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Passenger Ship Evacuation Simulation and Validation by Experimental Data Sets

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Abstract

Due to the rapid expansion of cruise travel market as well as in light of the great loss caused by several maritime disasters, passenger ship evacuation in case of emergency has received increasing attention recently. For safety reasons, IMO has introduced a series of guidelines for undertaking full-scale evacuation analysis and certification of large passenger ships in the design stage. In this paper, an agent-based microscopic evacuation model—CityFlow-M has been introduced by a passenger ship evacuation case, and then validated using data sets from a semi-unannounced assembly trail at sea, which consists of passenger response times, starting locations, ending areas as well as the arrival times in the assembling stations. The results predicted from CityFlow-M for this case were presented and compared with the experimental data, which shows CityFlow-M is eligible of simulating the assembling process in the passenger ship.

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Keywords: passenger ship, evacuation model, CityFlow-M, agent-based microscopic model

1. Introduction

In view of the great loss caused by major maritime disasters and the boost in the number of large capacity cruise ships, issues regarding to the evacuation of passengers and crew at sea have received increasing attention. The International Maritime Organization (IMO) have introduced a series of guidelines for undertaking full-scale evacuation analysis and certification of large passenger ships in the design stage [1, 2]. Full-scale evacuation exercise is regarded as the most reliable way to demonstrate the circumstance is comply with evacuation requirements, but it is usually expensive and difficult to organize. Modeling and simulation tools, on the other hand, provide an effective way to help improve ship design with respect to ease of evacuation at sea. Considerable interest has been paid on the development of simulation tools, and many computer simulation software packages have been developed so far [3]. However, Passenger ship evacuation is still a very young research topic and only limited publications can be found. It has been claimed that the evacuation process on a ship can be very different because of the special environmental factors, including the motion, listing, heeling and rolling of the ship as well as the complex geometry of the passenger ship *etc*. [4, 5].

Recently several simulation tools specialized for modeling passenger ship evacuation have been developed. A not necessary completely list of these software tools include *maritime*EXODUS [6], AENEAS [7, 8], EVI [9], IMEX [10], and VELOS [11]. AENEAS and *maritime*EXODUS are both grid-based models in which the floor plan of the ship is divided into uniformly distributed rectangular grids and people are only allowed to move from one grid to another step by step

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according to a set of local Cellular Automata modeling rules. Although this type of models show great advantages on computing efficiency, their abilities to represent the reality are limited because of the over discretization. IMEX is built by combining a force-based pedestrian dynamics model and an intelligent human behavior model. The force-based model used strict Newtonian equations to describe the physical and psychological factors of local human movement behaviors but suffers from known drawbacks [12]. And it is not clear that how the route choice behavior is handled and how the intelligent human behaviors mentioned would affect the movement of people in the simulation. EVI is a multi-agent mesoscopic model in which individual agents move towards the target in a topological graph representation of the ship map according to very simple local rules to avoid collisions. EVI's focus was to incorporate the fire dynamics simulation results into the evacuation modeling, but human behaviors were not sufficiently explored in the local movement model. VELOS is a more recent work specialized on agent-based modeling of ship evacuation. Advanced Virtual Reality technology has been used in this software to realize multiple users' immersion and active participation in the evacuation process by putting "avatars" into the simulation scenarios. The local movement of the agents was modeled by a "steering behavior" method which has prevailed in computer game industry. The model showed abundant capabilities to fulfill the passenger ship evacuation analysis tasks, but a systematic verification and validation is still essential by using the real data. However, as concluded in most of the existing publications, the limited available empirical data on ship evacuation and human behaviors have led to many difficulties to the validation of the current models.

For calibration and validation of ship-based evacuation models, the EU framework 7 projects SAFEGUARD has conducted a series of semi-unannounced full-scale assemblies on three different types of passenger vessel and provided two full-scale data sets (the validation data set can be found on the FSEG web site http://www.safeguardproject.info/) [13, 14]. In this paper, a passenger ship evacuation case was simulated using an agent-based microscopic model—CityFlow-M. The first Safeguard Validation Data Sets (SGVDS1) generated from assembly trials conducted on a large RO-PAX ferry were used [15]. The simulation results were then compared with the measured data.

2. The simulation model—CityFlow-M

The ship evacuation model CityFlow-M is developed based on a pedestrian traffic simulation model—CityFlow, which is produced by City University of Hong Kong. It has been described in detail in a recently published paper [16], and thus only a very brief introduction of the model will be presented in this paper. CityFlow is an agent-based microscopic pedestrian simulation model, and CityFlow-M is the maritime evacuation version.

The layout information in our simulation model is represented in a network approach by dividing the geometry into "zones" connected to one another by "connections". This network structure can be automatically generated from the pre-processed AutoCAD drawing in DXF format. Then the system demand can be set up through an Origin-Destination matrix that defines all the possible routes and their properties, including the flow rate at the source, the construction of every type of pedestrians, and probabilities of choosing every route.

The model is implemented in two levels: the strategic, tactical level behavior in macroscopic level and the operational behavior in microscopic level. The macroscopic level mainly deals with the long-term route choice and map navigation tasks to decide a route and obtain a regional perceptive target. The microscopic level decides the local movement of the agents at every time step, which comprises the following two modules. The route choice and map navigation module identifies the temporary desired regional target of movement, and the agent-based individual movement module uses the target to govern the actual movement, and then calculate the real movement direction and distance in the next time step based on detailed environment information and a set of rules. As some of the rules are stochastic in nature, the simulation results will be a slightly different even when the simulation repeats with the same input information. As a result, it is necessary to run the model a number of times for the certain case in this study.

3. Modeling of passenger ship case

3.1. The passenger ship layout information

The passenger ship is a three-deck structure containing different public spaces such as seating areas, retail and restaurant areas, bar areas, and general circulation spaces (Fig. 1). It has four assembly stations (AS), three of them located on Deck 1 (the AS A, B, and C), and the other one located on Deck 2 (the AS D). The AS A and D are located in the middle parts of the decks, whereas the AS B and C are outer. Different decks are linked by several staircases, as shown in Table 1.

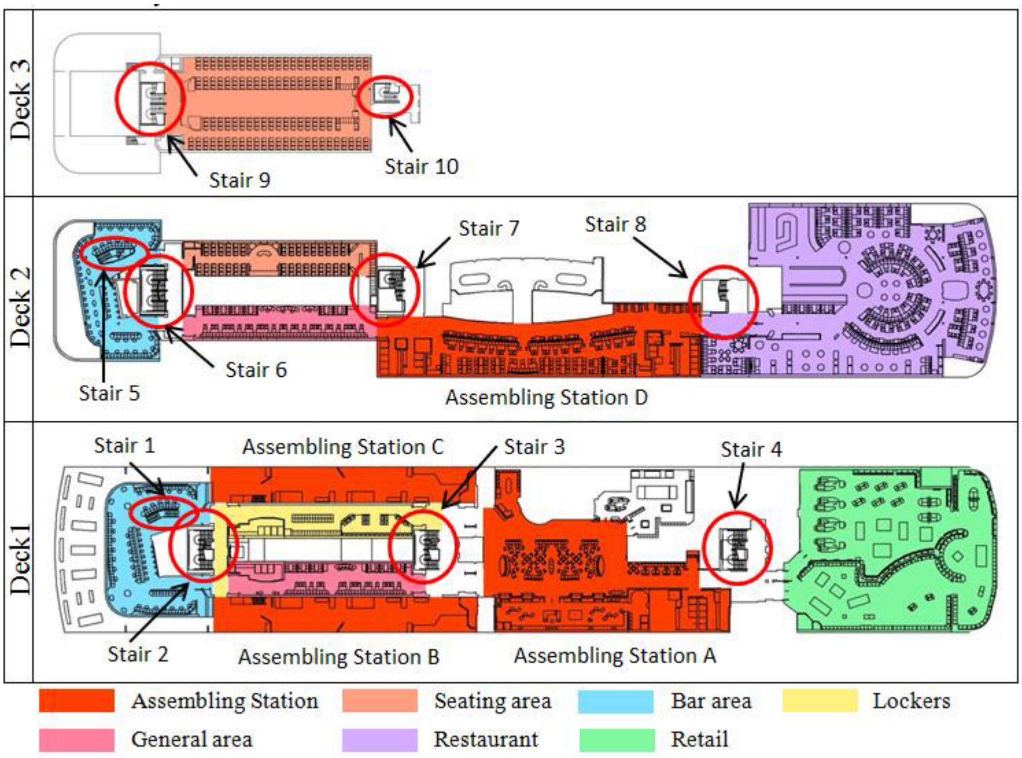


Fig. 1. The passenger ship Layout with highlighted starting locations and assembly stations

Table 1. Information about the staircases in the passenger ship

Staircase	Connecting Deck (Lower)	Connecting Deck (Higher)	location	width
Stair 1/5	Deck 1	Deck 2	Inside the bar area	1m
Stair 2/6	Deck 1	Deck 2	Outside the bar area	1.35m
Stair 6/9	Deck 2	Deck 3		
Stair 3/7	Deck 1	Deck 2	By the AS A and AS D areas	1.35m
Stair 7/10	Deck 2	Deck 3	By the AS D area	1.2m
Stair 4/8	Deck 1	Deck 2	By retail area	1.35m

3.2. The model input information

The parameters such as movement speed used in the simulation are uniform, indicating the region and demographic differences on passengers were not considered. And the response time distribution, the initial locations as well as the final destinations of the passengers are determined from the trial data. When approaching the final assembly stations from their initial locations, passengers theoretically can choose varied routes. As the detailed route information for each passenger is unknown in this case, the route with shortest distance is adopted in this study. Based on the DXF file of the passenger ship in case, Fig. 2 gives an example of network graph for representing part of the ship layout (suppose a passenger starts from Deck 3 Seating area and the graph shows all the possible routes to each Assembly Station), and thus the system would automatically define the route for each passenger in simulation. For example, 77 tagged passengers were initially in the bar area on Deck 3, 2 of them finally arrived in the AS A through Stair 7/10 and 3/7, 45 passengers chose the AS B as their ending area and can move either through Stair 6/9 and 2/6 or through Stair 7/10 and 3/7, and rest of the routes can be deduced like this.

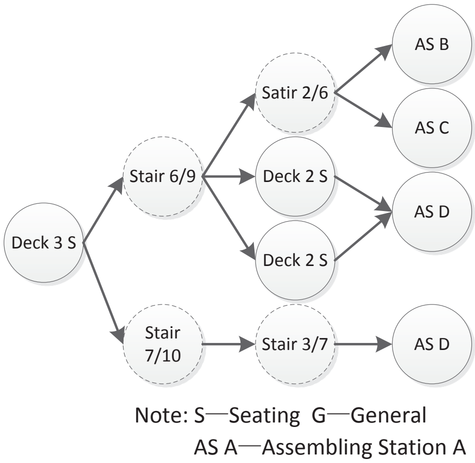


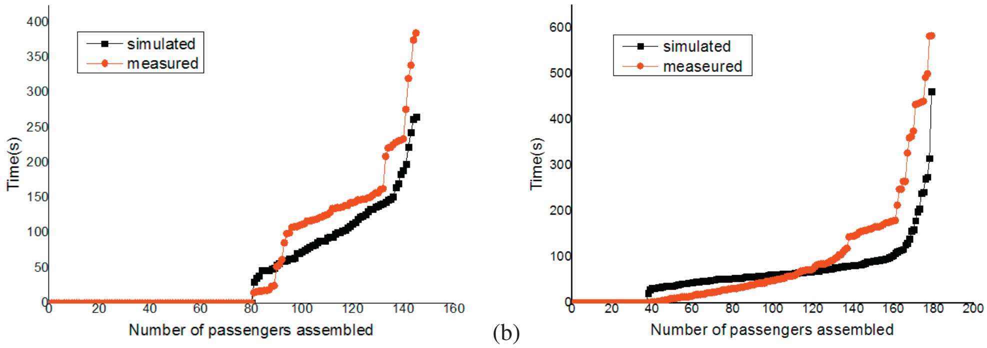
Fig. 2. Example of the ship geometry network representation

In the trail, though there were 1349 passengers on board, 780 wore tags and so were tracked during the evacuation process, but only 764 of them were included in the analysis. And there were already 145 tagged passengers in the AS D, 34 in the AS C, 42 in the AS B and 99 in the AS A at the sounding of the alarm, and most of them remained in the same area during the trail. It is therefore only those who moved to other assembly stations were simulated in our case.

There were also some untagged passengers took part in the assembly trail, but their response time and location information was unknown. In order to obtain a more precise result, we added 250 untagged agents in our simulation case but they would not be included in the analysis of the AS arrival curves and the overall assembly process. The response times, starting locations and ending points of these 250 agents were assigned according to the tagged population on ship.

4. The comparison of simulation results and experimental results

The simulation results in terms of the assembly times for passengers on ship are shown in Fig. 3 along with the experimental measured data. Presented are the simulated and measured arrival curves for each AS and the overall assembling of the passenger ship in case. As at the beginning of the trail, some passengers were already in the AS, the arrival curves do not start from origin of the horizontal axial. We can find the simulated curves shifted to the right of the measured arrival curves in Fig. 3(a) and 3(c) by varied degrees, illustrating the simulation model underestimates the evacuation time for the AS A and C. Some passengers in simulation arrived in the AS B, D earlier than experimental measured time, whereas others arrived late. And the greatest difference between the simulated and measured arrival curves occurs in the AS B.



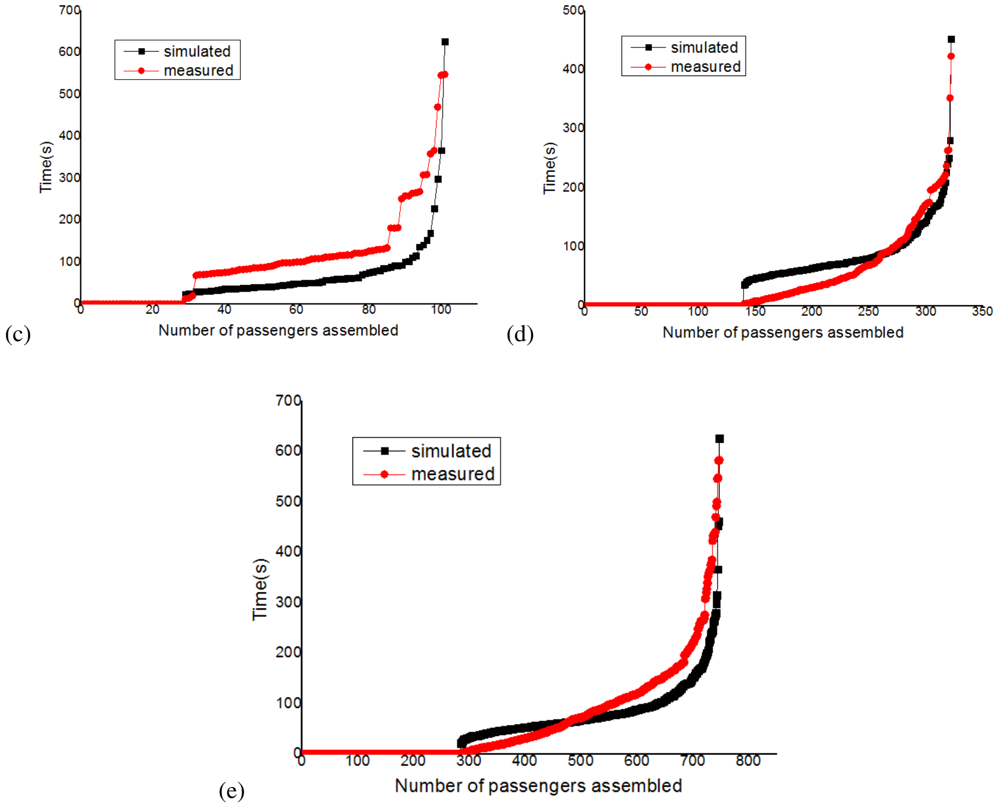


Fig. 3. Comparison of simulated and measured arrival curves for (a) Assembly Station A, (b) Assembly Station B, (c) Assembly Station C, (d) Assembly Station D and (e) Overall Assembling process

Theoretically, this trail data set is perfect for validation purposes as important simulation input information such as the response times of the passengers, starting locations as well as ending points are known. However, there are some uncertainties in the experimental data, which may contribute to the above variances in our simulation.

As described earlier, in this case we did not separate passengers' moving speed by different genders and age groups as well as varied regions on ship, which may result in certain deviations of simulation result.

Second, a significant number of untagged individuals in this trail eventually took part in the evacuation drill. The presence of them would influence the other tagged passengers during the whole evacuation process, especially in the highly congested areas like stairs and narrow corridors. However, the actual untagged passenger populations, their starting locations as well as their assembly times were not included in the overall assembly data.

Third, the exact starting locations and ending points of the tagged passengers were not known. As the starting and assembly regions on the passenger ship have certain dimensions with a length between 24 m and 48 m, it is possible to lead a deviation as high as 50 seconds for the assembly time of an individual. This factor may have significant influence on the evaluation of simulation results especially most tagged passengers arrived in assembly stations with 180 seconds after the sounding of the alarm (Fig. 3).

Furthermore, the response times given in the data sets are region-based, in other words, we cannot assign the exact response time for each agent in the simulation model. As a result of the random allocation of the response time for an agent, deviation may occur with varied degrees according to response time distribution of each AS. Taking all the above uncertainties into consideration, the variations of assembly times between simulated and experimental results seem acceptable.

5. Conclusions

By referring to the literatures on passenger ship evacuation and the guidelines of the International Maritime Organization (IMO), this paper studied the ship evacuation problem by means of simulation. An agent-based microscopic evacuation simulation model—CityFlow-M has been introduced and a passenger ship evacuation case was simulated and validated by data of a semi-unannounced assembly trail at sea. The simulation results were found to be in reasonable agreement with the experimental measured data, suggesting that CityFlow-M is eligible to simulate the assembling process in this RO-PAX passenger ship. This model is being further developed, and we will refine it by optimizing the evacuation route assignment approach as well as adding new parameters to simulate the human performances under special circumstance, such as lifting, trimming and ship motions.

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