in oil tanker was applied by Yang et al. (2013). The paper introduces a modified