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# Developing an Evacuation Evaluation Model for Offshore Oil and Gas Platforms Using BIM and Agent-based Model

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**Abstract:** Accidents on offshore oil and gas platforms (OOGPs) usually cause serious fatalities and financial losses considering demanding environment platforms locate and complex topsides structure platforms own. Evacuation planning on platforms is usually challenging. The computational tool is a good choice to plan evacuation by emergency simulation. However, the complex structure of platforms and varied evacuation behaviors usually weaken the advantages of computational simulation. Therefore, this study developed a simulation model for OOGPs to evaluate different evacuation plans to improve evacuation performance by integrating building information modeling (BIM) 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 simulation environment by integrating matrix model and network model. During agent definition, in addition to basic characteristics, environment sensing and dynamic escape path planning functions are also developed to improve simulation performance. An example OOGP BIM topsides with different emergent scenarios is used to illustrate the developed model. The results showed that the developed model can well simulate evacuation on OOGPs and improve evacuation performance. The developed model was also suggested to be applied to other industries such as the architecture, engineering, and construction industry.

**Keywords:** agent-based model, BIM, evacuation evaluation, simulation, offshore platforms

## 1. INTRODUCTION

Accidents on offshore oil and gas platforms (OOGPs) usually cause serious fatalities [1] and financial losses as OOGPs have demanding environment and oil production is a difficult and potentially dangerous operation. There are many offshore platform accidents such as gas leak, fire and explosion, below out, structural failure, and adverse weather condition [2, 3]. Evacuation during these emergency circumstances is one of the most significant aspects to be considered when evaluating the safety performance of OOGPs. It is challenging to conduct evacuation planning since OOGPs are built on sea using complex structures and workers cannot simply leave from the OOGPs during an emergency [4].

According to the historical offshore platform disaster records, OOGP accidents have not stopped around the world since the 1960s. Even in the twenty-first century, accidents sometimes happened. For example, one of the worst offshore platform disasters is the Piper Alpha disaster in the North Sea [5], in which 167 people were killed in July 1988. In 1982, the accident on Ocean Ranger Oil Rig in North Atlantic Sea capsized and killed 84 people due to a very strong storm with 190 km/h winds and 20 m high waves [6].

Another example is one of the latest accidents happened in 2010 at Deepwater Horizon Oil Spill, which caused an explosion and serious oil leak and killed 11 people in the Gulf of Mexico [7]. Therefore, effective emergency response planning on an offshore platform is important and necessary.

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]. EER addresses the entire process by which personnel is removed from a major accident event to an ultimate place of safety. 2D escape routes planning and escape drills exercise [9] are important parts in the EER plans. However, 2D evacuation plan may cause different understanding on the emergency response. Although 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 manpower, even causing safety issues as OOGPs have limited working space and the extreme environment around them.

Computational tools for emergency evacuation simulation take 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 platforms. Agent-based model (ABM) is a common computational model 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 simulation environment modeling. Therefore, this study proposes a model based on BIM and ABM to evaluate and improve the performance of different evacuation plans on OOGPs.

The rest of this paper is organized as follows. Related works were reviewed in Section 2. Section 3 introduced the developed model. An example is used to illustrate 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 a few research efforts have been made to it. For example, Musharraf and Smith [10] used a virtual environment to assess offshore emergency evacuation behavior by using Bayesian Network approach. In this study, behavior indicators were measured to assess unobservable performance influencing factors like moral, motivation, and attitude which play an important role in shaping the evacuation performance. In addition, human error for critical steps in the escape, evacuation, and rescue (EER) process on offshore installation has been identified and evaluated using the framework proposed by Deacon and Amyotte [11]. Norazahar and Khan [12] 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 [7], which is one latest offshore accident that has also been studied in [13]. It concludes that emergency drill exercises include 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 suggested to improve the EER system such as conducting evacuation drills considering the worst scenario. 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 model (ABM) simulation is a modeling method that simulates the behaviors and interactions between agents in a computer model and assesses their overall effects on the modeling system [14]. 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. For example, studies such as [15] used ABM or integrate ABM with Fire Dynamics Simulator (FDS) to simulate and evaluate evacuation behaviors and performance under emergencies such as fire disaster. In addition, to improve the simulation performance, social behaviors under emergent situations were considered in [16, 17]. Simulation environment modeling is an important part of ABM-based evacuation model development. Matrix (Cell decomposition) model and Network (or Roadmap) model are two widely used models in previous studies. In matrix-based models, the potential environment divided into grids or nodes with defined attributes, which can easily store and collect different environment information during simulation. However, the accuracy of evacuation path generated using search algorithm such as A* is heavily dependent on grid size, while the grid size has an impact on the computing time. In the network, the optimized evacuation path can reflect real escape route better, but the environmental information is hard to represent.

### 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 [18] and used for robot motion planning. As mentioned in Section 2.2, network or roadmap models take advantages over the matrix models in escape route planning. Therefore, visibility graph is applied in this paper to plan escape paths. Traditional global path planning algorithms using visibility graph usually search for a path after a complete visibility graph is constructed [19, 20]. However, it is very time consuming to construct a complete visibility graph and the route path optimization efficiency is drastically decreased when edge number of the obstacles increases [21]. In order to reduce the computational time, some algorithms have been proposed by previous studies. For example, some improved the efficiency of path planning by ignoring redundant obstacles that have no impact on optimal path [22], some reduced the number of the visibility edges by simplifying obstacles to rectangle or combining tiny obstacles [23], and others tried to construct visibility graph and search the path simultaneously, for instance, the proposed bi-directional SVGA (simultaneous visibility graph construction and path optimization by A*) algorithm [21]. All reviewed VG-based path optimization methodologies seam only considering static path planning, the Euclidean plane including the obstacles and start position is assumed not to be changed during path planning. However, the constructed visibility graph is likely to change during emergencies such as 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 past decades. The rich geometric and semantic information contained by BIM can be utilized to create emergency simulation environment efficiently and accurately, a few studies have applied BIM to emergency response in the AEC industry. For example, a BIM-based model is designed to support fire safety management, including evacuation assessment, escape route planning, safety education, and equipment maintenance [24]. Since BIM can provide rich information on building, integrating BIM and fire dynamic simulation (FDS) software has also been studied. Wang et al. integrated BIM and FDS software by using the .dwg file, exporting from Revit, as the input file for FDS software [25]. Shi and Liu presented a powerful platform, which integrated BIM, 3D GIS, and FDS software, to simulate occupant evacuation in fire environment [26]. Locating trapped occupants during fire emergency is meaningful, therefore Li et al. [27] designed an environment beacon deployment algorithm to support a sequence based localization schema. BIM has also been applied to the oil and gas industry, for instance, 4D BIM in supporting LNG construction projects [28] and BIM applications in OOGP decommissioning [29-32]. However, BIM-based emergency responses studies on OOGPs are still lacking. More efforts should be made to take the advantage of BIM to facilitate emergency response study on OOGPs.

## 3. MODEL DEVELOPMENT

As shown in Fig. 1, the developed BIM-based evacuation model for OOGPs consists of four main parts: (1) evacuation model input, (2) simulation environment modeling, (3) agent definition, and (4) simulation and comparison. The evacuation model input part (Part 1) is based on BIM models of OOGP topsides, which contains dimensions, locations, and semantic information of all functional modules on topsides, required information is extracted and simplified. In simulation environment modeling (Part 2), based on the information obtained from Part 1, simulation environment is modeled by integrating matrix and network models. The agent definition part (Part 3) is based on the modeled simulation environment, basic characteristics, environment sensing function, and dynamic escape path planning are involved in this part. Based on Part 3, multiple agents with the defined attributes can be generated, integrating with the modeled simulation environment, evacuation plans can be simulated and evaluated. Escape path and behavior with the optimum evacuation performance are proposed after comparison in the end. More development details of these four main parts are introduced and discussed in the following sections.

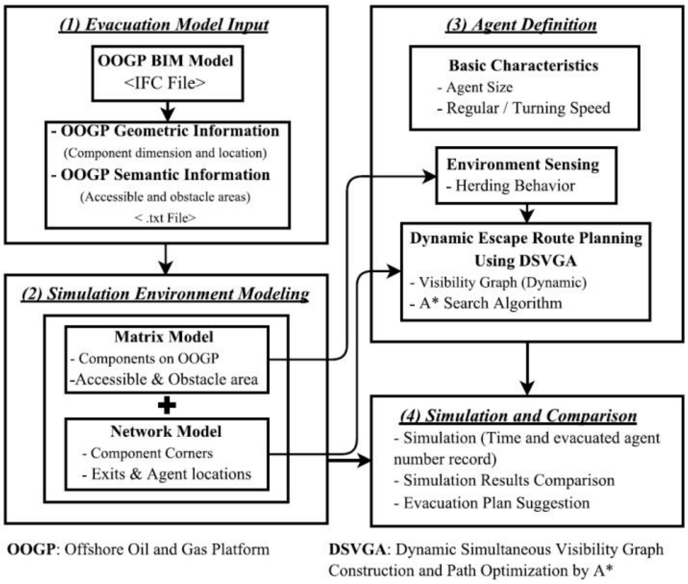


Fig. 1. The developed BIM-based evacuation model for OOGPs

### 3.1. Evacuation model input

For the past decade, BIM plays an increasingly important role in the architecture, engineering, and construction (AEC) industry considering the rich geometric and semantic information it contains. The digital representations applied through the lifecycle of building projects makes the AEC industry be involved in the information age. Even though BIM has been well applied to support the design, construction, operation, and demolition of building, BIM applications to the oil and gas industry, especially for offshore platforms, is still limited. Industry Foundation Classes (IFC) is currently the main neutral file format for data exchange among AEC/FM software [33]. IFC is designed to represent as much building information as possible, facilitating the data exchange among different BIM-supported software. However, IFC has not been extended to the oil and gas industry completely. *IfcBuildingElementProxy* [34] is usually used to represent elements that have not be defined in IFC entities. The utilization of *IfcBuildingElementProxy* can refer to our previous study [32].

The OOGP BIM model used in this paper has a high level of detail and the functional modules on topsides can be visualized with detailed features. When conducting evacuation simulation, these functional modules are usually considered as obstacles in the simulation environment. To represent obstacles in a simulation environment, bounding box approach is commonly used. The smallest box that covers all components in a module is obtained by using the extraction and simplification methodology developed in [32]. The purpose of obstacle simplification is to facilitate information input for the evacuation model setup. The extracted and simplified results include the length, width, height, and location coordinates of all modules on the topsides. In addition to the geometric information, semantic information is also extracted. In this study, the considered semantic information is risk level for each module depending on its function. Since escape path will pass by different modules, the risk of exposure to modules will impact the evacuation performance. The output of information extraction and simplification is a text file that contains eight attributes *(id, x, y, z, l, w, h, r)* for each module and the file is used as the input for evacuation simulation environment modeling. Here, *id* is to identify each module, *l* is the length, *w* is the width, *h* is height, *x, y, and z* are the location coordinates and *r* is the risk level for each module.

### 3.2. Simulation environment modeling

The simulation environment is the basis to conduct and evaluate different evacuation scenarios. The target of environment modeling is to transfer real environment into readable virtual representation formats that can be read and operated by computer programs. Virtual representation formats can be both two dimensions and three dimensions. According to the reviewed evacuation simulation studies, multiple models or representation formats can be used to model simulation environments. Matrix models and network models are two commonly used models. As pointed out in Section 2.2, matrix model has the advantages of implementation and collecting environment information as each cell or grid can store predefined attributes to represent dynamic surrounding changes. However, the cell or grid size has an impact on escape path accuracy and computational time, and it is a challenge to determine the size. A network model can generate a path that is closer to reality, but collecting dynamic environment changes is challenging. Therefore, integrating the advantages of both models can model the simulation environment better. In the next sections, details of each model development and their integration will be presented.

#### 3.2.1. Matrix model generation

The main task of using matrix model is to divide the simulation environment into cells (or grids, nodes) with the proper size. Previous research [35] have studied grid size determination, a 0.4 m × 0.4 m space, which is the average space size of a person occupied, was used. The reason to consider person's size on the divided cells is to locate person and search escape path during evacuation simulation. In this paper, when determining cell size, it is only considered from the perspective of environment dynamic changes recording. More details of person (or agent) definition are introduced in Part 3. Since dimensions and relative locations of real topsides environment including functional modules, which are treated as obstacles, have already be extracted, simplified, and written into a text file from Part 1, it is easy to model simulation environment as a matrix format. An example matrix model is presented in Fig. 2.

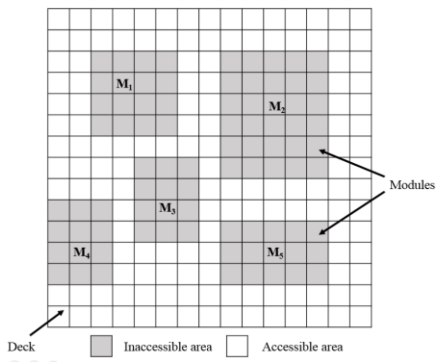


Fig. 2. Generated matrix model illustration

In order to use the generated matrix model to collect dynamic environment changes during evacuation simulation, each grid will be assigned with necessary attributes that can be updated over time. The attribute defined in this paper is accessible. The accessible attribute is used to determine whether the cell is accessible or not. Accessible cells allow persons to pass through, while inaccessible cells do not. Cells occupied by functional modules (obstacles) and crowded people (herding behavior) are usually inaccessible.

#### 3.2.2. Network model generation

In building indoor evacuation planning, a network of potential escape paths is usually generated based on building floor plans. Those potential paths will be optimized according to some constraints and an optimum escape path will be selected [36]. Different methodologies can be used to generate a path network and four most commonly used ones including door to door, room to door to room, straight skeleton, and corner graph were summarized by Rüppel and Abolghasemzadeh [37]. As this study aims at improving evacuation performance on topsides of OOGPs, where different functional modules locate without doors or rooms, the corners of modules (obstacles) were used to generate a path network (see Fig. 3.). Based on the generated path network, the escape path was optimized by the developed path planning methodology, which will be introduced in Section 3.3.3.

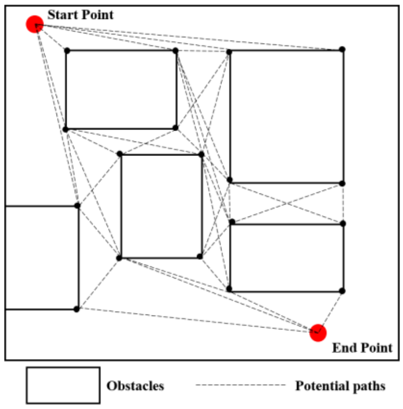


Fig. 3. Illustration of potential path network generation based on corners

Since the matrix model used to store and collect dynamic environment changes over time and network model used to conduct escape path planning are created respectively, then the two created models are integrated together to model the OOGP topsides environment for evacuation simulation. With such model integration, the simulation environment modeling of topsides evacuation is almost finished. Agents that are required to be defined to interact with the modeled simulation environment are introduced in the next section.

### 3.3. Agent definition

Another important component for evacuation simulation using ABM is to define agents in the virtual simulation environment. The target of evacuation simulation is to study how persons behave and interact with surrounding environments during the emergency and then improve the whole evacuation performance by shortening escape time and selecting safer escape path. In order to make agents behave similarly to actual situations in an emergency, important and necessary characteristics and behaviors require being well considered when defining agents. In this study, basic characteristics such as agent size and speed, environment sensing ability to collect dynamic environment change information, and the ability of escape path planning over time are considered during agent definition.

#### 3.3.1. Basic characteristics

Agent size is based on the average space size of a person occupied mentioned in Section 3.2.1. A radius of 0.2 meters was used in this study. The escape speed usually varies during an emergency when different actions performed by agents. For example, the running speed reaches the maximum when escaping in a straight direction and reaches zero when an agent requires escaping to reverse direction. Running speed ranges from zero to maximum at the corners with different angles or in crow with different densities. Since this study focuses OOGP evacuation simulations, the target persons are usually males who have already gone through systematically safety training, five meters per second is applied as many objects located on the narrow space of topsides. As for corner speed or speed in a crowd, a predefined rate of regular speed will be used. The rate is based on the angles of corners and densities of crowed situations.

#### 3.3.2. Environment sensing

Timely understanding environment around is important for each person in emergent situations. Accurate surrounding information collection is the prerequisite to understand dynamic changes of the environment. Therefore, a function named *environment sensing* is developed for all agents in this study. People all tend to choose the shortest path that they are familiar with, and then crowd situations such as herding behavior happen at a certain exit. Such crowd situations may not only increase evacuation time but also cause injury accidents among people. It is better for people to make full use of potential exits rather than being trapped in the crowd. Therefore, sensing crowd people can help improve evacuation performance. The previous study used similar concept [38], a sensor that has a visual angle of 170 degrees was assigned to each agent. However, when a person escapes under emergency, they usually will look around in 360 degrees to get as much information as possible to make a better escape choice. Therefore, in this study, all visible nodes for each agent are checked to collect complete dynamic environment changes.

### 3.3.3. Dynamic escape path planning

As mentioned in Section 2.3, classic path search on constructed VG is time-consuming and even though studies have conducted to reduce VG construction time, the VG-based path search is usually conducted in a static manner, supposing that evacuation environment will not change, which does not reflect real emergent situations. Therefore, a methodology named dynamic simultaneous visibility graph construction and path optimization by A* (DSVGA) is developed by modifying SVGA proposed in [21]. The path search process of DSVGA is illustrated in Fig. 5.

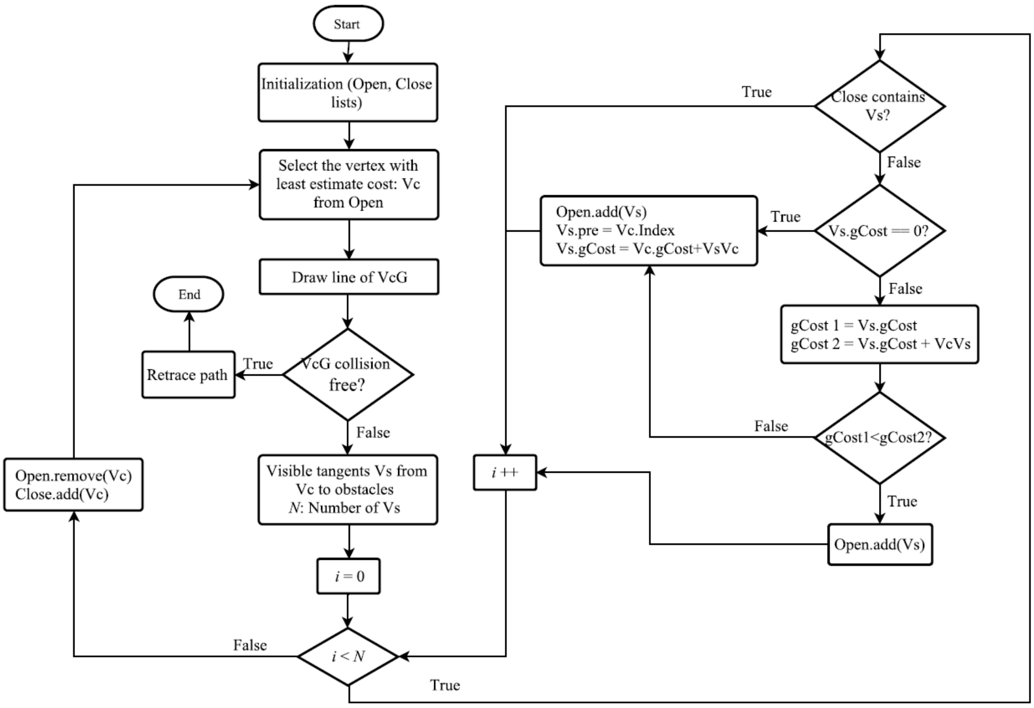


Fig. 4. Illustration of DSVGA process

In DSVGA process as shown in the above flowchart, *Open* and *Close* are two lists to store potential vertices (nodes) to be evaluated and vertices have already been evaluated respectively. $V_c$ is current vertex under evaluation and $V_s$ is visible tangent vertex from $V_c$ to an obstacle crossed by the line of $V_cG$. Distance from current vertex to its previous vertex is represented as *gCost*. All vertices including start point *S*, target point *G*, and vertices of all obstacles are stored and each is assigned with a unique *index*. The estimated cost is *fCost* = *gCost* + *hCost*, where *hCost* is the heuristic cost (distance) from vertex to *G*.

### 3.4. Simulation and comparison

Based on the developed model, different evacuation plans can be simulated and compared. Evacuation time is used to evaluate the performance of evacuation plans. In addition, the number change of successfully escaped people is also plotted to show the evacuation performance over time. First, original evacuation plan (Scenario 1) usually presented in 2D format is simulated. The simulation result will be used as the baseline to evaluate other evacuation plans. Then, the developed DSVGA function is applied in Scenario 2 to automatically simulate evacuation and generate escape path for each agent. Finally, total evacuation time and successfully escaped people over a time of both scenarios are evaluated and compared with each other.

## 4. ILLUSTRATIVE EXAMPLE

An example is herein used to illustrate the developed evacuation model. In the example, the topsides of a fixed offshore platform has one deck containing six modules. The modules have different functions such as accommodation, processing oil and gas, and providing electricity. The original file format of topsides is in 3dMax, which can be transferred to DWF file and imported into Autodesk Revit. After grouping related components into individual modules, the topsides was exported to IFC file that was used as the input of the developed evacuation model. Required dimension and location information of modules were extracted and simplified (see Fig. 5.).

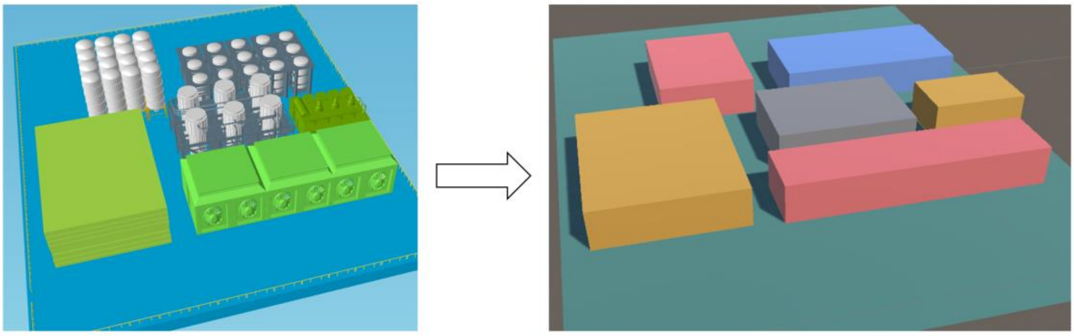


Fig. 5. Illustration of OOGP information extraction and simplification

The escape paths of both original plan and generated by the developed evacuation model are compared by simulation based on evacuation time and escaped people number over time (see Fig. 6 ). Compared to original escape path, the path planned with the developed model cost 22.9% less escape time and people seem to behave more reasonable, herding behavior is avoided, and people can take full advantage of potential exits on topsides of offshore platforms. Therefore, with the simulation of the developed evacuation model, the evacuation performance on OOGPs was improved.

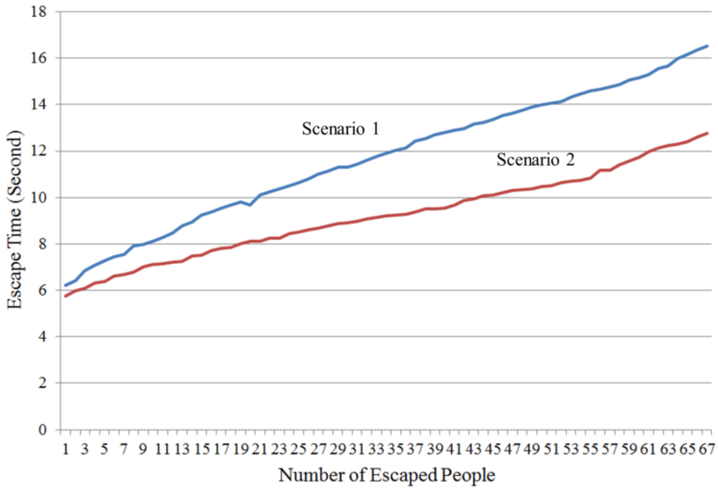


Fig. 6. Comparison of evacuation scenarios

## 5. CONCLUSIONS

This paper developed a simulation model to evaluate different evacuation plans and to improve evacuation performance on topsides of OOGPs. BIM and agent-based model were integrated into the evacuation evaluation model. Information of topsides was extracted from BIM and used to model simulation environment. Two commonly used simulation environment generation models, namely matrix model and network model, were firstly integrated to efficiently collect dynamic environment changes and accurately plan escape path simultaneously during evacuation simulation. Dynamic escape path planning is based on visibility graph and A* algorithm, which constructed visibility graph and search escape path simultaneously considering dynamic changes of the simulation environment. An example was used to illustrate the developed evacuation evaluation model. Compared to real escape drill exercises, the developed model can not only improve evacuation performance but also result in less cost and risk. In addition, the developed model can also be applied to emergency simulations in buildings, on construction sites, and other public places such as shopping malls and Metro stations.

However, some limitations still exist in the developed model. In agent definition, since many social behaviors exist, this study considered only spatial recognition, herding behavior, and communications, while other behaviors like queueing have not been studied limited to the defined scope of this study. One potential direction for the extension of this paper is to study related social behaviors in detail to make evacuation simulation more realistic and accurate.

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