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The use of a virtual environment in managing risks associated with human responses in emergency situations on offshore installations

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ABSTRACT

This paper presents the use of a virtual environment for investigating risks associated with human responses in emergency situations on offshore installations. The virtual environment and the risk management can be used to analyze risks associated with human responses by investigating the effectiveness of existing safety measures, identifying areas of improvement, and proposing new designs for safety measures.

Problems: Dealing with emergency scenarios on offshore installations is a tremendous undertaking. The interaction of personnel using the safety measures in emergency situations can be affected by hazards, environment conditions, malfunctioning equipment, and inadequate emergency preparedness. Such factors have the potential to prevent personnel from arriving at a safe area, increase the level of risks, and consequently, cause injuries or fatalities to personnel. Risks associated with human responses in emergency scenarios are often unforeseen due to difficulties with modeling realistic emergency scenarios.

Objective: The objective of the research is to study demonstrate the use of virtual environments for investigating and managing risks associated with human responses in emergencies.

Method: Risk management is employed to assess and manage risks associated with human responses in emergency scenarios. The risk management is tested using experimental data collected from past studies of human responses in virtual environments.

Results: Risks associated with human responses during emergency scenarios are determined by safety measures, the environment, and the egress route choices that have been taught. Participants' performance and interaction with improved safety measures are better than the performance of participants without safety measures.

Conclusion: This paper provides a demonstration of the utility of virtual environments to assess risks associated with human responses in emergency situations.

Application: The findings of this study may be useful for offshore energy operations.

1. Introduction

The organization or operator of offshore installations should prioritize the emergency response plan and safety barriers for escape in emergency situations. Safety measures for escape can include an alarm system, primary and alternative escape routes, muster stations, and personal protective equipment (e.g., Health and Safety Executive [HSE], 1997; Canadian Association of Petroleum Producers [CAPP], 2010). For offshore installations operating in harsh environmental conditions, both escape routes and muster stations can be heat traced and fully enclosed to protect individuals when performing escape activities in cold temperatures (Eikill et al., 2007).

The organization must ensure that personnel practice emergency drills to familiarize themselves with the equipment and procedures, and identify limitations, potential hazards, and risks in performing escape from hazardous areas. The challenges and risks of performing escape depend on an individual's skills and experience, teamwork, procedures, roles and responsibilities, communication, as well as the emergency response plan, environment conditions, and reliability of emergency equipment (HSE, 2007; CAPP, 2010a, 2010b). All of these factors influence the effectiveness of safety barriers, the success of escape operations, and the safety of individuals should an emergency occur.

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The potential of hazards cannot be eliminated totally. Emergency situations in the presence of hazards can worsen when personnel fail to interact with emergency equipment and follow procedures consistently. The effects of fires, explosions, and poor environmental conditions can cause failures of both personnel responses and the escape. The probability of failure will increase further when escape is performed in adverse weather conditions or harsh environments, such as in the presence of ice and snow, cold temperatures, darkness, or strong winds (Mould, 2001; Kjellén, 2007).

There are many studies that have introduced or proposed effective tools and techniques as safety measures in emergency situations on offshore installation. DiMattia et al. (2005) and Deacon et al. (2010) proposed prevention and mitigation barriers in risk management focusing on personnel performing escape, evacuation and rescue (EER) activities. Andersen and Mostue (2012) presented integrated operations (IO) on risk management approaches using real-time data, collaborative techniques, and multiple expertise in making better decisions and implementations for the Norwegian oil and gas industry.

Simulation-based studies have been used before to investigate human performance in emergency scenarios. Doheny and Fraser (1996) modelled an individual making decisions in an emergency scenario on offshore installations while considering the offshore facility relatively sparsely populated. In a study of individuals' behaviours conducted by Ha et al. (2014), walking direction was determined based on destination, obstacles, and visibility during emergency scenarios. Kim et al. (2004) integrated both individuals' behaviours and a dynamic model in the study of evacuation during marine accidents. Joo et al. (2013) investigated dynamic individual actions interacting with emergent hazards, such as fire, using an agent-based simulation. Duarte et al. (2014) used a virtual environment to investigate dynamic versus static signs on human behaviour during emergency evacuation. Augustijn-Beckers et al. (2010) studied pre-evacuation behaviour and exit choice during emergency scenarios involving a group of individuals. Using a virtual environment of an offshore installation, Bradbury-Squires (2013) assessed efficacy of active and hybrid learning modes on task performance during emergency training. Smith (2015) and Smith et al. (2015) studied the effectiveness of simulation training on individual's competency and learning during emergency situations. Colombo and Golzio (2016) introduced a simulation-based approach to training teams, including operators and managers, in making decisions and increasing their competencies as a team in critical situations.

Poor performance or lack of response in emergency situations can result in injuries and fatalities to personnel. There is a need to reduce and manage risks associated with personnel performance in emergency situations on offshore installations. The objective of the present work is to demonstrate the use of virtual environments for investigating and managing risks associated with human responses in emergencies. Engineered and procedural safety measures are studied and discussed in this paper (see Sections 3.1.2 and 3.2.2). The approach uses experimental data of human responses obtained from previous studies that used virtual environments (Duarte et al., 2014; Smith, 2015).

Section 2 describes the risk calculation and its formulation. Section 3 explains experimental studies of human responses using virtual environments. Sections 4 and 5 present and conclude the risk management study.

2. Calculation of risks

In this paper, risk is assessed with regard to the probability of failures only. In case studies used here, we treat consequences of failure as neutral (i.e. risk is proportional to probability only).

The probability of failures is calculated by considering the performance score in the emergency scenarios from two experimental studies, as further explained in Section 3. The performance score is analysed to determine the mean and standard deviation (Duarte et al., 2014; Smith, 2015). Information on mean and standard deviation is used to calculate a probability based on a normal distribution (Modarres, 2006). This paper assumes a normal distribution to simplify the calculations.

The probability is calculated considering a normal distribution function. A normal density function in Equation (1).

$$f(x;\ \mu,\ \sigma) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{ -\frac{(x-\mu)^2}{2\sigma^2} \right\} \tag{1}$$

where

x is the passing score;
μ is the average of overall scores;
σ is the standard deviation of scores;
σ^2 is the variance in the distribution.

The next step is to estimate the risks associated with the human responses by comparing two different failure probabilities; one is the emergency situation equipped with safety measures, and the other is the emergency situation without safety measures.The calculation of the change in risk is formulated as shown in Equation (2).

$$\Delta\text{RISK} = \textit{Pr}\text{obability without safety measures} - \text{Probability with safety measures} \tag{2}$$

Confidence intervals are employed to verify the calculation of probabilities and risks (Kumamoto and Henley, 1996). Equation (3) is a formula for determining confidence interval. The sample size, mean, and standard deviation are used to calculate the confidence interval of the mean. The calculation is based on a normal distribution and a 95 percent confidence interval. The results are presented in Section 4.4.

$$CI = \mu \pm \alpha \left(\sigma/\sqrt{n}\right) \tag{3}$$

where

α is the desired confidence level, and
n is the sample size.

3. Case studies of emergency scenarios in virtual environment

Data from two published experimental studies of different virtual environments have been selected to provide data for this risk management study. The first experimental study, entitled 'The effect of virtual environment training on participant competence and learning in offshore emergency egress scenarios', is the source of data on human responses in an emergency scenario on an offshore installation (Smith, 2015). The second experimental study, entitled 'Behavioural compliance for dynamic versus static signs in an immersive virtual environment', is the source of data on behavioural compliance with signage (Duarte et al., 2014).

Both experimental studies were conducted using virtual environments (VE) with the purpose to observe human responses and behaviours during emergency conditions (Duarte et al., 2014; Smith, 2015; Smith et al., 2015). Simulating emergency conditions in the VE can provide a safe medium for participants to acquire artificial experience, which is otherwise impractical and risky to obtain in a real situation. Details of emergency scenarios in the VE are explained in Sections 3.1 and 3.2.

3.1. Offshore emergency egress scenario on an offshore installation

Smith (2015) studied the effectiveness of simulation training on individual's competency and learning during emergency situations using the All-hands Virtual Emergency Response Trainer (AVERT) software. The layout in AVERT includes accommodations, and a muster station and lifeboat station, both located on the main deck. Three routes were provided as egress routes: the primary route characterized as an interior