

Space Design Simulation for a Crowd Accident: case study of the 2014 Shanghai Bund Accident

雑踏事故とスペースデザインに関するシミュレーション
—2014年上海外灘を事例として—

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1. Introduction

Along with the growing city density and large gatherings happening all over the world every year, crowd management has become a new science. Contrasting with the rapid development of multiple computational technologies is the fact that most city planners and managers still base their work on traditional empiricist methods. In this paper, we try to use agent-based simulation model as a tool to diagnose crowd safety in different space designs. First, we analyzed the original space design in the Shanghai Bund accident in 2014 for fact-finding. Then we tested the performances of two alternative space designs and compared the results with the original plan.

Shanghai Bund waterfront is a world-famous walking area along the Huangpu River. It combines historical buildings with commercial areas, attracts more than 300 thousand visitors on a normal day, and this number will climb to more than 1 million on holidays. The high density was a constant threat to urban safety and an accident finally occurred on 31 December, 2014, at 23:35pm, when people were gathering hoping to see the New Year fireworks. The large tragedy caused 36 deaths and 49 injuries. The following January, the government investigation report was released, and the accident details became clear.

2 Methodology for Analyzing the Crowd Accident

Based on the findings from the accident report and survey of space, we developed a pedestrian movement simulator. To model the accident, we extracted findings from the government accident report. Findings from the report are shown in Table1. A space plan was also made using satellite map and measurement (Fig.1).

Table1 Extractions from Government Report¹⁾

	Accident report
A. Bund scenic area	1. Area: 3.1 km ² .
B. Chen Yi Square	1. Public activity area: 2877 m ² . 2. 580 m from East Nanjing Road subway station.
C. Accident stairs	1. Located in southeast corner of Chen Yi Square, connecting to the viewing platform. 2. Two groups of stairs, in total 17 steps. 2.3 m distance between the groups. 3. Step width 6.2 m, the highest point to ground is 3.5 m, the depth of the stairs is 8.4 m. (Supplementary explanation: the original plan had no column to divide the up and down flows. Stone column was added after the accident)
D. Waitan Yuan	1. 550 m from Chen Yi Square was the actual event location.
E. Visitor number	1. Since 20:00, more people came in than left. Large amounts of visitors gradually gathered on viewing platform. 2. Comprehensive visitor number: 20:00 - 21:00, about 120 thousand. 21:00 - 22:00, about 160 thousand. 22:00 - 23:00, about 240 thousand. 23:00 - 23:35, about 310 thousand. (Supplementary explanation: corresponding density of Bund area: 20:00 - 21:00, 3.9 people/ m ² . 21:00 - 22:00, 5.2 people/ m ² . 22:00 - 23:00, 7.7 people/ m ² . 23:00 - 23:35, 10 people/ m ² .)
F. Isolation measure	1. 20:27, set up one-way belt in the entry (stairs) of the viewing platform. 2. 22:44, set intercept line in Nanjing Road to slow down people flowing towards Bund area.

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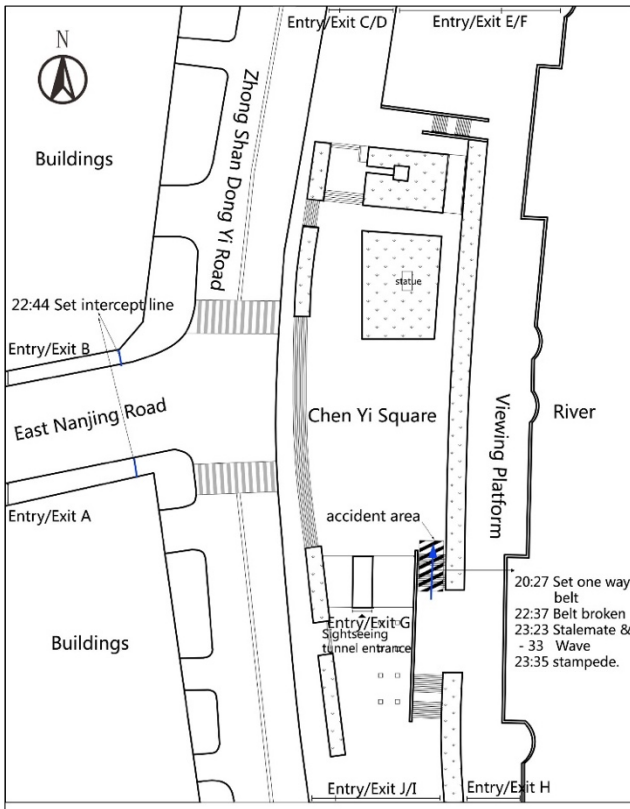


Fig.1 Simulation map of accident area

Chen Yi Square, located in the middle of the Shanghai Bund scenic area, has the highest pedestrian density in the area. On the west side, it joins to the East Nanjing Road, a high-density pedestrian street. Exits of subway line 10 and 2 are also on East Nanjing Road, making the pedestrian density even higher. On the east side, it connects to the river viewing platform, which is considered to be the best location to view the historical buildings on this side and the modern buildings across the river.

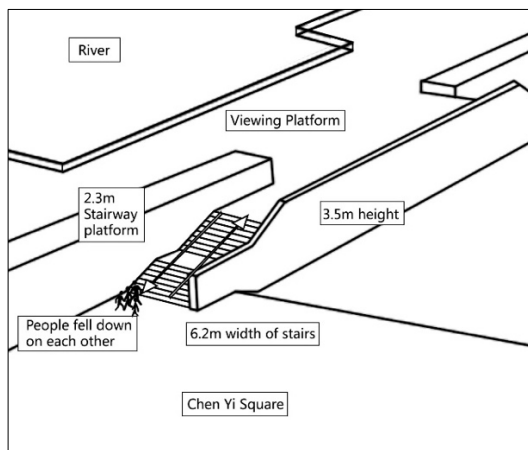


Fig.2 The accident location

Table1 (continued)

G. Procedure	1. 22:37, one-way belt was broken, many visitors went in opposite direction onto the viewing platform.
	2. 23:23 – 23:33, people moving upwards and downwards constantly collided and stalemated in the middle of the stairs, and then formed a “wave”.
	3. 23:35, the downward pressure of the stalemate suddenly increased, causing someone at the bottom to fall down. After the first person fell, people started to fall down on each other. Then a stampede happened.

This high-density square is connected to the viewing platform only by 17 steps, 6.2 m in width. The stairs are like the tight part of an hourglass, squeezing crowds. According to the report, people moving upwards and downwards stalemated in the middle of the stairs, and then formed a “wave”. A few minutes later, the downward pressure suddenly increased, causing someone at the bottom of the stairs to fall down. After the first person fell, people started to fall down on top of each other. Then a stampede happened¹⁾.

3 Survey

A survey was conducted between 15:00 and 16:00 on a September weekend in 2107. In the survey, we counted the flow-in value over 5 minutes in each entry; survey data is shown in Table 2.

Table 2 Survey of flow (people/minute)

Entry: A	Entry: B	Entry: C	Entry: D	Entry: E
119	44	2	13	5
Entry: F	Entry: G	Entry: H	Entry: I	Entry: J
51	14	38	48	10



Fig.3 Aerial view of the survey area

4 Model development

In the simulation model, an agent moves forward while avoiding other agents according to several behavioral rules on the cell-grid space of 40 cm per side. The space plan in Fig.1 was used. One step was set at 0.5 seconds.

4.1 Modeling of Space

The simulation area has 10 entries/exits. In the original space design, 43 waypoints and 109 action routes were set in the space to form a walking network (Fig.4). The flow line pattern of making a waypoint network is shown in Table 3.

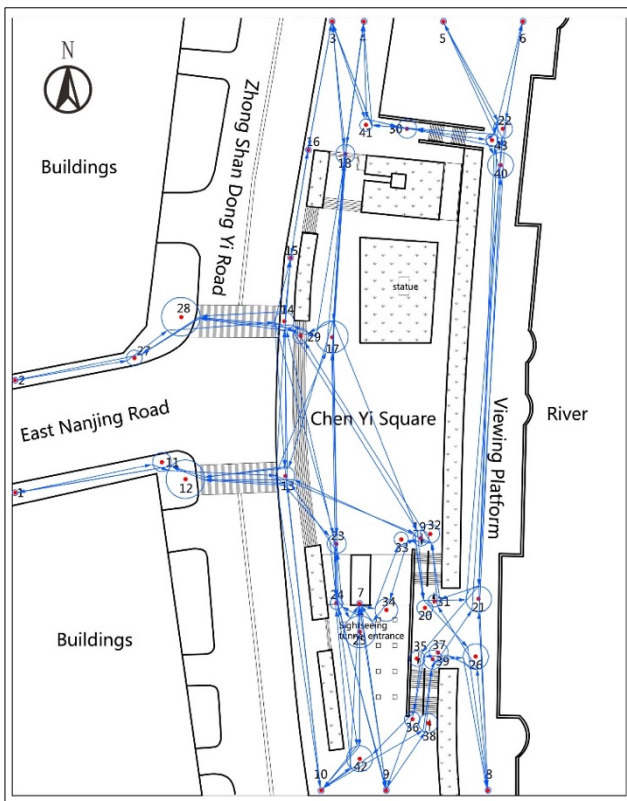


Fig.4 Setting of waypoints and routes

Table 3 The flow line pattern

Step 1	Draw natural walking paths between 10 entries/exits. Natural walking path usually is based on the shortest road principle.
Step 2	Set a waypoint when the destination is not directly visible in the direction that the agent is moving.
Step 3	Draw a choice-making circle around the waypoint. The radius of each circle is based on actual observation. When an agent moves into the sphere of its destination circle, it updates its destination. However, when passing through a circle which is not the destination of the agent, the agent does not update its destination.
Step 4	Use straight blue line to simplify natural

walking paths.

4.2 Creation of Agent

Two types of agents are created in the model, wall agents and passing agents. Wall agents occupy obstacle cells in the map. A passing agent moves along the waypoint network following several behavioral rules.

ASPF (Agent Simulator of Pedestrian Flows), developed by Kaneda and others, are introduced as behavioral rules into this model^{4, 5}. ASPFver.4.0 has a total of 36 rules, including: 6 basic behavior rules, 8 slow-down rules, 4 avoidance rules, 3 high density flow rules, 1 pattern cognition rule and 14 wall avoidance rules.

Behavior rules were applied to an agent in the following order:

- Choose the shortest route to the given exit
- Maintain the target
- Walking towards the target using behavior rules
- Update the target when the choice-making circle is reached

5 Simulation analysis for fact-finding

We set four density measurement areas as shown in Fig.4. Area 1 is the direction of the subway, where most high-density pedestrians come from. Area 2 is the place people fell on each other. Area 3 is set to measure one-way crowd density. Area 4 is where mixed groups of people coming from different directions meet.

People moving upward and downward are on the right. The simulation was conducted without the separation belt because the one-way belt was broken at 22:37.

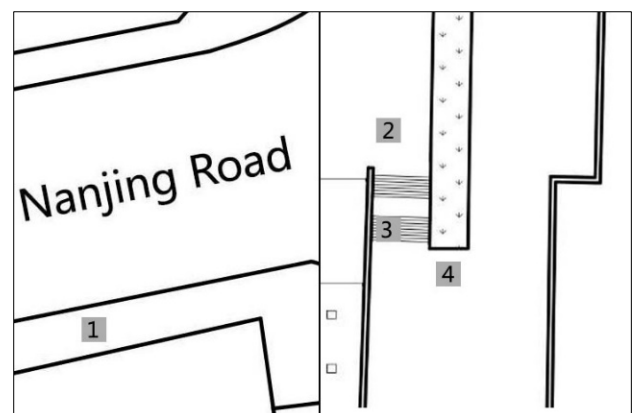


Fig.5 Density measurement area

In experiment 1, we timed up the measured flow in value from 1 to 10 times to exam the density changes (Fig.6).

In experiment 2, we imitated the density distribution in

only upward flow case (Fig.7), only downward flow case (Fig.8) and counter flow case (Fig.9) with 10 times flow in value, which is closest to the actual accident. Blue agents come from the subway direction, red agents come from north and south direction, and black agents come from the viewing platform.

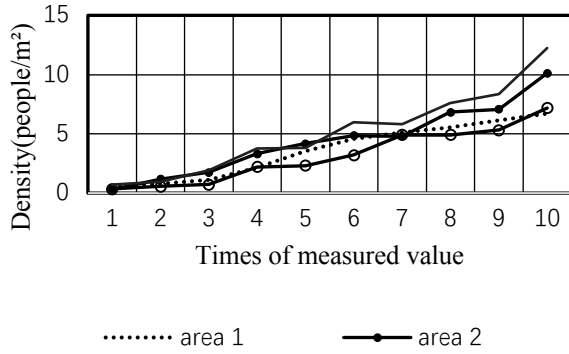


Fig.6 The relationship between flow-in-amount and density



Fig.7 Snapshots of upward flow case

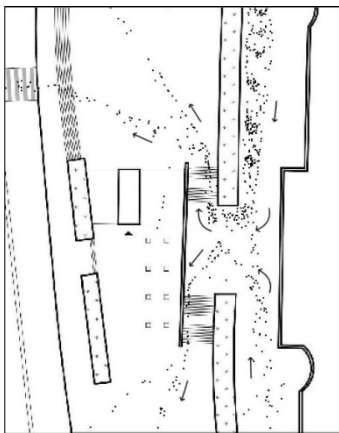


Fig.8 Snapshots of downward flow case

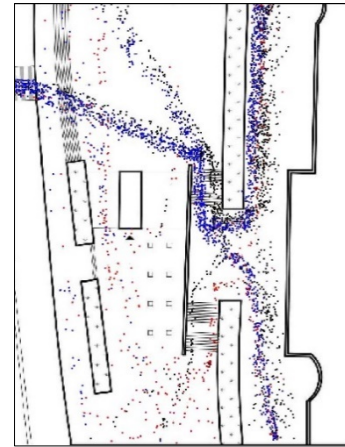


Fig.9 Snapshots of counter flow case

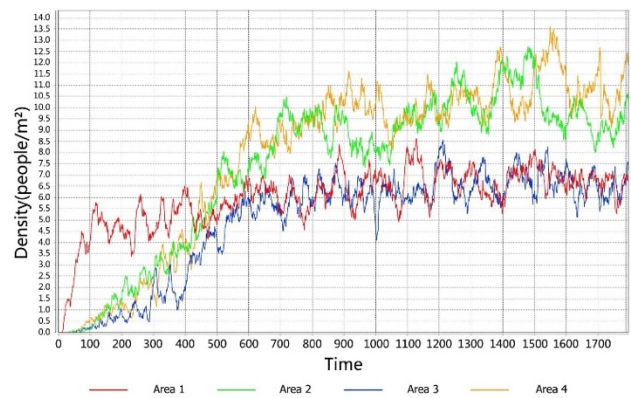


Fig.10 Density change in counter flow case

Fig.6 shows that: (1) The change of the density in area 2 followed the density in area 4. This means there is a downward pressure on the stairs. When someone at the bottom of the stairs fell down, a domino effect was easily triggered. (2) The density of area 2 went through a stable period from 4 to 5, then sharply increased to 7. It means the situation can become dangerous without warning.

From Fig.7 to Fig.10, we conclude that pedestrian flows from five different directions met on the top of the stairs (area 4), forming a high-density mixed crowd, causing enormous downward pressure. On the bottom of the stairs (area 2), pedestrian flows from three different directions also formed a high-density mixed crowd but the density was relatively lower than the top. When someone at the bottom fell down, enormous downward pressure caused balance loss and suddenly pushed down the people on the stairs, which led to the accident. This is in accordance with the conclusion in the accident report.

6 Alternative space designs

We made two alternative space designs and tested their efficiency. Alternative plan A is a one-direction plan, and alternative plan B is an open plan. Waypoint networks set are shown below.

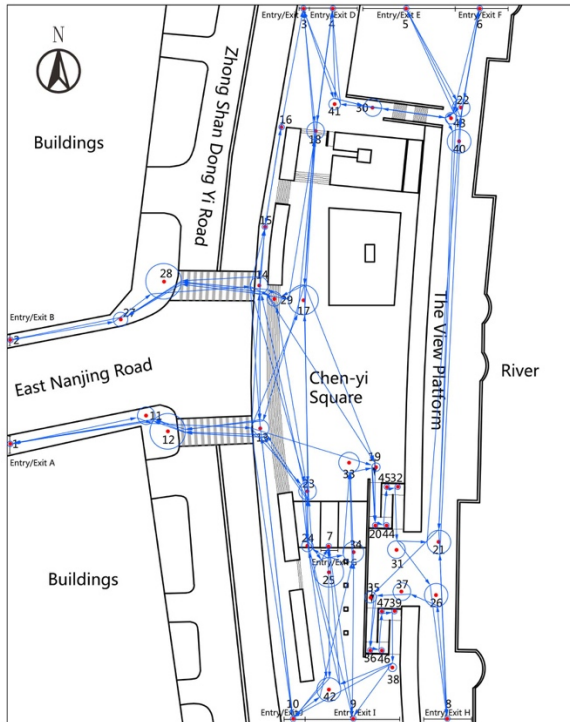


Fig. 11 Waypoints and routes of alternative plan A

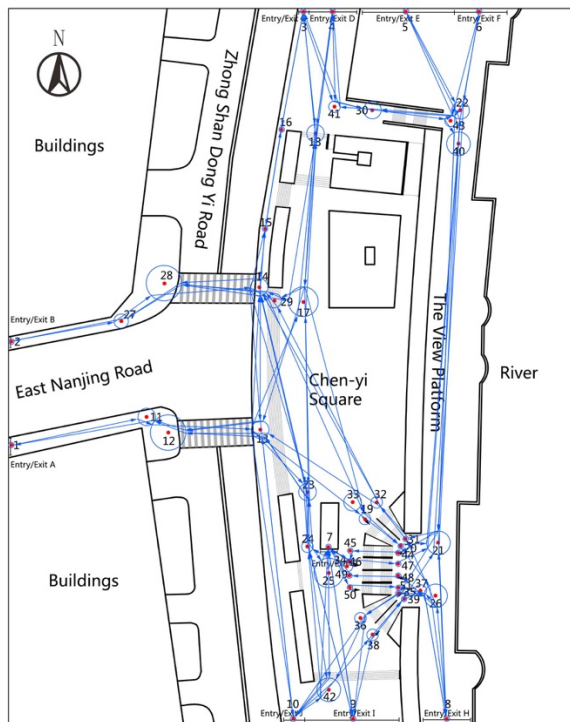


Fig. 12 Waypoints and routes of alternative plan B

We timed up the measured flow-in-value in the original space plan and two alternative plans to observe the density change in three measurement areas (Fig.13). The experiments stop when the density reaches 4 people/m², which is a commonly considered division between safety and danger. Each simulation was run for 1800 seconds each time and 10 times in total to get an average value.



Fig. 13 Measurement areas

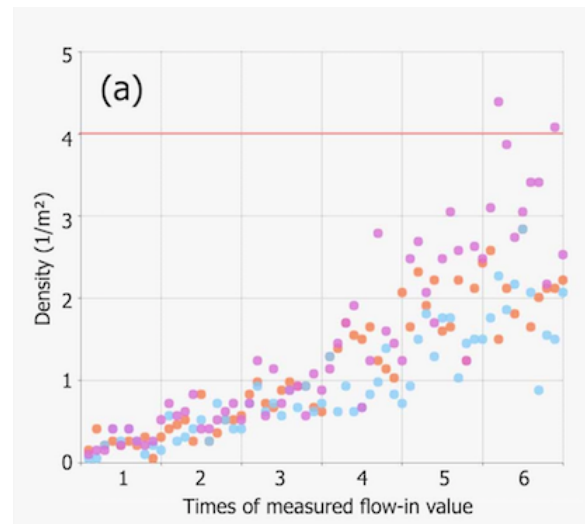


Fig. 14 Density distribution in original space design

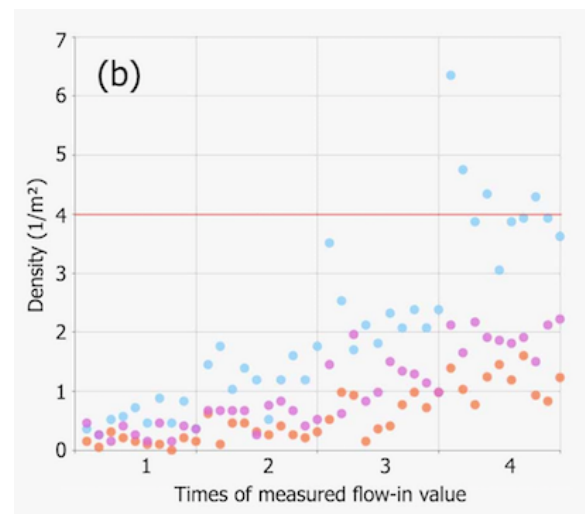


Fig. 15 Density distribution in alternative plan A

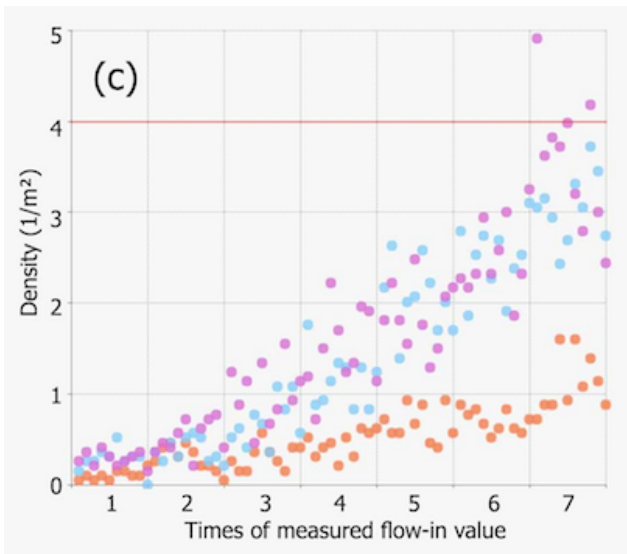


Fig.16 Density distribution in alternative plan B

From the results, we observed what flow-in amount will make each plan reach the risk density:

- (1) Alternative plan B, which is the open plan, has the best ability allow more people into the square while maintaining a relatively pleasant crowd density. When the flow-in value is 7 times the surveyed value it will make the top of the stairs reach risk density.
- (2) The original plan ranks second. When the flow-in value is 6 times the surveyed value it will make the top of the stairs reach risk density.
- (3) Alternative plan A, which is the one-direction plan, is the easiest plan to cause crowds to accumulate. When the flow-in value is 4 times the surveyed plan it will make the slope reach risk density.

From results we can find that the same space element, the connecting stairs, does not perform the same according to different space combinations and pedestrian movements. Either the body part or the upper part can reach danger density first.

Also, the accident does not have to occur in the area that has the highest density, but rather in a place with a poor location. In the real accident, the upper part of the stairs had a relatively higher density, which led to downward pressure, so when someone at the bottom of the stairs fell down the domino effect was triggered. When we analyze accident risk, we should not only take density into consideration but also account for the density difference in nearby locations.

Alternative plan B, though accumulate density slower than other two plans, has a bigger density difference on and under the stairs. This may become a new danger element.

The results also facilitate the management of public open space that the accumulation of pedestrian density can happen in a short time with no sign. Gasp the early sign in key areas according to different space plan become the crucial factor of crowd accident prevention.

References

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