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Research on the Accessibility Evaluation of the Cruise Passage Design Based on Passenger Movement Simulation

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Abstract. Cruise passage accessibility is defined as a kind of difficulty degree of getting close to the demanded place within the expected time in a typical cruise scenario. In consideration of the space utilization of cruise ships and the efficiency of passenger movement, the concept of cruise passage accessibility is proposed to improve cruise passage design. This study aims to build the passenger movement model under different scenarios in the complex cruise layout and the evaluation is carried out with the simulation results. According to the analysis of passenger movement characteristics, the social force model is improved. Besides, Analytic Hierarchy Process and Fuzzy Comprehensive Evaluation Method (AHP-FCA) are combined in the cruise passage accessibility evaluation. With the improved social force model, the passenger movement model on the Mediterranean Armonia Cruise are constructed through the AnyLogic simulation platform. Then, the cruise passage accessibility is evaluated by the simulation results and the evaluation method. Through the accessibility evaluation method, some effective suggestions are proposed to improve cruise passage accessibility.

Keywords: Cruise passage · Passenger movement · Social force model · Simulation experiment · Accessibility evaluation

1 Introduction

Cruise passage accessibility is an important measurement of cruise passage design quantity and the passenger movement efficiency. In order to study cruise passage accessibility evaluation, Anylogic Software Simulation and AHP-FCA evaluation method are applied.

Currently, research on evaluation of ship layout design has made good progress. Brown and Salcedo (2003) used multi-objective genetic algorithm to construct the evaluation system of ship layout design in the preliminary design of cruise [1]. Anil (2005) used parametric space exploration techniques to reduce ship design dimensions and simplify ship design evaluation [2]. Chen Miao (2009) deduced relationship formula between the speed and density of personnel movement by the dynamic equation

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in a crowded state, and evaluated the ship accessibility by the evacuation time [3]. Gesine Hofinger et al. (2014) analyzed the influence of psychological factors in evacuation process [4]. Li Feng (2014) established the ship accessibility evaluation index system with the environment, layout, process, and time indicators as the framework [5]. Marina Balakhontceva et al. (2016) proposed a multi-agent model and crowd dynamics modeling method by considering the evacuation process of ship movement [6]. However, cruise passage accessibility has not been clearly defined in the previous studies, and the evaluation of cruise passage design is still inadequate.

Therefore, passenger movement simulation is constructed to improve cruise passage accessibility. Combined with the cruise passage layout characteristics and movement characteristics, the social force model is improved. Then, AHP - FCA method is used to support the evaluation method. Finally, the Mediterranean Armonia cruise ship is taken as an example to simulate three kinds of passenger movement scenarios. Through the analysis of simulation results, the evaluation score, which is obtained by AHP-FCA evaluation method, comprehensively reflects the pros and cons of cruise passage accessibility, and has a good guiding significance for the cruise passage design.

2 Passenger Movement Characteristics and Improvement of Social Force Model

2.1 Passenger Movement Characteristics

The distribution and movement efficiency of cruise passengers are mainly subject to the surrounding environment and psychological quality of passengers [7].

For dining activities, the passenger behaviors are simple with the assistance of staffs. When passengers enter into or leave off the dining room, the passenger density in the dining room is highest.

For entertainment activities, the distribution of passengers will be gathered in a short time, and it is possible to cause the phenomenon of conformity, small groups and overcrowding.

For emergency evacuation, the behaviors of passenger movement are always different from the usual:

1) Due to panic psychology, passengers expect to move faster than usual.
2) In the narrow areas of cruise passage, passenger movement could produce overcrowding and even colliding.
3) Some passengers are unfamiliar with the cruise passage layout so that they sometimes get wrong in evacuation direction.
4) Nervousness would affect the efficiency of passenger movement.
5) The number of people in the different evacuation exits is uneven.

2.2 Improvement of Social Force Model

Through the analysis of the movement characteristics of passengers, influence factors would be considered to improve the social force model and build a model for simulation experiment analysis.

According to the concept of social force, Helbing et al. introduced dynamic characteristics and constructed a social force model [8]

$$\begin{cases} m_i \frac{dv_i}{dt} = m_j \frac{v_i^o(t)e_i^o(t) - v_i(t)}{\tau_i} + \sum_{j \neq i} f_{ij} + \sum_w f_{iw} \\ f_{ij} = \left\{ A_i \exp\left[\frac{r_{ij} - d_{ij}}{B_i}\right] + kg(r_{ij} - d_{ij}) \right\} n_{ij} + \kappa g(r_{ij} - d_{ij}) \Delta v_{ji}^t t_{ij} \\ f_{iw} = \left\{ A_i \exp\left[\frac{r_i - d_{iw}}{B_i}\right] + kg(r_i - d_{iw}) \right\} n_{iw} - \kappa g(r_i - d_{iw})(v_i \cdot t_{iw}) t_{iw} \end{cases} \quad (1)$$

where, m_i is the mass of person i, $v_i^o(t)$ is the expected speed of person i, $e_i^o(t)$ is the unit vector of the person moving in the desired direction at time t, $v_i(t)$ is the actual motion velocity vector of person i at time t, τ_i is the relaxation time of i, A_i is the intensity of interaction, B_i is the range of interaction. The parameters k and κ determine the obstruction effects in case of physical interactions. Besides, $r_{ij} = r_i + r_j$ is the sum of their radii r_i and r_j. $d_{ij} = \|r_i - r_j\|$ is the distance between 2 people's mass centers, n_{ij} is normalized vector pointing from person j to person i, t_{ij} is the tangential direction, Δv_{ji}^t is the tangential velocity difference, d_{iw} is the shortest distance between person i and barrier j, and n_{iw} is the direction perpendicular to it.

In combination with the above passage design characteristics and the movement characteristics of passengers, the social force model is improved: one is the influence of introducing panic psychology, conformity psychology and small group behavior on the expected speed of passengers; the other is the influence of introducing congested areas on the movement space of passengers.

Panic Psychology. Sharad Sharma et al. indicated that panic could slow movement during an evacuation [9]. P_{panic} is used to express the impact of panic factors on the actual velocity of personnel [10], and the actual expected velocity, as amended

$$v_i(t)' \in (v_i^{\min}(t) - P_{panic} * v_\Delta(t),\ \ v_i^{\max}(t) + 2 * P_{panic} * v_\Delta(t)) \quad (2)$$

where, $v_i(t)'$ is revised actual speed, $v_i^{min}(t)$ and $v_i^{max}(t)$ are the maximum and minimum of the normal movement speed of person i, and $v_\Delta(t)$ is a unit of speed (m/s).

Small Group Behavior. In the emergency evacuation, dining activities or large-scale entertainment activities, cruise passengers have the characteristics of gathering together. The small group phenomenon has a more significant impact on the movement efficiency of passengers. Therefore, when the model is running, there is a certain probability that passengers will move in a small group, and the passenger group behavior is expressed by Lakoba's definition of attraction [11]

$$f_{iq} = F_i \exp\left[(r_{iq} - d_{iq})/B_i\right] n_{iq} \tag{3}$$

where, q is a companion of person i, r_{iq} is the sum of their radii, d_{iq} is the distance between their centers of mass, B_i is the range of the force between them, F_i is negative constant, and n_{iq} is the acting force is opposite to that of the original model.

Guidance of Crowded Areas. Due to the high tonnage and large passenger capacity of cruise ships, it is possible to cause local regional congestion in the process of evacuation, which reduces the evacuation efficiency of passengers. Therefore, it is necessary to arrange staff to guide the evacuation path and direction. The guiding path of evacuation is determined by specific scenes, while the guiding direction is the desired direction of passengers

$$e_i^o(t)' = \frac{e_i^o(t) + t_{impact} e_{leader}}{\left|e_i^o(t) + t_{impact} e_{leader}\right|} \tag{4}$$

where, e_{leader} is the direction guided by cruise crew, t_{impact} is the guiding force of staff, and the range is [0, 1], $e_i^o(t)'$ is the direction of desired velocity after correction.

3 Accessibility Evaluation Method

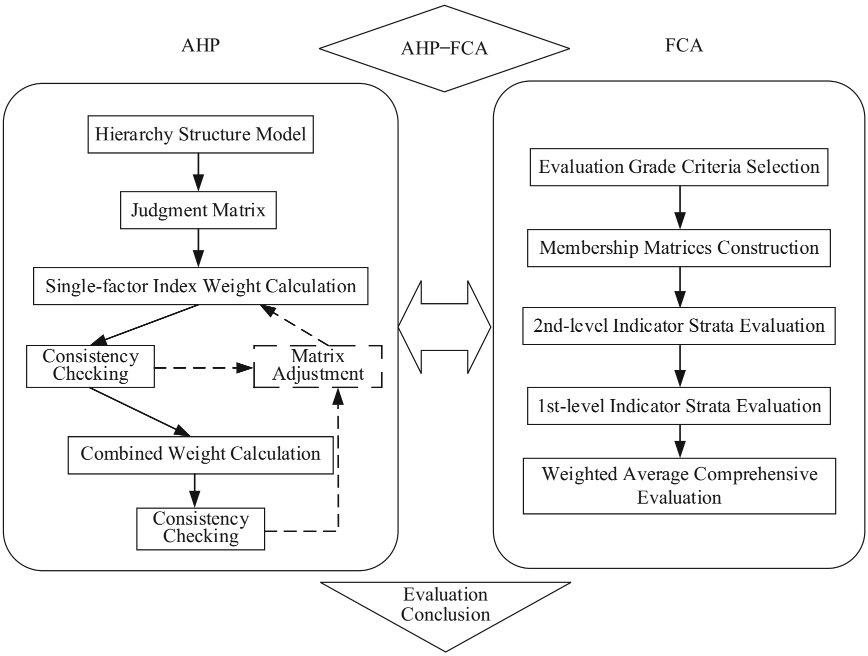


Fig. 1. Accessibility evaluation process.

According to the definition of cruise passage accessibility, the accessibility evaluation of cruise passage needs to be carried out from the perspectives of passage layout and passenger movement. Besides, accessibility evaluation is a synthesis evaluation which refers to many factors.

Therefore, based on the simulation results of the social force model, AHP-FCA comprehensive evaluation method is applied to evaluate cruise passage accessibility [12]. The specific evaluation process is shown in Fig. 1.

3.1 Index System and Empowerment Analysis

Hierarchical Structure Model. By taking the accessibility of the overall passage layout of cruise ships as the overall goal, a 3-level evaluation index system is constructed (Fig. 2).

In Fig. 2, U is the comprehensive evaluation set, u_1, u_2, and u_3 respectively represents the evaluation set under the scenarios of emergency evacuation, dining activities and large-scale entertainment activities; u_{ij} (i = 1, 2, 3; j = 1, 2, 3, 4, 5) represents each indicator in the 2nd-level indicator strata.

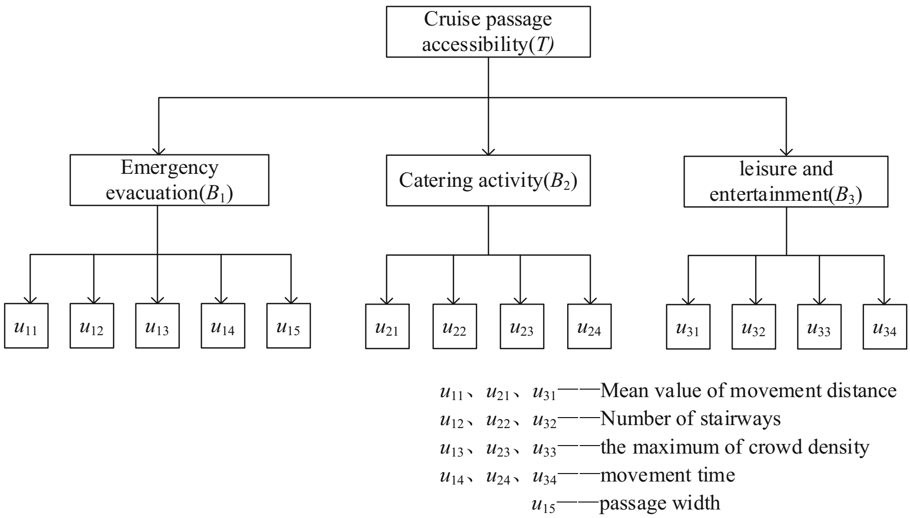


Fig. 2. Evaluation index system of cruise passage accessibility.

Single-Factor Index Weight. The judgment matrix, weight vector and consistency ratio of the following levels are obtained by pairwise comparison and characteristic root method (see Table 1, Table 2, Table 3, and Table 4).

Table 1. 1st-level index B_i in hierarchical single arrangement

A	B_1	B_2	B_3	b
B_1	1	4	5	0.6833
B_2	1/4	1	2	0.1998
B_3	1/5	1/2	1	0.1169
$\lambda_{\max}$	3.0246			
CI	0.0123			
RI	0.58			
CR	0.0212			

Table 2. 2nd-level index u_{ij} in hierarchical single arrangement (1)

B_1	C_1	C_2	C_3	C_4	C_5	w
C_1	1	2	2	1/2	1	0.1956
C_2	1/2	1	1	1/4	1/2	0.0978
C_3	1/2	1	1	1/4	1/2	0.0978
C_4	2	4	4	1	3	0.4274
C_5	1	2	2	1/3	1	0.1814
$\lambda_{\max}$	5.0198					
CI	0.0049					
RI	1.12					
CR	0.0042					

Table 3. 2nd-level index u_{ij} in hierarchical single arrangement (2)

B_1	C_6	C_7	C_8	C_9	w
C_6	1	2	3	1/3	0.2372
C_7	1/2	1	2	1/4	0.1406
C_8	1/3	1/2	1	1/4	0.0913
C_9	3	4	4	1	0.5309
$\lambda_{\max}$	4.0875				
CI	0.0292				
RI	0.89				
CR	0.0328				

Table 4. 2nd-level index u_{ij} in hierarchical single arrangement (3)

B_1	C_{10}	C_{11}	C_{12}	C_{13}	w
C_{10}	1	2	3	1/3	0.2372
C_{11}	1/2	1	2	1/4	0.1406
C_{12}	1/3	1/2	1	1/4	0.0913
C_{13}	3	4	4	1	0.5309
$\lambda_{\max}$	4.0875				
CI	0.0292				
RI	0.89				
CR	0.0328				

According to the consistency checks of single-level ranking ($CR \leq 0.10$), the weight values of 2nd-level index u_{ij} are calculated.

Combined Weight. According to the consistency checks of single-level ranking ($CR \leq 0.10$), the weight values of 1st-level index B_i are calculated, and the total hierarchical ranking is calculated to obtain the synthetic weight of 2nd-level index u_{ij} relative to target T (Table 5).

Table 5. Combined weight calculation.

2nd-level indicator strata	1st-level indicator strata			Combined weigh (a_{ij})
	B_1	B_2	B_3	
	0.6833	0.1998	0.1169	
u_{11}	0.1956			0.1337
u_{12}	0.0978			0.0668
u_{13}	0.0978			0.0668
u_{14}	0.4274			0.2920
u_{15}	0.1814			0.1240
u_{21}		0.2372		0.0474
u_{22}		0.1406		0.0281
u_{23}		0.0913		0.0182
u_{24}		0.5309		0.1061
u_{31}			0.2372	0.0277
u_{32}			0.1406	0.0164
u_{33}			0.0913	0.0107
u_{34}			0.5309	0.0621

According to the result of weight set calculation of AHP method, the combined weight of the 2nd-level indexes is determined

$$\begin{cases} A = \{a_1, a_2, a_3\} \\ A_1 = \{a_{11}, a_{12}, a_{13}, a_{14}, a_{15}\} \\ A_2 = \{a_{21}, a_{22}, a_{23}, a_{24}\} \\ A_3 = \{a_{31}, a_{32}, a_{33}, a_{34}\} \end{cases} \tag{5}$$

where, A is combined weight set, A_1, A_2, and A_3 respectively represent the weight set of evaluation factors under the scenarios of emergency evacuation, dining activities and entertainment activities, a_i (i = 1, 2, 3) is the weight set of 1st-level indicator strata, and a_{ij} (i = 1, 2, 3; j = 1, 2, 3, 4, 5) is the weight set of 2nd-level indicator strata.

3.2 Fuzzy Evaluation and Scores

Based on their own experience and relevant specifications, 10 experts who have experience in ship general arrangement evaluation were invited to score each index of the cruise passage accessibility evaluation index system on a 5-point scale. According to the scoring results, the membership degree r_{ijk} of the second-level indicator u_{ij} on each rating grade v_k is obtained. Then the fuzzy evaluation matrix R_i of the single-factor u_i is established

$$\begin{cases} r_{ijk} = \frac{N_{ijk}}{N} \\ R_i = \begin{bmatrix} r_{i11} & r_{i12} & \cdots & r_{i1p} \\ r_{i21} & r_{i22} & \cdots & r_{i2p} \\ \cdots & \cdots & r_{ijk} & \cdots \\ r_{in1} & r_{in2} & \cdots & r_{inp} \end{bmatrix} \end{cases} \tag{6}$$

where, N_{ijk} represents the number of people who have made v_k grade evaluations on the 2nd-level indicator u_{ij}, N = 10 means total number of evaluators.

Fuzzy evaluation method is used to evaluate 1st-level indicator (u_1, u_{21}, and u_3), and single factor evaluation vector B_i is constructed

$$\begin{cases} B_1 = A_1 \cdot R_1 \\ B_2 = A_2 \cdot R_2 \\ B_3 = A_3 \cdot R_3 \end{cases} \tag{7}$$

The 2nd-level fuzzy comprehensive evaluation vector is established by synthesizing single factor evaluation vector

$$\begin{cases} R = [B_1, B_2, B_3]^T \\ B = A \cdot R \end{cases} \tag{8}$$

The evaluation vector B is weighted by score, and the comprehensive evaluation score of passage accessibility evaluation is obtained

$$P = B \cdot V^T \tag{9}$$

where, $V = [5, 4, 3, 2, 1]$.

If the evaluation score is equal to or more than 3 marks, passage accessibility meets the requirement. Besides, through the result of 10 experts' single-factor evaluation, passage accessibility can be improved with specific purpose.

4 Case Study

Based on the improved social force model and Anylogic 7.3.5 simulation platform [13], the Mediterranean Armonia Cruise Ship is used as the prototype to construct passenger movement simulation tests under three scenarios: emergency evacuation in cabin area, dining in dining area, and large-scale entertainment activity in recreation area. To make the simulation results are approach to the actual condition, we respectively improve the simulation of static environment and dynamic environment. For static environment simulation, the deck model is constructed with the actual size and shape. For dynamic environment, the social force model is improved by panic psychology, small group behavior, and guidance of crowded areas. The specific modeling process [14] is shown in Fig. 3.

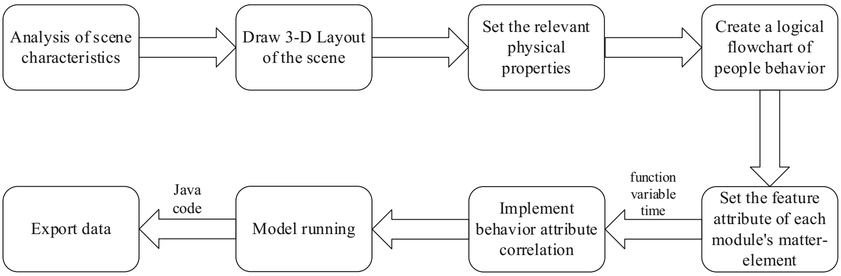


Fig. 3. Anylogic simulation modeling flowchart.

4.1 Scene Simulation

Emergency Evacuation in Cabin Areas. There are 5 main staircases on each of the three decks (Fig. 4). The deck parameter information is shown in Table 6. The passengers start from their own living cabin and move to the cabin door, then they select the nearest stairway and the gathering place for evacuation. When all of passengers arrive on the lifeboat deck (Deck 7), the evacuation on this floor will be regarded as the end. Professor Helbing D. [8] pointed out that "under normal conditions, the average

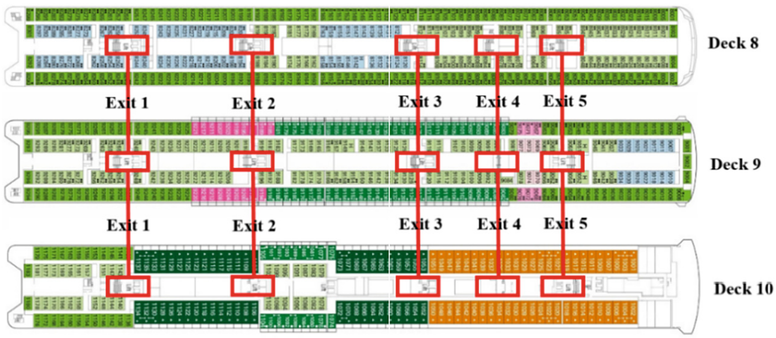


Fig. 4. Cabin area scene on Decks 8–10.

Table 6. Relevant parameters of Decks 8–10.

Deck	Cabin quantity	Passenger quantity
8	300	968
9	297	709
10	182	376

speed of evacuees in the horizontal passage is 1.25 m/s". However, due to the unfavorable environment of the cruise ship and the influence of panic psychology, the initial speed is set to 0.7–1.2 m/s and the movement speed is 1.2–1.4 m/s.

Dining in Marco Polo Main Dining Room. Marco Polo Main Dining Room (located on Deck 5) has an area of 1050 m^2 and a maximum seating capacity of 718 people. Among them, 352 people enter from Stair 1 to Area 1 and 366 people enter from Stair 2 to Area 2. And there are four exits for passengers (Fig. 5).

Passengers randomly select the entrances (Stair 1 and Stair 2) and enter into the dining room. Then 3–5 passengers gather as a small group and randomly select the dining table. The dining time is about 20–35 min. When all of passengers have reached the exits after meal, the simulation is regarded as an end. As the dining room is divided

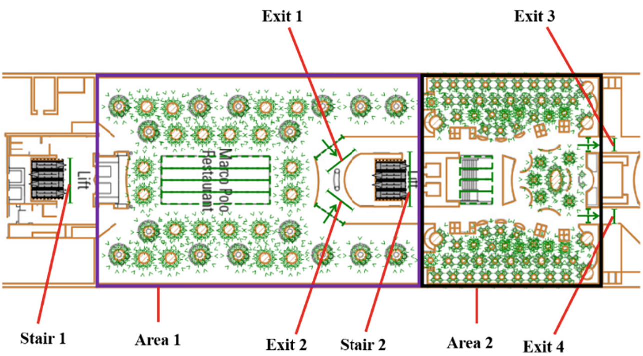


Fig. 5. Marco Polo Main Dining Room.

into Area 1 and Area 2, there are 2 source points of passenger flow. Due to the average movement speed of passenger flow is about 1.30 m/s under normal conditions and the internal layout design is relatively compact, the movement speed of passenger flow is set to 1.1–1.3 m/s.

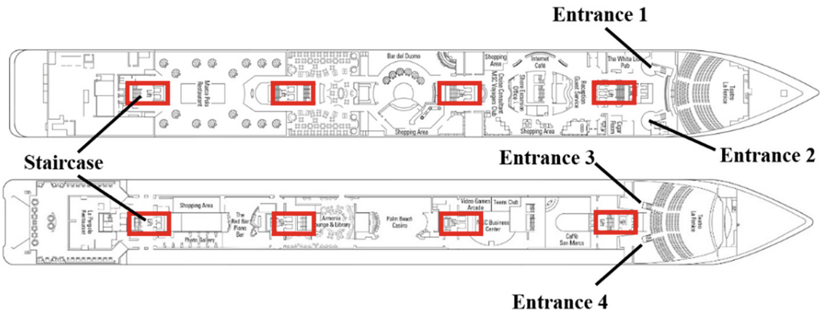


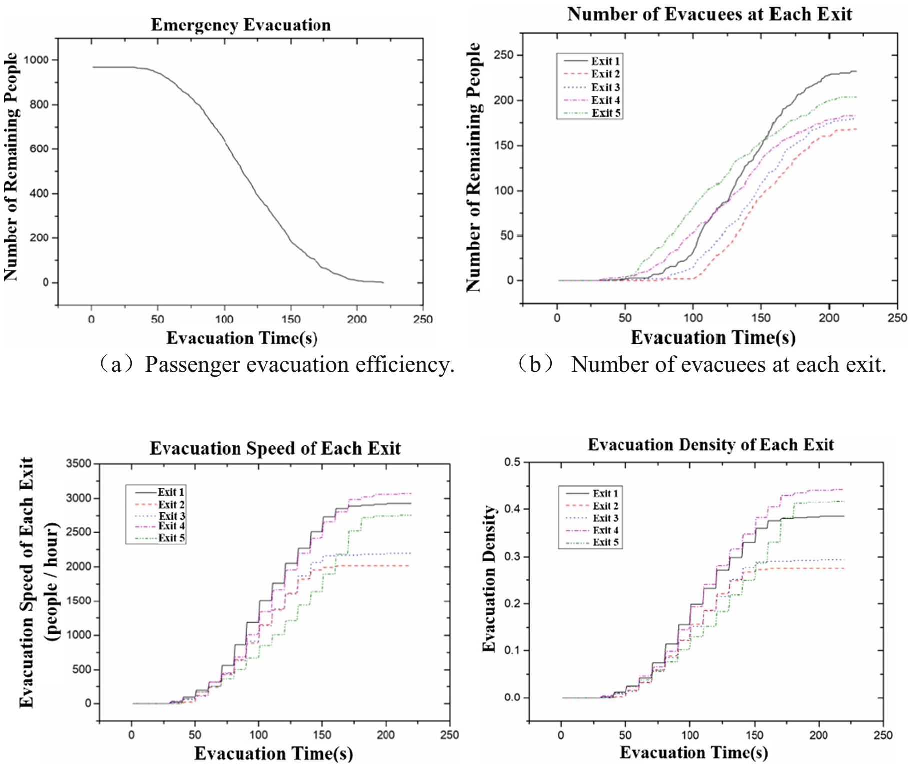
Fig. 6. Entertainment area on Deck 5–6.

Large-Scale Entertainment Activity. Teatro La Fenice Theatre with an area of 1135 m^2 and a maximum capacity of 557 people, has 2 decks (Decks 5–6). According to the distribution of cruise passengers, the passenger quantity of Decks 5–6 are set to 385 and 172 respectively. Besides, there are four entrances in the theatre, and there are eight staircases located on the bow of Decks 5–6 (Fig. 6).

Passengers randomly appear at any staircase of the entertainment deck and guided by the staff to move towards the theatre in small groups. When all the passengers arrive at the entrances of the theatre, the simulation is deemed to be over. As the theatre is divided into 2 parts, there are 8 source points of passenger flow. Under normal conditions, the average speed of young people is 1.32 m/s [15]. According to the complex environment and the different individual behaviors, the speed of passenger flow is set to 1.2–1.4 m/s.

4.2 Results and Discussion

Results of Emergency Evacuation Simulation. As is shown in Fig. 7, although the number of evacuees at each exit is approximately equal, the evacuation density of Exit 3 (or Exit 4) are smaller than other exits. In the cabin layout design, there should be more 3-people rooms and 4-people rooms near Exit 3 and Exit 4.



(a) Passenger evacuation efficiency.

(b) Number of evacuees at each exit.

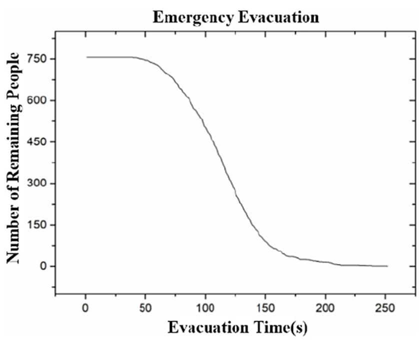
(c) Evacuation speed of each exit.

(d) Evacuation density of each exit.

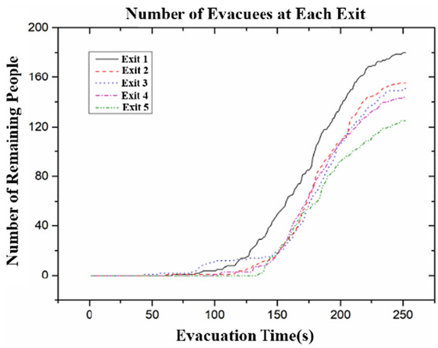
Fig. 7. Emergency evacuation on Deck 8.

Figure 8 shows that number of evacuees, evacuation speed, and evacuation density of each exit are relatively close in the whole progress. The results indicates that the layout of this deck are reasonable.

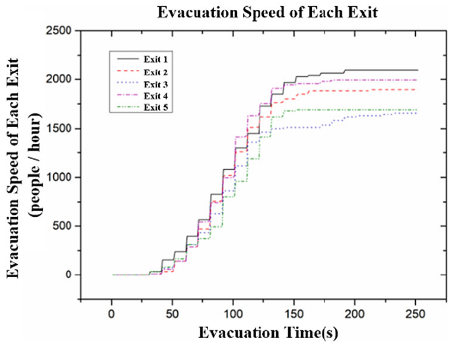
As is shown in Fig. 9, it takes 167 s from the successful evacuation of first passenger (at 39 s) to the successful evacuation of all passengers. And the number of evacuees, speed and density at each exit are directly proportional. The numbers of evacuees at Exit 1 and Exit 2 are respectively 120 and 112. While the numbers of evacuees at Exit 3–5 are 60, 36 and 48, respectively. The evacuation densities of the exits are unequal: Exit 1 and Exit 2 are crowded, while there are much fewer people at other exits.



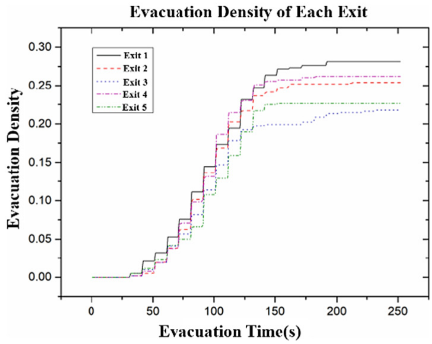
（a）Passenger evacuation efficiency.



（b） Number of evacuees at each exit.



（c） Evacuation speed of each exit.



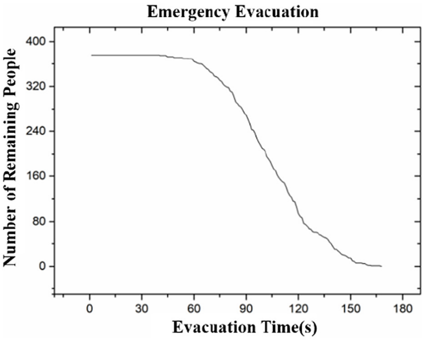
（d） Evacuation density of each exit.

Fig. 8. Emergency evacuation on Deck 9.

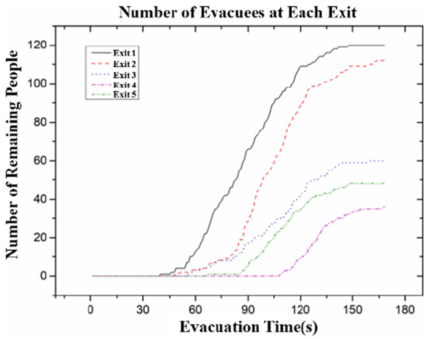
Due to the small number of people and the low evacuation density, the evacuation time on Deck 10 is shortest (Table 7). The evacuation time of passengers in the cabin areas shall be the largest one of the three, so T is 252 s.

Results of Dining Activity Simulation. As shown in Fig. 10, passengers start leaving the dining room at 22 min. And it takes 48 min 23 s to serve 718 passengers in the main dining room.

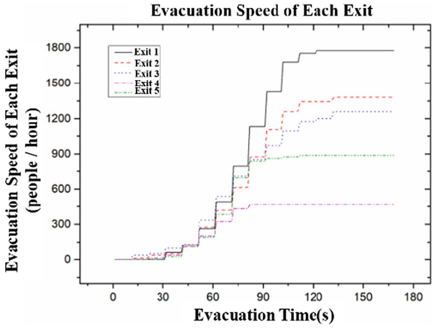
Although the maximum passenger capacity of Area 1 (352 people) is equal to that of Area 2 (366 people), the size of Area 1 is about twice as the size of Area 2. Besides, the width of the exits in Area 1 is wider than the width of the exits in Area 2. Therefore, the flow densities of Entrance 3 and Entrance 4 are higher than those of Entrance 1 and Entrance 2 (Figs. 10 and 11).



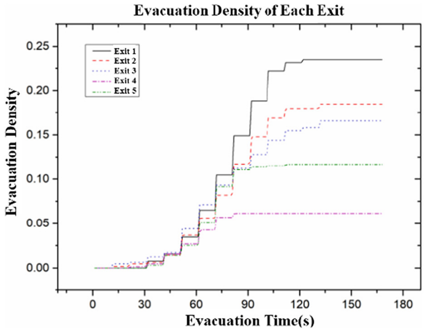
（a）Evacuation efficiency.



（b） Number of evacuees at each exit.



（c） Evacuation speed of each exit.



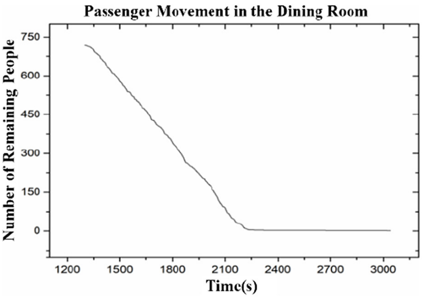
（d） Evacuation density of each exit.

Fig. 9. Emergency evacuation on Deck 10.

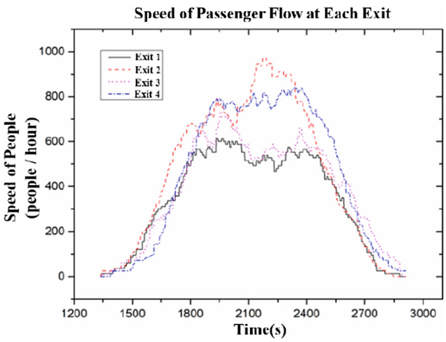
Table 7. Statistics of emergency evacuation simulation results.

Deck	Width of passage (m)	Maximum evacuation speed (people/hour)	Maximum evacuation density	Evacuation time (s)
8	1.38	3072	0.44	220
9	1.36	2100	0.29	252
10	1.28	1776	0.22	167

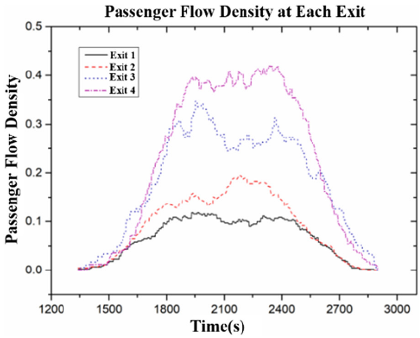
Results of Large-Scale Entertainment Activity Simulation. Figure 12 shows that it takes 379 s for 557 passengers to arrive at the entrance of the theatre. Since there is no fixed form in the recreation areas, the density and speed of passenger flow at each entrance are greatly different and the passage in the recreation areas is prone to local overcrowding (Fig. 13).



(a) Dining efficiency.

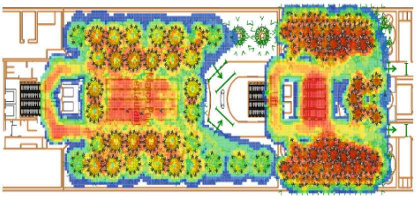


(b) Speed of passenger flow at each exit.

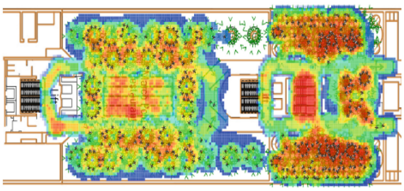


(c) Flow density at each exit.

Fig. 10. Passenger movement in the main dining room.

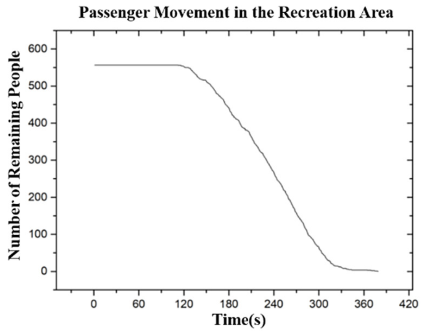


(a) At beginning.

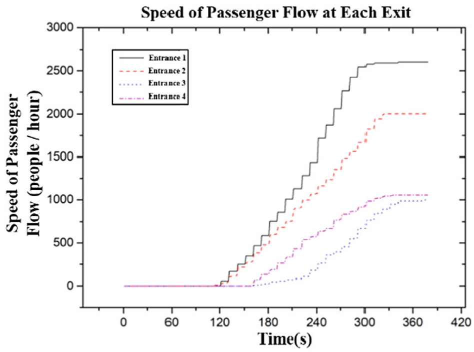


(b) In the end.

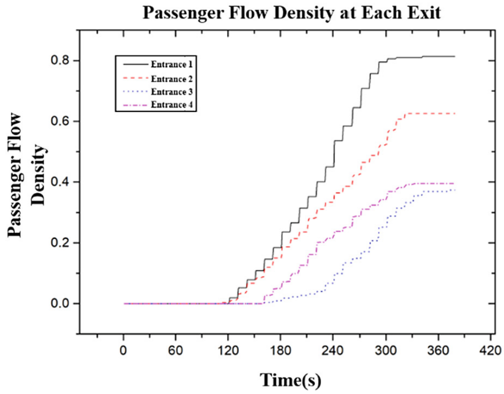
Fig. 11. Movement density of people in Marco Polo's main dining room.



(a) Movement efficiency.



(b) Speed of passenger flow at each exit.



(c) Passenger flow density at each exit.

Fig. 12. Passenger movement in the recreation areas.

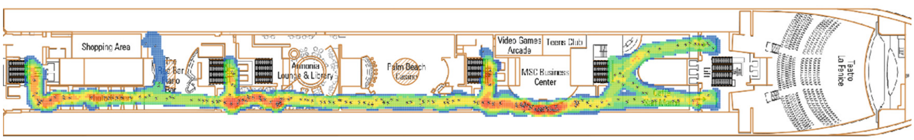


Fig. 13. The movement density of people in the recreation areas.

Evaluation and Analysis of Accessibility. Table 8 shows the layout characteristics of cruise passage and the simulation results under three scenes. According to the simulation, 10 experts' evaluation scores is given in Table 9. Combined with the above results and AHP-FCA comprehensive evaluation method, the Fuzzy score of MSC Armonia Cruise passage accessibility is 3.4154, which indicates that there are still problems in some indicators of the accessibility of the cruise passage design:

1) In the dining and recreation areas, the accessibility index is good at stairway quantity and the average distance of passenger movement, but insufficient consideration is given to the maximum evacuation density of the passage. For instance, the passage in the recreation areas is so narrow to cause possibly the phenomenon of personnel crowding.
2) Staircase layout of cabin areas is unreasonable. One part of Staircases are crowded, and another one part of Staircases are not. For example, on Deck 10, the numbers of people escaping from Exit 1 and Exit 2 are respectively 120 and 112, while the numbers of people escaping from Exit 3, Exit 4 and Exit 5 are respectively 60, 36 and 48. It indicates that the passenger quantity of Exit 3, Exit 4, or Exit 5 are even less than half of the passenger quantity of Exit 1 or Exit 2.

Table 8. Accessibility index data of the cruise passage.

	Mean value of movement distance (m)	Stairway quantity	Maximum of crowd density	Passage width (m)	Movement time (s)
Cabin areas	47	5	0.44	1.32	252
Dining areas	9.4	3	0.42	/	2903
Recreation areas	8.9	6	0.84	/	379

Table 9. Statistics of 10 experts' evaluation scores.

1^{st}-level indicator strata	2^{nd}-level indicator strata	Number of evaluation scores (from 5 to 1)				
		5	4	3	2	1
Emergency evacuation	u_{11}	0	4	6	0	0
	u_{12}	5	2	3	0	0
	u_{13}	0	0	5	5	0
	u_{14}	3	4	1	2	0
	u_{15}	1	4	2	3	0
Catering activities	u_{21}	2	2	3	3	0
	u_{22}	5	3	2	0	0
	u_{23}	0	2	4	4	0
	u_{24}	0	2	4	3	1
Leisure and entertainment	u_{31}	3	4	2	1	0
	u_{32}	4	4	2	0	0
	u_{33}	0	0	6	3	1
	u_{34}	1	3	4	2	0

5 Conclusions

In order to improve cruise passage design, the cruise passage accessibility is proposed. Based on passenger movement characteristics, social force model is improved, and passenger movement simulation under different scenarios is constructed. Through the simulation results, AHP-FCA evaluation method is applied and the fuzzy score of the cruise passage accessibility is obtained. This study can comprehensively evaluate cruise passage accessibility and effectively guide cruise passage layout design.

In this study, three concluding remarks could be drawn as listed below:

1) Considering the limitation of passage layout, the minimum passage width should be noticed to avoid the phenomenon of local overcrowding.
2) As shown in Table 9, the evaluation scores under u_{13}, u_{23}, and u_{33} is relatively lower than other factors. So as to improve the maximum of crowded density, staircase layout should be adjusted by passenger density in the special area, rather than evenly distributed along length direction.
3) The passenger movement simulation and AHP-FCA evaluation method need to be continually improved in practice. Through the improvements, the simulation results and the proposed method can be more approach to the actual condition.

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