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Dynamic risk assessment of escape and evacuation on offshore installations in a harsh environment

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ABSTRACT

The execution of escape and evacuation on offshore installations in harsh environmental conditions poses potential risks. A quantitative risk assessment focusing on escape and evacuation must be introduced to improve the safety of personnel performing these activities. This paper presents a risk assessment for escape and evacuation systems on offshore installations conducted in harsh environmental conditions. The research work uses Bayesian analysis and binomial distribution to demonstrate the impact of harsh environmental conditions to personnel performing escape and evacuation on offshore installations. The probability of success of personnel detecting alarms can be affected by environment conditions. Risk assessment considering environmental conditions illustrates the importance of defining the risk acceptance criteria to be used for safe escape and evacuation.

1. Risk assessment of escape and evacuation

Risks of escape and evacuation activities can be assessed either through qualitative or quantitative analysis. Guidelines for assessing the risks of escape and evacuation of offshore installations are provided by several organizations. The OGP [1] provided quantitative risk assessment data for escape and evacuation. The CAPP [2] presented a qualitative risk assessment by identifying credible hazards and predicting the consequences of hazards associated with escape and evacuation activities. The Norwegian Oil Industry Association (OLF) and the Federation of Norwegian Industries [3] integrated risk assessment and an emergency preparedness plan for planning and implementing activities associated with escape and evacuation and making decisions in the event of emergencies.

Methods of risk assessment of escape and evacuation on offshore installations have been studied by many researchers. Researchers have also studied human error to assess the risk it poses. DiMattia et al. [4] used the Success Likelihood Index Methodology (SLIM) to calculate human error probabilities associated with muster activities on offshore installations. Stress, task complexity, emergency training or drills, personnel's experience, initiating events leading to escape and evacuation, and atmospheric factors are calculated to determine risks that contribute to the failure of escape and evacuation activities.

Risk assessment considering human error probabilities has been incorporated in studies of personnel's response during escape and evacuation. Khan et al. [5] developed a tool called the Human Error Probability Index (HEPI) to assess risks of escape and evacuation. Risks are determined based on i) the probability of failure of personnel's response and ii) the consequences. Khan et al. [5] applied the HEPI to the Ocean Odyssey accident to assess risks associated with personnel's response during the escape and evacuation activities.

Risk assessment of escape and evacuation on offshore installations should evaluate the failures of personnel to respond effectively. Deacon et al. [6] compiled information on the consequences of failing to perform escape and evacuation activities. The information determined the severity of consequences involving personnel's responses. Based on the risk assessment, Deacon et al. [6] proposed safety barriers and risk reduction measures to minimize the severity level should personnel fail to respond during escape and evacuation.

Risk assessment consisting of the probability of occurrence and the consequences is considered a static basis for decision making [7]. A scenario such as an escape and evacuation requires a risk assessment that can be used for dynamic decision making. In an emergency situation, risks associated with personnel performing escape and

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evacuation can frequently change because of the dynamic interaction between personnel and environmental conditions. Adverse weather conditions could hinder the escape and evacuation and consequently increase the operation times [8–10]. Such a situation will make it challenging for personnel to perform the escape and evacuation safely and effectively [11].

This paper presents a risk assessment of human responses in the escape and evacuation of offshore installations considering environmental conditions. The objective of the research work is to use Bayesian analysis and binomial distribution for demonstrating the impact of harsh environmental conditions on personnel performing escape and evacuation on offshore installations.

Section 2 discusses the risk assessment, Bayesian analysis, and binomial distribution. Section 3 presents the use of binomial distribution in the event of an alarm sounding due to hydrocarbon release. Section 4 shows the risk assessment using Bayesian analysis and binomial distribution. Finally, Section 5 concludes the research work.

2. Risk assessment using Bayesian analysis and binomial distribution

Bayesian analysis has been used in many studies for assessing risks of dynamic situations as is briefly discussed in Section 2.1. Section 2.2 presents the potential use of binomial distribution in risk assessment.

2.1. Risk assessment using bayesian analysis

A Bayesian network can integrate a harsh environment with human responses. There are many studies that convert an event tree analysis to Bayesian analysis [12–14]. The Bayesian network is employed to study dependency or relationships among emergency equipment, evacuation procedures, and human responses [15,16]. Hugin software is used in the present research work as a tool for developing the Bayesian network [17].

The Bayesian network has three types of cause-effect relationships: serial, common cause, and common effect connections [18–20]. The cause-effect relationships should be developed based on qualitative information. The cause-effect relationships can be illustrated using a directed acyclic graph (DAG) that has parent, intermediate, and child nodes [7].

For translating the qualitative information to quantitative assessment, the cause-effect relationships should be converted into a conditional probability table. The conditional probability table requires probabilities of failure and success of the interaction between personnel, equipment, evacuation procedures, and environmental conditions. The quantitative assessment depends on the conditional probability table with probabilities of failure and success.

Bayesian analysis is a practical tool for dynamic risk assessment. Bayesian analysis can model the complexity of abnormal events to include incidents and near-misses for quantifying risks. Dynamic risk assessment can predict the probability of frequencies of abnormal events based on accident precursor data. Meel and Seider [12] developed a dynamic risk assessment to be applied in the chemical processing industry to estimate the probability of occurrence of accident precursors. Bayesian analysis can also be used to predict consequences in dynamic situations. Using Bayesian analysis, Khakzad et al. [21] investigated the probability of occurrence and the magnitude of consequences considering a dynamic consequence analysis for escalating fires. Bayesian analysis in dynamic risk assessment can investigate dependency or relationships among emergency equipment, evacuation procedures, and human responses.

2.2. Risk assessment using a binomial distribution

The effectiveness of emergency equipment, evacuation procedures, human response, and environmental conditions can have two possibilities: fail or succeed. The number of failures or successes is a discrete variable that can determine a probability of occurrence. The probability distribution for a discrete variable is called a discrete probability distribution.

The binomial distribution is one example of a discrete probability distribution. The probability of getting x successes in n trials is given by the probability mass function and is shown in Eq. (1). Eqs. (2)–(4) are the mean, variance, and standard deviation of the binomial distribution, respectively.

$$\Pr(x,\ n,\ p) = \binom{n}{x} p^{x}(1-p)^{n-x} = \frac{n!}{x!(n-x)!} p^{x}(1-p)^{n-x} \tag{1}$$

where,

$x = 0, 1, \ldots, n$
n = numbers of trials
p = probability of success
for $0 \le p \le 1$

The mean of the binomial distribution is

$$\mu = np \tag{2}$$

The variance of the binomial distribution is

$$\sigma^2 = np(1-p) \tag{3}$$

The standard deviation of the binomial distribution is

$$\sigma = \sqrt[2]{np\,(1-p)} \tag{4}$$

The probability of success or failure can be estimated using the binomial distribution in the Hugin software [17]. The binomial distribution and Bayesian analysis are demonstrated in a case study.

3. Case study: escape and evacuation in the harsh environment

The release of hydrocarbon fluid and gas could potentially result in fires and explosions. The release of hydrocarbon is an initiating event that triggers the evacuation process of personnel [22]. The activation of the emergency alarm is considered the first stage of escape and evacuation operations on offshore installations [1]. This paper focuses on personnel in a working area when the emergency alarm is triggered.

3.1. Emergency equipment as safety barriers

Gas, heat, and fire detectors are the primary physical barriers that can detect the hazards associated with hydrocarbon release during the emergency scenario. Audible and visual alarms are the second safety barriers, with the purpose of notifying personnel of the presence of hazards on the installation. Upon hearing or seeing the alarms, personnel have to secure the work area, stop work, and move to muster stations.

3.2. The presence of environmental conditions

Changing environmental condition are one of the challenges to operating offshore installations in remote areas and Arctic regions [11]. Performing escape and evacuation in the presence of severe weather, cold temperatures, poor visibility, and sea ice can reduce personnel's chances of survival [23]. Noroozi et al. [24] investigated the effects of cold temperatures on personnel working on offshore installations. Personnel's attention, memory, ability to analyze, and decision making can be affected by cold environments [24]. Yun and Marsden [9] studied environmental conditions in the Arctic region and estimated the probability of cold temperature, high winds, and low visibility for each month. This paper considers low visibility and strong winds that have potential to affect personnel performing escape and evacuation.