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Modeling and simulation of offshore personnel during emergency situations

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ABSTRACT

The offshore oil industry functions in a team work culture, in which operations depend not only on individuals' competency, but also on team skills. Team skills are even more necessary when it comes to handling emergency conditions as they challenge personnel on board with high risk, time pressure, and complexity. This raises the need for training that goes beyond conventional training programs and incorporates team skills exercises. The major difficulty to design such training is that it involves practicing emergency exercises with a potentially large number of participants. Such large-scale team exercises suffer from both organizational and educational drawbacks. One solution to this problem is to use artificial agents that can reproduce the behavior of the team members. This paper presents a behavior model that can simulate the response of general personnel during emergency situations. The variability in human behavior is modeled using different performance influencing factors (PIFs). Empirical evidence is used to identify the sources of variability that are encoded in the agents to allow a realistic range of human behaviors. Though variability can come from both physical and mental differences, the focus of this paper is on the later. Focus is given to across-subject variability rather than within-subject variability.

1. Introduction

The offshore oil industry functions in a team work culture and operations usually involve a group of people working together. This makes teamwork an essential component of effective emergency responses. Members of a team not only need to understand their own roles and responsibilities, but also need to have clear understanding of the roles and responsibilities of the other team members. Such understanding is critical for emergency situations as most of the members will have different roles and responsibilities than their everyday duties (Flin, 1997). However, traditional training programs are often generic and are not designed to provide trainees with the understanding of social and cognitive aspects of effective team work.

O'Connor and Flin (2003) discuss the possibility of adopting the crew resource management technique, pioneered in the aviation industry, in offshore oil industries to enhance team performance. Crew resource management (CRM) is defined as "using all the available resources – information, equipment, and people – to achieve safe and efficient flight operations" (Moffat and Crichton, 2015). A significant part of the CRM training requires the trainees to participate in team training exercises using simulator flights. Organizing such team exercises for offshore industries may suffer from both organizational and educational drawbacks (Van Diggelen et al., 2010). Gathering all the team members at the same time and at the same location itself is a challenge. Even when it is possible, the financial requirement is high. Also, the members often have different training needs based on their competency levels. One solution to this problem is to develop a team training platform in a simulator where the roles of some of members are played by humans, while the roles of others are played by artificial intelligent agents (Van Diggelen et al., 2010). Though extensive research has been done to create artificial intelligent agents in military (Jones et al., 1999; Sampson and Ripingill Jr, 2003; Wray and Laird, 2003), aviation (McNally, 2005; Sharma, 2009), and nuclear power plant (Cacciabue et al., 1992; Chang and Mosleh, 2007a; Dang, 1996) training simulators, no such model is available to date for offshore emergency training simulators.

This paper presents a computational human behavior simulation model (HBM), which is the first step to create such intelligent agents for an offshore emergency training simulator. Realism of agents largely depends on their underlying HBMs. HBMs are computational models that probabilistically simulate human behavior in different conditions. The purpose of the HBM presented in this paper is to reproduce the behavior of people working on offshore petroleum platforms, general personnel in particular, during emergency situations.

Unlike other human behavior models, the proposed model considers a larger fraction of the possible behavior space, which includes both correct and incorrect behaviors (Wray and Laird, 2003; McNally, 2005). Different performance influencing factors (PIFs) are used to model the variability across the behavior space. As use of subject matter experts' (SMEs') opinion often leads to a less reliable model (Chang and Mosleh, 2007c), empirical evidence is used in the development of the HBM. To this end, a two-level, three factor experiment was conducted to observe

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the influence of different PIFs on emergency response. Earlier works of the authors have discussed in detail the underlying mathematical models that capture the impact of external (Musharraf et al., in press) and internal PIFs (Musharraf et al., 2016) on human performance. Details of the learning and decision making process of individuals have been discussed in Musharraf et al. (2018). The goal of this paper is to present an HBM that integrates the different mathematical models and memory structure discussed in previous papers to produce automated probabilistic simulation of offshore workers' response under the pressure of an emergency. Prior to implementing the HBM in the actual simulator, it is modeled in the Integrated Performance Modeling Environment (IPME) simulation framework to define the implementation work scope and identify the technical challenges. Example results generated by the HBM during an IPME scenario simulation are discussed in this paper. Implementation of the HBM in the training simulator and validation of the HBM are discussed separately in Musharraf et al. (2017a).

2. Overview of the HBM

Modeling human behavior is a challenging area of research that needs considerations of both modeling and simulation, and behavioral and cognitive psychology (Goerger et al., 2005). There are qualitative models that focus mostly on the behavioral and cognitive psychology, and describe in detail the evolution of the human cognition process upon receiving an external stimulus from the environment (Trucco and Leva, 2007). Then, there are quantitative models that are based on the structure of the qualitative ones, but focus on the computational functionalities of modeling and simulation (Chang and Mosleh, 2007a). The HBM presented in this paper is a computational behavior simulation model that is a simplification of complex environmental settings and complex cognitive processes of human operators.

Section 2.1 introduces the different components of the HBM model. Section 2.2 describes how knowledge gained from training and experience is stored and retrieved during cognitive functions. The reasoning module is also discussed in this section.

2.1. Dynamic response model

The dynamic response model consists of four component models – an environment model, an operator model, a performance shaping model, and a task network model (after Chang and Mosleh, 2007a). The dynamic response model presented in this paper looks at individuals in isolation. Collaboration of team members and the concept of shared situation awareness is out of scope of this paper.

Environment model: The environment model includes external factors that define the circumstances or environment in which the individual is situated. This allows modeling human response under different environment conditions. External factors in the environment model include team-related factors (e.g. communication availability and quality, team composition), organization factors (e.g. safety and quality culture, procedure availability, adequacy, and quality), environment factors (e.g. temperatures, visibility), and conditioning events (e.g. latent failures) (Chang and Mosleh, 2007b).

Operator model: The operator model defines the characteristics of an operator in terms of internal factors. In the context of this paper, operator refers to general personnel working on offshore petroleum platforms. Though internal factors include both physical and non-physical attributes of the operator, this paper focuses on non-physical attributes only. The operator model allows modeling operators who may have different responses given the same environmental condition. Examples of internal factors used in the operator model include attention, bias, compliance, and efficacy of information use.

Task networking model: Task network modeling focuses on understanding the tasks that need to be simulated. The task network model graphically represents the sequence of tasks performed by an operator. Operators' behavior generally consists of different interrelated cognitive functions (Trucco and Leva, 2007). This paper considers four cognitive functions performed by the general personnel: perception, interpretation, decision making, and execution. Any function is decomposed into a series of sub functions, which in turn are decomposed into tasks for the development of the task network. Failure can happen at any stage of performing a task. Also, there can be more than one correct behavior or way to fail. The task network helps to identify possible deviations from the ideal behavior path(s) that may lead to error.

Performance shaping model: This model includes a set of performance shaping functions (PSFs). The PSFs generate the rules of behavior that govern the performance of general personnel while performing cognitive tasks. The response of general personnel depends on the state of the operator (e.g. stress, task related and non-task related load) and the current state of knowledge (e.g. scenario based knowledge from training and experience). The PSFs take the state of the operator and current state of knowledge into account and generate the associated operator response for a given set of PIFs. The PSFs used in the HBM development process are defined using a Bayesian Network (BN) approach. BNs have proven to be a powerful modeling tool due to their capability to (1) consider dependency among PIFs and associated actions, (2) quantify the impact of different PIFs on successful or erroneous behavior, and (3) update success or failure likelihood each time new evidence becomes available (Fenton and Neil, 2012; Podofillini and Dang, 2013; Sundaramurthi and Smidts, 2013). BNs have been widely used to model the impact of different PIFs on human performance or human error (Baraldi et al., 2009; Dang and Stempfel, 2012). Details of the PSF development is discussed in Section 3.

Fig. 1 shows the interaction between the external world and the component models. At any time 't' the state of PIFs in the environment model and operator model are defined based on the events happening in the external world. The state of the internal and external factors defines the operator's state of mind. The PIFs also influence how information is memorized from training and experience, and retrieved when necessary. The PSF model takes the operator's state of mind and current state of knowledge into account, and generates the behavior rules that govern the operator's response during cognitive tasks.

2.2. Memory structure and cognitive functions

This section describes the memory structure and the cognitive functions as part of the HBM. The HBM used here simplifies the complex memory and cognitive processes of human operators.

The purpose of the HBM presented in this paper is to create intelligent agents for an offshore emergency training simulator. It is assumed that these agents' response to emergency situations depends in part on the knowledge they have stored in their memory. A database representative of human memory is created in the HBM. The two main components of the memory structure are knowledge base and working memory, which are modeled based on the idea of long-term and short-term memory in the information processing model of Atkinson and Shiffrin (1968). According to the information processing model, memory consists of several 'stores' with different storage capacity. In the proposed HBM, the working memory has a finite capacity and stores the information relevant to the current cognitive process. The knowledge base has a theoretically infinite capacity and stores all the knowledge gained through training and experience.

A reasoning module, or inference engine, is added in the HBM to model the agents' reasoning process (after Li, 2013). Among different reasoning approaches, inductive reasoning is used (Li and Mosleh, in press). In inductive reasoning, generalizations are created from observed phenomena or principles. Decision tree induction is used in the HBM development (Musharraf et al., 2018). Decision tree offers a visual representation of the reasoning process and has useful diagnostic capabilities. Compared to other methods, such as artificial neural networks,