Research on people search of metro station in the condition of low visibility after disasters

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Abstract: In recent years, public safety issues have received increasing attention from people. And the safety of subway station operations is one of the problem which lots of experts are concerning. At present, the emergency treatment research on the sudden situation of subway stations is mainly focused on emergency evacuation and emergency management. It rarely involves the post-disaster rescue field, but rescue is also an important process. This paper first analyzes the more commonly used directed search methods in the case of post-disaster low visibility. Next, it analyzes the search speed and effective search depth of firefighters in different search posture through directed search experiments. Then, it proposes an algorithm of time-balanced based on directed search in areal division and developes the simulation environment through C#. Last, it validates the method through a subway station platform in Beijing. The results show that the method can effectively divide the search area and the overall search efficiency is good.

1. Introduction

In recent years, natural disasters have occurred frequently around the world, and dangerous phenomena such as terrorist activities have occurred frequently. Public safety issues have received widespread attention. Most of the subway stations are underground and the space is relatively closed. Some large stations have complex structures and many passengers. Once a disaster occurs, the consequences can be very serious. After the disaster, how to carry out search and rescue process safely, efficiently and orderly is an important task. We study this issue, which is of great significance in controlling the disaster and reducing the loss of people's lives and property.

After the 1995 Kobe earthquake in Japan, people began to think about applying robots to the post-disaster rescue process in response to dangerous and complex post-disaster search and rescue process. Subsequently, the RoboCupRescue project appeared. Many experts [1-5] have continuously optimized the multi-agent rescue strategy, and analyzed the team cooperation mode, path planning method, information interaction strategy, and decision evaluation system and so on. By these tasks, the rescue plan has been gradually improved. However, the related research does not reflect the characteristics of the post-disaster relief work of the subway station, such as low visibility and strong chimney effect. Most of the experts have studied the emergency evacuation of the subway station after the disaster. And they have conducted research on emergency evacuation through experiments and simulations, and have achieved many results. Motonari et al. [6] simulated the evacuation of people in dark or smokey environments by letting the researchers wear eye masks. Peng et al. [7] used trained mice to conduct experiments to study the effects of different stimulation levels on evacuation time in an evacuated environment. Helbing et al. [8] used a lattice gas model to simulate the evacuation process of a person in a room in normal conditions. Varas et al. [9] used a cellular automata model to study the evacuation of people in obstructed rooms. Sungryong et al. [10] used FDS and evacuation simulation software to explore the effects of smoke on evacuated personnel, and then proposed a smoke effect model that reflects the force of smoke on person. However, evacuation is only the beginning, we must pay more attention to the post-disaster relief work after the evacuation. This paper first simulates the post-disaster personnel search process of the subway station, and then analyzes the personnel search method in the station. Finally, this paper determines the search scope of each firefighter by searching the partition model to improve the rescue efficiency.

2. The Method of Searching for People in the Station

2.1 The method of search in Low visibility condition

According to the "China Firefighting Handbook", when a fire occurs at a subway station, the chimney effect is strong, and the smoke will fill the entire station quickly in a short time. At the same time, the normal lighting facilities in the station were cut off and the underground space was in the dark. It is difficult for people to escape when the visibility is less than 3m, even if he is familiar with the environment. This also makes it difficult for people to evacuate and rescue. At present, the manpower search for large-area space mainly uses the directional search method and the layout method in low-visibility conditions, such as the hall in the station. As shown in Fig 1, the firefighters searched for a 12m * 12m room. (a): It is the directed search method. The search process consists of three steps: move: the firefighter moves a certain distance along the wall; search: the firefighter searches the interior perpendicularly to the wall for a certain distance; return: firefighter returns to the wall. During the search, the wall is always on the left or right side of the firefighter, and repeat the process until the room is searched completely. Obstacles such as floor escalators, straight ladders, and structural columns in the platform usually have regular geometric boundaries. According to whether the boundary points Q_1 and Q_2 of the obstacles are included in the field of view, obstacles can be bypassed according to the route shown in Fig 2. Through the above method, the search can be prevented from being missed, and the directed search flow chart is shown in Fig 3. (b): It is the layout method. It is made up of a number of firefighters in a row from the side of the wall to the opposite wall in the room, and then they search together in the room and return at the end of the room. In general, there are fewer firefighters required for directed search, but the search process is complicated. The search process of the layout method is simple but it requires more firefighters.

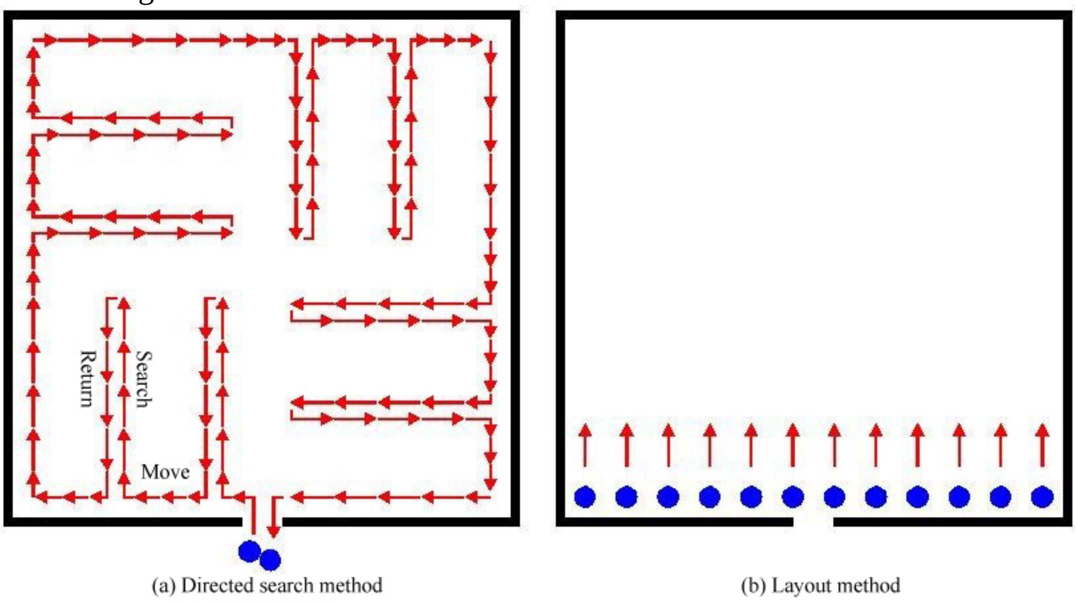

Figure 1. Schematic diagram of two search methods

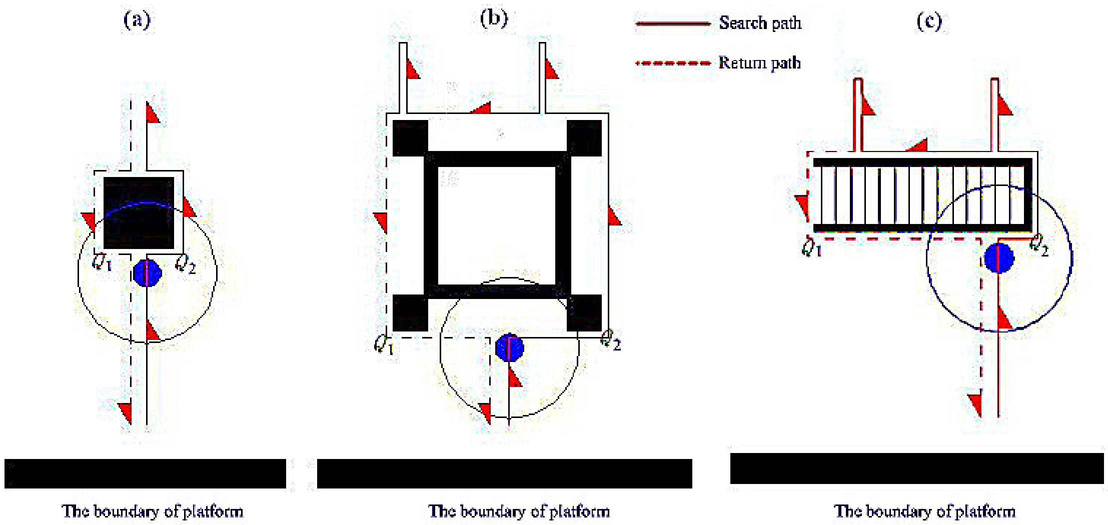

Figure 2. Obstacle bypassing method

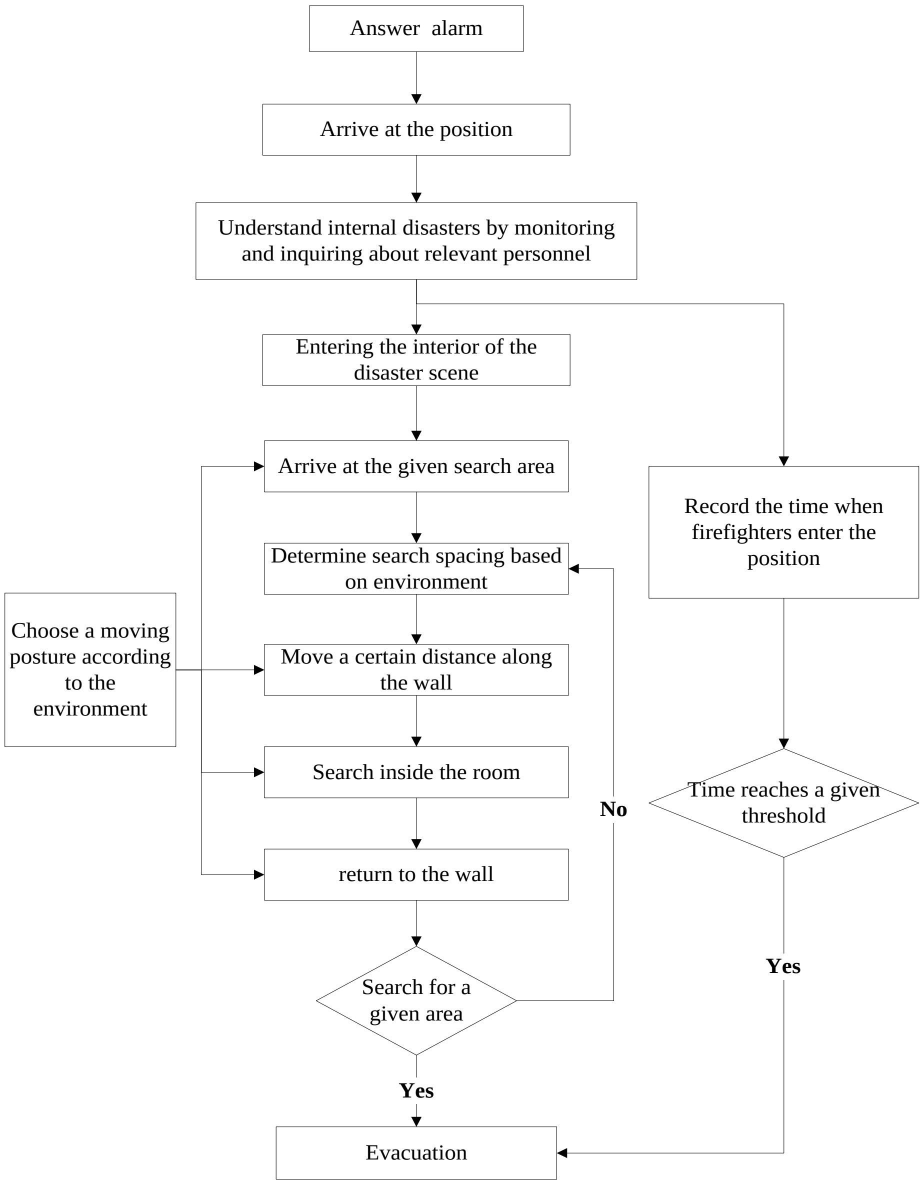

Figure 3. Flow chart of directional search method

2.2 Directed search experiment

The purpose of the experiment: In the directed search process, the speed of the search, the search pitch of the two adjacent searches, and the depth of the search will all affect the search results. During the search process, the environment has a significant impact on the search speed. When the environment is good, the firefighter can stand up and search. If the firefighter feels that his head is hot or can't see his feet when he is standing, he should use the posture of kneeling or crawling to search. At this time, the search speed will be reduced. When the visibility is lower than the firefighter's arm length, the firefighter needs to use a low posture and feel the search area by hand, so the speed is further reduced. At the same time, during the search process, if the firefighter does not have a reference object in the field of view, they may not be able to search perpendicularly to the wall, which may cause deviation in the search process. Therefore, this paper uses a directed search experiment to determine the search speed and appropriate search depth in different postures.

Experimental process: The experimental environment is shown in Figure 4. The experimenters used a standing or kneeling posture to search between two rows of obstacles 7 meters apart. We simulated different low-visibility states by casting different layers of black gauze on the eyes of the experimenter. Then we placed several items in the venue as the searched objects randomly, and the experimenters reported the number of searched objects it found at the end of the search. Next we use the above method to simulate the search status. Finally, we recorded the location and time of the experimenters each time when they reached the obstacle on both sides. As is shown in Figure 4, when the search spacing is 2 times visibility, the search range of two adjacent inbound search processes is not lacking. When the visibility is less than the firefighter's arm length, the firefighter needs to explore with his hand. At this time, the search range is at least 2 times the arm length.

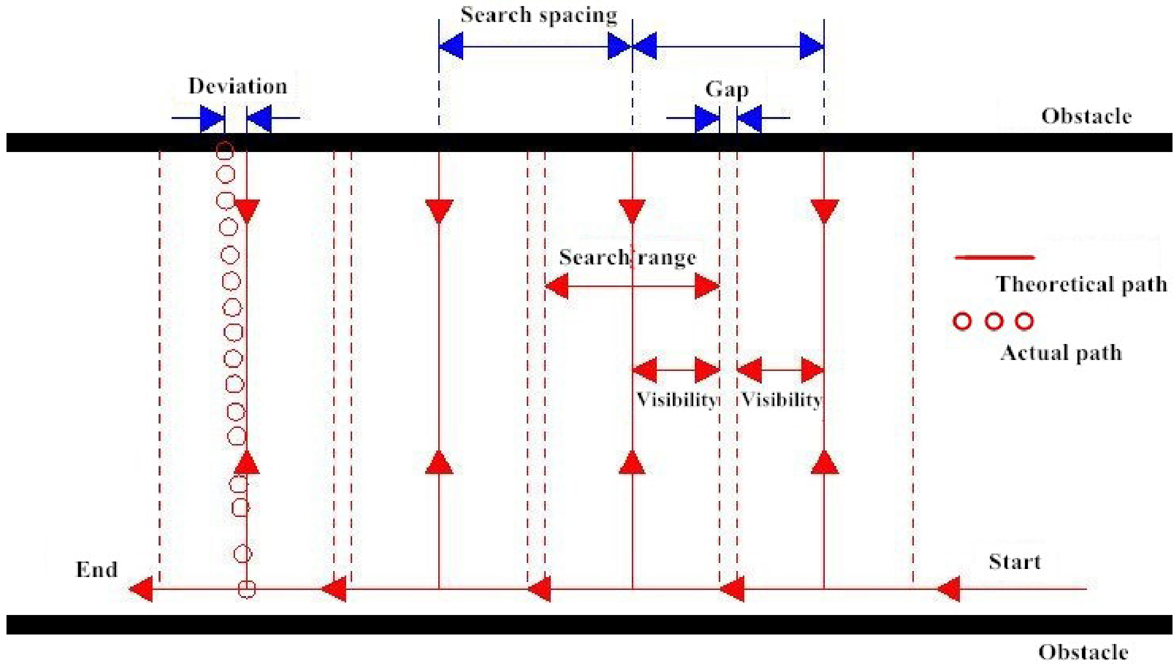

Figure 4. Schematic diagram of experimental environment

Experimental results: Each posture experiment is performed 20 times, and the search speed and deviation of the firefighters in the standing and kneeling postures are as shown in Table 1. We can come to the conclusion that when we are searching, the speed of the kneeling posture is significantly lower than that of the standing posture, but the deviation is little. The existence of deviations causes some areas to be missed during the search process. We consider the randomness of the deviation to the left or right and the size of the trapped individual, so this paper determines that the effective search depth when deviation in a search process does not exceed 0.25m. In other words, when we use the standing posture search, the effective search depth is 5m, and when the search is in the kneeling posture, it is 7m.

Table 1. Search speed and deviation of different posture.

Search posture	The speed of search(m/s)		deviation (m/m)	
	average value	Standard deviation	average value	Standard deviation
standing posture	1.065	0.034	0.031	0.02
kneeling posture	0.505	0.014	0.024	0.012

3. Search Area Division in Directed Search

When there is a fire at the station and it is necessary to search for the wounded, the platform and the station hall must be the main areas to be searched, but these areas are large in size and it needs a long time for one person to search. So we need multiple firefighters to start searching at the same time. Therefore, it is necessary to scientifically divide the search area of each firefighter, and ultimately improve the overall search efficiency.

3.1 The model of calculate the search task time-consuming

We assume that the situation during the rescue process is as follows:

(1) The evacuation of passengers has finished.

(2) All the wounded are in a coma.

(3) Firefighters need a comprehensive search for the target area.

(4) Within the effective search depth, firefighters can search perpendicularly to the boundary of the platform.

(5) Each area has only one firefighter.

When we perform a search task, the most important thing is to shorten the search time. We divide the search task into three processes: The in-place process P from the point of rescue to the starting point of the search, the search process S from the start of the search point to the end of the search point, the evacuation process from the end of the search point to the return to the rescue point. For example, a firefighter walks from the point of rescue l^0 to the end of the search point l^n. There are some turning points $l^1, l^2, \cdots, l^{n-1}$ in the path due to changes in search methods and obstacles in the path. We use $D(a, b)$ to indicate the distance between two points a and b.

$$L_S = \sum_{j=0}^{n-1} D_S(l^j, l^{j+1}) \tag{1}$$

L_S Is the length of the search path. According to the analysis in 1.2, the search speed of the firefighters will be affected by the ambient temperature and visibility. There may be three states: standing search, low posture search, and low posture, so searching speed can be expressed as follow:

$$v_s = \begin{cases} v_{S_0} & R < r \\ v_{S_1} & r \le R < R_0 \cup T > T_0 \\ v_{S_2} & R \ge R_0 \cap T \le T_0 \end{cases} \tag{2}$$

R represents visibility, *T* represents a temperature of 1.5 m high, *r* represents the arm length of the player, R_0 and T_0 are given thresholds. So the search time can be expressed as follow:

$$t_S = \frac{L_S}{v_S} = \sum_i \frac{\sum_{j=0}^{n-1} D_{S_i}(l^j, l^{j+1})}{v_{S_i}} \tag{3}$$

v_{S_i} represents the search speed in the *i*-th case, D_{S_i} represents the route length corresponding to the current speed. There is no search behavior during the in-place process and the evacuation process. They only have changes in body posture. The corresponding speed can be expressed as follow:

$$v_P = \begin{cases} v_{P_0} & R < R_0 \cup T > T_0 \\ v_{P_1} & R \geq R_0 \cap T \leq T_0 \end{cases} \tag{4}$$

$$v_E = \begin{cases} v_{E_0} & R < R_0 \cup T > T_0 \\ v_{E_1} & R \geq R_0 \cap T \leq T_0 \end{cases} \tag{5}$$

Therefore, the task of the *k*-th member can be expressed as time t^k:

$$t^k = \frac{L_P^k}{v_P} + \frac{L_S^k}{v_S} + \frac{L_E^k}{v_E} = \sum_i \frac{\sum_{j=0}^{n-1} D_{P_i}^k(l^j, l^{j+1})}{v_{P_i}} + \sum_i \frac{\sum_{j=0}^{n-1} D_{S_i}^k(l^j, l^{j+1})}{v_{S_i}} + \sum_i \frac{\sum_{j=0}^{n-1} D_{E_i}^k(l^j, l^{j+1})}{v_{E_i}} \tag{6}$$

Restricted by breathing apparatus which the firefighters carried, t^k generally can not exceed 40 minutes.

3.2 The algorithm of time-balanced based on directed search in areal division

Due to the characteristics of directed search, we consider dividing the entire station into several rectangular search areas, when multiple firefighters search for stations at the same time. The search time for the whole platform is equal to the maximum value of all firefighters' tasks time. In order to make this time as small as possible, our goal of dividing the area is to minimize the search time on the platform t:

$$t = \min(\max t^k), k \in K \tag{7}$$

K is a collection of firefighters. In theory, when all firefighters' tasks time are equal, the above formula can get the minimum value. We divide the platform into several areas of equal area by the method of area-balanced. Due to the difference between the in-place process and the evacuation process, the time taken to complete the task may vary considerably. Then, we propose a search area partitioning method that aims to balance the time of each area task. Usually we regard the subway station as a large rectangular space (ignoring internal structure). If there are *k* firefighters searching for it, you need to divide it into *k* smaller rectangular areas. As shown in Fig 5, we regard the upper left corner of the platform as the origin, the length direction as the x-axis, and the width direction as the y-axis. Then, we establish a Cartesian coordinate system. The platform can be divided into two rectangular areas by the line x=a (ignoring internal structure). Finally, you can divide the search area by following the steps below:

Step 1: Determine the number of partitions k according to the number of firefighters, and make a=0 in the straight line $x=a$;

Step 2: Add a search range U in a according to the visibility R, and then simulate the single search time in the two areas $x<a$ and $x>a$ in the station, which are respectively recorded as $t_{x<a}$ and $t_{x>a}$;

Step 3: Calculate $\Delta t_{x=a} = \|\max(t_{x<a}, t_{x>a}) - (k-1) \times \min(t_{x<a}, t_{x>a})\|$;

Step 4: Repeat steps 2 and 3 throughout the entire platform;

Step 5: Compare all Δt, when $\Delta t_{x=a}$ is the smallest, record $a = a_0$, $t_{1x} = \min(t_{x<a_0}, t_{x>a_0})$;

Step 6: Make a straight line $y=b$ in the y-axis direction, similarly obtain $t_{1y} = \min(t_{y<b_0}, t_{y>b_0})$, and then compare t_{1x} and t_{1y}, the smaller corresponding line is the first boundary of the search area, the corresponding search area is the first search area divided;

Step 7: Make k=k-1, then we repeat the above six steps for the remaining undivided rectangular areas, and finally we get the required k search partitions after k-1 divisions.

Step 8: If the time of each partition task is different, we adjust the partition boundary according to U to balance the time of each area task.

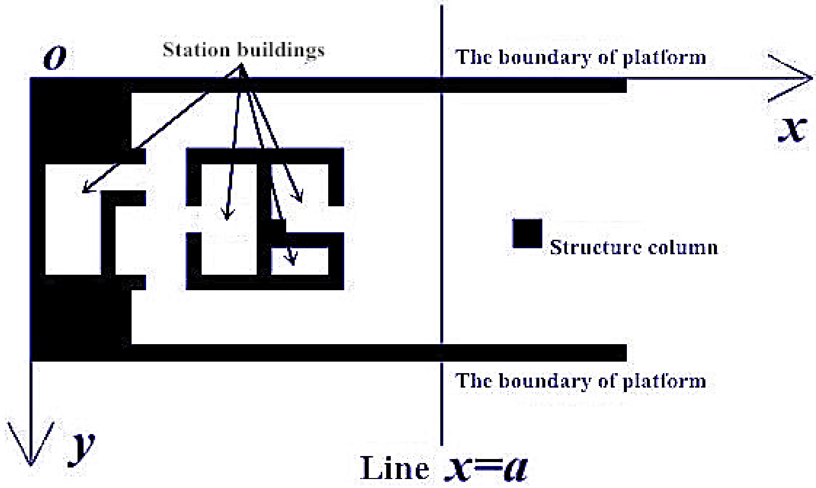

Figure 5. Coordinate system of the platform

4. Case Study

4.1 Scene setting

We get an island-type subway platform in Beijing which is 118m long and 11m wide as an example. The platform has station buildings at both ends and a toilet at one side. There is an elevator in the middle of the platform, and there is a group of escalator and stair on each side. We set 4 scenes according to the fire source and the visibility of the platform, as shown in Table 2, the firefighters enter the platform from the stair on the right side of the platform. The relevant parameter settings are shown in Table 3. It is assumed that the search time of the toilet on the left side of the platform is 15s. The temperature change on the platform is obtained by FDS simulation.

Table 2. Scene Setting

No.	Fire Source	Station visibility R(m)
1	Stair on the left side of the platform	1.5
2	Stair on the left side of the platform	2
3	Stair on the left side of the platform	2.5
4	In the middle of the platform	2

Table 3. Correlation parameter value

Parameter	Value	Parameter	Value
Time to arrive at the scene after receiving the police (min)	10	v_{S_0}(m/s)	0.5v_{S_1}
Rate of heat release from the fire source (MW)	10	v_{S_1}(m/s)	0.5
Fire source area (m^2)	1	v_{S_2}(m/s)	1
Search depth (m)	3.5	v_{P_0}(m/s)	1.1v_{S_1}
T_0(°C)	65	v_{P_1}(m/s)	1.1v_{S_2}
R_0(m)	1.6	v_{E_0}(m/s)	1.2v_{S_1}
r(m)	0.6	v_{E_1}(m/s)	1.2v_{S_2}

4.2 Result analysis

We use the area-balanced method and time-balanced method to divide search area in scenes 1, 2, and 3. The searching time on the platform for different partition numbers is shown in Fig 6. It can be seen from the figure that as the number of partitions increases, the searching time on the platform obtained by the two methods gradually decreases, and the results obtained by the time-balanced method are better. We can see that the slope of each curve gradually decreases, and the overall trend is flat after five divisions. When R=2.5m and the number of partitions is 6 or more, the searching time on the platform obtained by this method is 338s. Through the simulation process, we find that the firefighter only searched the toilet at the end of the platform, so it is difficult to reduce the task time further. Of course, the size of this value is still related to the size of the platform and the location where the firefighters entering the platform. But this still shows that the result obtained by this method has a minimum value, and increasing the number of partitions cannot infinitely shorten the searching time on the platform.

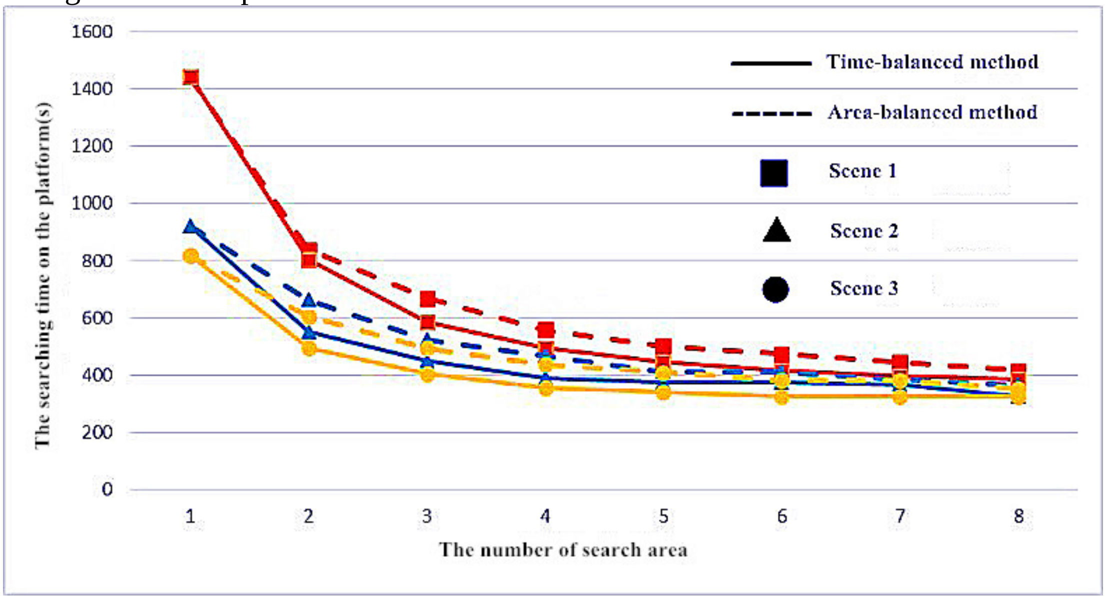

Figure 6. Results of two methods under different number of search area (scene 1, 2, 3)

From Fig. 6, we can see that when R=1.5m, the searching time on the platform obtained by the two methods is significantly higher than that of R=2m and R=2.5m, and it is more obvious when the number of partitions is small. On one hand, this is due to the low visibility and shorter search interval, so the search distance is longer. On the other hand, the environment also has a certain impact on the search process. When R=1.5m, the firefighters should always search in a low posture, and the speed drops significantly. Fig. 7 can explain this point further. Compared with scene 2, the fire source position of scene 4 is in the middle of the platform, and during the search, the temperature of the entire platform at the height of 1.5m is higher than 65°C. Although the visibility of the two scenes is the same and the search route is similar, the firefighters in scene 4 always take a low posture to search, and the increase in the task time is mainly caused by the difference of the search speed, which is mainly determined by the environment of the search space.

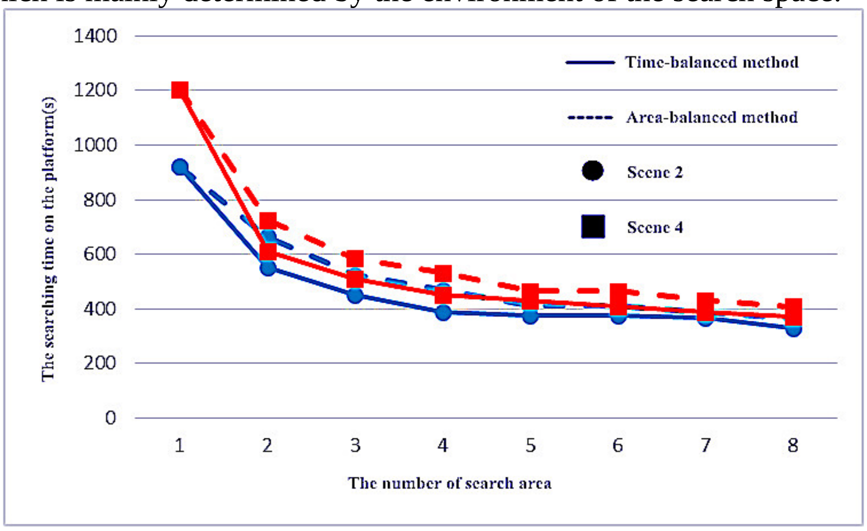

Figure 7. Results of scene 2 and scene 4

Firefighters usually enter the fire field with a group of 4-5 people. In scene 2, we use the time-balanced method and the area-balanced method to divide the platform into 4 search areas. The result is shown in Fig 8. And we obtain the tasks time of the four search areas (From left to right: Area 1, Area 2, Area 3, Area 4) by the two methods provided in Table 4, the maximum task time obtained by the time-balanced method was reduced by 78 seconds, Compared with the task time obtained by the area-balanced method. We conclude from the simulation process that the temperature in the left side of the elevator needs to be searched in a low posture due to the temperature exceeding 65 °C, and the speed of firefighters is reduced. That's why when we use the area-balanced method, the task time of area 1 is significantly higher than that of area 3 and area 4. While when we use the time-balanced method, the task time of each search area is more balanced, and the overall search efficiency is also improved.

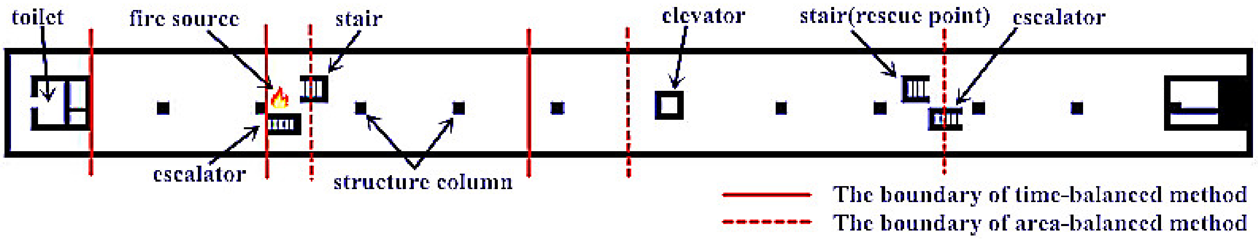

Figure 8. Search area division results

Table 4. Task time of each search area

Method of areal division	Search time for area 1	Search time for area 2	Search time for area 3	Search time for area 4
The method of time-balanced	338	357	368	385
The method of area-balanced:	476	412	175	142

If we use the method of layout to search and form a row on a width of 10m, the distance between firefighters is affected by visibility. For example, if the visibility is 2.5m, 4 firefighters are required. Compare the results of the layout method with the results of the method of time-balanced, as shown in Table 5. We have come to the conclusion that the search route of the layout method is basically fixed, and the time is mainly affected by the environment. In the scenes 1 and 4, the firefighters always search in a low posture, so the speed is slow and the time is longer. At the same time, people need to walk back and forth on the platform. Therefore, the overall efficiency of the layout method is still not superior. The main advantage of the layout method is that the search process is relatively simple and the firefighters can better interact with each other.

Table 5. Results of the method of layout and the method of time-balanced

Task of time	Scene 1	Scene 2	Scene 3	Scene 4
Number of people	7	5	4	5
The method of layout(s)	468	362	362	468
The method of time-balanced	398	364	356	428

5. Conclusion

This paper first analyzes the more commonly used directed search methods in the case of post-disaster low visibility. Second, it analyzes the search speed and effective search depth of firefighters in different search positions through directed search experiments. Third, it proposes an algorithm of time-balanced based on directed search in areal division. Last, it validates the method through a subway station platform in Beijing. The case results show that the method can get the search areas faster, and the tasks of times in each search area are relatively close. Compared with the results obtained by the area-balanced method, the search time of the whole station obtained by the time-balanced method is significantly shortened. Compared with the method of layout, the time-balanced method still has a higher search efficiency when the number of firefighters are the same. The result shows that the time-balanced method can improve the search efficiency and help the firefighters to quickly find out the basic situation inside the disaster scene, especially in the early stage of the disaster and when we don't have many firefighters on the disaster site, the time-balanced method proposes in this paper is more efficient for the use of personnel, so it has important significance in the process of search and rescue after disasters.

Acknowledgments

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References

[1] Kitano H, Tadokoro S, Noda I, et al. RoboCup Rescue: search and rescue in large-scale disasters as a domain for autonomous agents research [C] IEEE International Conference on Systems, Man, and Cybernetics, 1999. IEEE Smc '99 Conference Proceedings. IEEE, 1999: 739 - 743 vol.6.

[2] Kitano H, Tadokoro S. RoboCup Rescue: A Grand Challenge for Multiagent and Intelligent Systems [J]. 2001, 22 (1): 39 - 52.

[3] Nair R, Tambe M, Marsella S. Team Formation for Reformation in Multiagent Domains like RoboCupRescue [J]. Lecture Notes in Computer Science, 2002, 2752: 150 - 161.

[4] Maitreyi N, Alexander E, Sean A, et al. Decision and coordination strategies for RoboCup rescue agents [C]. SIMPAR, 2010:473 - 484.

[5] Fabio M, Riccardo R, Alessandro F, et al. RMASBench: a benchmarking system for multi-agent coordination in urban search and rescue [C]. Int'l Conference on Autonomous Agents and Multi-Agent Systems, 2013: 1383 - 1385.

[6] Motonari Isobe, Dirk Helbing, Takashi Nagatani. Experiment, Theory, and Simulation of the Evacuation of a Room without Visibility. Physical Review, 2004: 1 - 10.

[7] Peng Lin, Jian Ma, Tianyang Liu, Tong Ran, Youliang Si, Tao Li. An Experimental Study of the "Faster Is Slower" Effect Using Mice under Panic. Physica A, 452 (2016): 157 - 166.

[8] Helbing D., et al. Lattice gas simulation of experimentally studied evacuation dynamics. Physica Review E, 2003, 67 (6).

[9] A. Varas, M.D. Cornejo, D. Mainemer, et al. Cellular automaton model for evacuation process with obstacles [J]. Physica A, 2007, 382: 631 - 642.

[10] Sungryong Bae, Hong Sun Ryou. Development of a smoke effect model for representing the psychological pressure from the smoke. Safety Science, 2015 (77), 57 - 65.