Automation in Construction 89 (2018) 214–224

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Developing an evacuation evaluation model for offshore oil and gas platforms using BIM and agent-based model

Jack C.P. Cheng[a], Yi Tan[a,*], Yongze Song[b], Zhongya Mei[c], Vincent J.L. Gan[a], Xiangyu Wang[b]

[a] Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Hong Kong, China
[b] Australian Joint Research Centre for Building Information Modeling, School of Built Environment, Curtin University, Australia
[c] School of Economics and Management, Chongqing Jiaotong University, China

ARTICLE INFO

Keywords:
Agent-based model
BIM
Evacuation evaluation
Simulation
Offshore platforms

ABSTRACT

Accidents on offshore oil and gas platforms (OOGPs) usually cause serious fatalities and financial losses considering the demanding environment where such platforms are located and the complicated topsides structure that the platforms have. Conducting evacuation planning on OOGPs is challenging. Computational tools are considered as a good way to plan evacuation by emergency simulation. However, the complex structure of OOGPs and various evacuation behaviors can weaken the advantages of computational simulation. Therefore, this study develops a simulation model for OOGPs to evaluate different evacuation plans to improve evacuation performance by integrating building information modeling (BIM) technology and agent-based model (ABM). The developed model consists of four parts: evacuation model input, simulation environment modeling, agent definition, and simulation and comparison. Necessary platform information is extracted from BIM and then used to model the simulation environment by integrating matrix model and network model. In addition to essential attributes, environment sensing and dynamic escape path planning functions are developed and assigned to agents in order to improve simulation performance. Total evacuation time for all agents on an offshore platform is used to evaluate the evacuation performance of each simulation. An example OOGP BIM topsides with different emergency scenarios is used to illustrate the developed evacuation evaluation model. The results show that the developed model can accurately simulate evacuation and improve evacuation performance on OOGPs. The developed model is also applicable to other industries such as the architecture, engineering, and construction industry, where there is an increasing demand for evacuation planning and simulation.

1. Introduction

Accidents on offshore oil and gas platforms (OOGPs) usually cause acute fatalities [1] and financial losses as OOGPs have demanding environment and oil and gas production is a difficult and potentially dangerous operation. The demanding environment includes limited accessibility and danger of encountering hurricanes, massive waves, and storms. Drilling and processing oil and gas turn offshore platforms into a high-pressure, inflammable, and dangerous environment with frequent accidents, including a gas leak, fire, explosion, blow out, structural failure, and adverse weather condition [2,3]. According to the historical records, the deadliest offshore platform accident was the Piper Alpha disaster in the North Sea [4], in which 167 people died. In 1982, the accident on Ocean Ranger Oil Rig in North Atlantic Sea capsized and killed 84 people due to a powerful storm with 190 km/h winds and 20 m high waves [5]. Another example is one of the latest accidents happened in 2010 at Deepwater Horizon Oil Spill, which caused an explosion and severe oil leak and 11 people died in Gulf of Mexico [6]. Therefore, effective emergency response planning is important and necessary to improve safety management on offshore platforms.

Evacuation during these emergency circumstances is one of the most significant aspects to be considered when evaluating the safety management of OOGPs. Conducting evacuation planning is a challenging task as OOGPs are built on sea using complex structures and workers cannot simply escape from the OOGPs during an emergency [7]. Compared to buildings, evacuation on offshore platforms faces more limiting conditions as platforms locate on the sea and contain congested working space. In addition, the facilities (functional modules) on offshore platform have higher possibility of catching fire, which makes evacuation on offshore platforms more challenging. Therefore, in order to well simulate such dynamic environment changes, the possibility of catching fire (risk level) of each module is also required. These risk levels for functional modules can be obtained

* Corresponding author.
E-mail address: ytanai@connect.ust.hk (Y. Tan).

https://doi.org/10.1016/j.autcon.2018.02.011
Received 2 October 2017; Received in revised form 28 December 2017; Accepted 2 February 2018

by analyzing historical accident database of similar modules from other offshore platforms. Offshore oil and gas platforms usually have Escape, Evacuation, and Rescue (EER) plans and resources to protect personnel in the event of a major accident [8–10]. EER addresses the entire process based on which personnel is removed from a major accident event to an ultimate place of safety. Escape means people move away from a dangerous situation to a safe place; evacuation means people are leaving hazard zones following the planned method; and rescue is the process that people move from a temporary safe place to a place of safety where medical assistance is available [11,12]. 2D escape routes planning and escape drill exercises [10] are important parts of EER programs. However, evacuation plans based on 2D escape routes only provide simple accessible paths without considering potential changes of evacuation environment. In addition, 2D evacuation plan may also cause different understanding of the emergency response. Although the escape drill exercise is a useful approach to evaluate the efficiency of the escape paths and to provide workers with a detailed understanding of emergency response on OOGPs, escape drill usually costs extra time and workforce, and can cause safety issues as OOGPs have limited working space and extreme environment around them.

Computational tools for emergency evacuation simulation and design have advantages over the traditional practices of 2D escape routes and evacuation drill exercises. Unlimited emergency scenarios, evacuation plans, and escape drills can be simulated and evaluated with the help of computational simulation models. Agent-based model (ABM) is one of the common computational models used to simulate the actions and interactions of people under emergency in the simulation. To generate the simulation environment efficiently, building information modeling (BIM), considering the rich geometric and semantic information it provides, has been increasingly popular in the modeling of simulation environment. Therefore, this study develops a model based on BIM and ABM to conduct evacuation simulations in a 3D virtual environment and to evaluate and improve safety management on OOGPs. BIM is used to set up the 3D virtual environment as it contains geometric and semantic information of OOGPs. ABM is used to simulate evacuation behaviors including basic attributes and social behaviors of all agents. The evacuation performance of each new scenario is evaluated by the total escape time.

The rest of this paper is organized as follows. Related works are reviewed in Section 2. Section 3 introduces the developed model. Detailed development of the proposed model is also included in this section. An example with evacuation simulation results is used to illustrate and evaluate the proposed framework in Section 4. Section 5 concludes the paper.

2. Literature review

2.1. Offshore emergency response

Well planned offshore emergency response is critical to OOGPs, and much research effort has been made to achieve a satisfactory emergency response. For example, Musharraf et al. [13] used a virtual environment to assess offshore emergency evacuation behaviors by using Bayesian Network approach. In this study, behavior indicators were measured to evaluate unobservable performance influencing factors like moral, motivation, and attitude which play a major role in shaping the evacuation performance. In addition, human error for critical steps in the escape, evacuation, and rescue (EER) process on offshore installations has been identified and evaluated using the framework proposed by Deacon et al. [14]. Norazahar et al. [15] also proposed a framework to address and discuss the contribution of human and organization aspects to the evacuation operations of the Deepwater Horizon Oil Spill [6], which is the latest offshore accident that has also been studied by Skogdalen et al. [9]. Escape and evacuation sequence from this accident was reviewed based on the testimonies from the survivors. Skogdalen et al. concluded that emergency drill exercises, including the worst-case scenarios to prepare for EER operations during offshore accidents, are important. Current studies pay more attention to learning lessons from offshore accidents and are suggested to improve the EER system such as conducting evacuation drills considering the worst scenarios. However, how to improve offshore evacuation performance in a more preventive and predictive manner, for instance, evacuation simulation using computational tools, is still lacking.

2.2. Evacuation simulation using agent-based model

Agent-based modeling (ABM) is a relatively new modeling paradigm for simulation of real-world systems. In ABM, every individual agent has certain attributes and behaviors controlled by decision rules and is persistently interacting with other agents in an environment to pursue specific goals [16–18]. Considering the advantages of low cost and risk to simulate various emergency scenarios for unlimited times, ABM is commonly used to simulate and evaluate evacuation plans. Previous studies [19–23] have used ABM or integrated ABM with Fire Dynamics Simulator (FDS) to study the human evacuation behaviors under fire emergencies. In addition, to improve the simulation performance, social behaviors in emergencies were investigated in [24–27]. Simulation environment modeling is an important part of ABM-based evacuation model development. Matrix-based model (also referred to as cell decomposition model) and network model (also called roadmap model) are commonly used in the reviewed ABM-based evacuation studies. In a matrix-based model, the simulation environment is divided into grids or nodes with defined attributes, which can easily store and collect environment information during simulation. However, the accuracy of escape path generated using search algorithm such as A* is heavily dependent on grid size, which has a direct impact on the computing time. In the network model, the optimized evacuation path can reflect real escape path better, but the environmental information is challenging to be represented. The two models are demonstrated in Fig. 1.

2.3. Path planning using visibility graph

Visibility graph (VG) is a graph of intervisible vertices among multiple polygons in the Euclidean plane, which is commonly discussed in computational geometry [28] and used for robot motion planning. As mentioned in Section 2.2, network models take advantages over the matrix models when planning the escape path. Therefore, visibility graph is applied in the development of the evacuation model in this paper. Traditional global path planning algorithms using visibility graph usually search for a path after a complete visibility graph is constructed [29–33]. However, it is very time consuming to construct a complete visibility graph, and path optimization efficiency is drastically decreased when edge number of the obstacles increases [34]. Algorithms have been proposed by previous studies to reduce the computational time. For example, Huang and Chung [35] and Zhang et al. [36] improved the efficiency of path planning by ignoring redundant obstacles that have no impact on the optimal path. Nguyet et al. [37] and Ping et al. [38] reduced the number of the visibility edges by simplifying obstacles to a rectangle or combining tiny obstacles. Other studies such as Lv et al. [34] tried to construct visibility graph and search the path simultaneously. All reviewed VG-based path optimization methodologies only considered static path planning. The Euclidean plane, including the obstacles and start position, is assumed to be unchanged during path planning. However, the constructed visibility graph is likely to change during emergencies such as fire accidents and structural failures. The changes can be caused by fire, collapsed facilities blocked, and herding behavior at a certain exit.

2.4. BIM application on emergency response

In the architecture, engineering, and construction (AEC) industry, building information modeling (BIM) has been increasingly used for the