Research on emergency evacuation under gas leakage based on social force model

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Abstract: Gas, as a clean and efficient energy source, plays an important role in the quality of life and economic development of urban residents, however, its use also has high risks, and it is easy to leakage to cause fire and explosion and other accidents. The population density of cities and towns is relatively high, and in recent years, gas pipeline leakage accidents have occurred frequently, and the impact of the accident is significant. A number of accidents show that people's emergency evacuation effect is not good, the evacuation ability is insufficient, therefore, in order to reduce the impact of gas leakage accidents, to protect the safety of human life and property, to improve the public's emergency evacuation ability is particularly important. In order to explore the factors affecting the emergency evacuation ability of the crowd, the accident scenario construction method and model are studied, the crowd evacuation scenario when the accident occurs is constructed, the evacuation process of people in the accident is systematically modeled and simulated based on the social force model, and the detailed process of emergency evacuation of gas leakage accidents in the public buildings in cities and towns is studied to find out the factors affecting the effect of the crowd evacuation, to make it clearer that the evacuation is important to the emergency management, and to put forward a reasonable proposal for emergency evacuation. The importance of evacuation for emergency management is clarified, and reasonable countermeasures are proposed. The study shows that by selecting typical accident cases and applying the accident scenario construction model and emergency evacuation simulation model proposed in this paper, it is concluded that the individual evacuation efficiency is better than the group evacuation efficiency, the faster the human reaction time is, the better the evacuation effect is, and the faster the warning is issued, the better the evacuation effect is, so as to provide a certain degree of technical support for the prevention of accidents and emergency evacuation, as well as to put forward reasonable countermeasures.

Keywords: Gas Leakage, Emergency Evacuation, Social Force Model, System Modeling and Simulation

1. INTRODUCTION

In recent years, urban gas leakage accidents have occurred frequently, easily causing secondary accidents such as fires and explosions. Once a gas accident occurs, serious accident consequences are likely to occur: casualties, property losses, etc[1-2]. Therefore, gas leakage accident prevention and accident response are particularly important. In view of the current reality of frequent gas accidents in high-density urban areas, improving people's emergency evacuation capabilities is the key to improving emergency response levels[3]. The Conference Proceedings will be in electronic format. The use of color versions are encouraged in all pictures and graphics. The Conference Organizer will not be responsible for shifting of tables and graphics in the final publication.

Since it is difficult to carry out experimental research on the actual evacuation process, the accident evacuation process can be simulated and analyzed through the construction of accident scenarios.

"Scenario construction" refers to the integration of similar events, based on historical cases, and a panoramic description of the inducing conditions, damage degree, loss and scope of impact of the emergency[4]. Regarding the construction of gas leakage accident scenarios, relevant researchers focused on the construction of disaster scenarios for important urban infrastructure, including the gas pipeline network system, and analyzed the characteristics, routes and scenario consequences of disaster scenario construction for important urban infrastructure[5]; Scholars from the China Academy of Safety Science and Technology divide the construction of emergency scenarios into three main stages: (1) data collection and decomposition; (2) event-centered evaluation and convergence; (3) integration and description of emergency scenarios[6]; the main process of dynamic scenario construction for fire and explosion accidents in energy facilities is to form dynamic scenarios, emergency response actions and assessment of unforeseen events based on various types of information generated by disasters that are constantly changing[7]; information-driven theory (IDT) can also be applied to strengthen and improve the information collection ability of accident scenario construction, and improve the prediction ability of scene dynamic update, so as to better play the role of scenario construction in accident emergency response[8]. In short, after a survey of academic literature, it was found that relevant scholars currently do more research on the construction of integrated accident scenarios that combine multiple disasters, but less on scenario analysis of gas leakage accidents. Research on emergency evacuation of gas leakage accidents includes: particle swarm optimization algorithm[9] to evaluate the process of evacuation; evacuation simulation study of toxic gas leakage in chemical park considering the psychological factors of crowd panic[10]; the WRF-OpenFOAM coupling leakage diffusion method was designed, and the improved ant colony algorithm was applied to predict the evacuation path of personnel[11]; a coupled evacuation model based on multi-speed cellular automata was proposed to quantitatively evaluate the impact of leakage on the evacuation process[12]; the social relationship between pedestrians was studied to reveal the impact on evacuation after a gas leak[13]; combined with computational fluid dynamics (CFD) and Dijkstra algorithm, an evacuation route optimization method under real-time gas diffusion is formed[14]; based on the multi-agent model, the evacuation process is divided into pre-evacuation process and evacuation motion process, which are modeled and optimized separately[15]. To sum up, many scholars mainly use algorithm design and application, computer simulation, etc. to study different elements such as the process and path optimization of gas leakage accident evacuation, and transform the elements of the leakage accident evacuation process into mathematical models to obtain meaningful numerical results. Therefore, this article attempts to establish an accident scenario construction model for gas accidents and an overall process model for accident emergency evacuation to provide reference for accident emergency response and related research.

The theoretical basis of accident evacuation research is pedestrian flow theory, which is divided into macroscopic, mesoscopic and microscopic models[16]. The macroscopic model mainly describes the macroscopic characteristics of pedestrian movement through mathematical models, and the mesoscopic model expresses the relationship between pedestrian density and speed through a dynamic model. However, the above two levels of models do not reflect the differences between individual pedestrians. Therefore, pedestrian flow microscopic models emerged as the times require, and are mainly divided into two categories based on driving forces and rules. The former includes social force models, centrifugal force models, etc., and the latter includes cellular automata[17], etc.

For the construction of accident evacuation simulation models, a relatively mature microscopic theory is the social force model, which describes the impact of the crowd's own factors and environmental factors on the evacuation process. At present, many scholars have applied social force models to the evacuation research of different places such as, high-rise buildings[18], subway stations[19]. The evacuation process based on the social force model can be realized using the Any Logic simulation tool. The Any Logic simulation tool is powerful and has a wide range of applications. It can realize discrete, continuous and hybrid system modeling. Any Logic can be used to realize computer simulation of crowd evacuation behavior at a gas leakage accident site. By designing accident scenarios, the crowd evacuation process can be simulated.

Therefore, this article intends to use the Any logic system modeling and simulation tool to establish a gas leakage accident evacuation scenario based on the social force model, and derive a method for establishing the accident evacuation simulation process.

The innovations of this article are as follows:

(1) This article proposes a gas leakage accident emergency model of scenario construction + emergency evacuation. By constructing a scenario model, the exploration of emergency evacuation elements is realized, and then some targeted opinions on emergency tasks in actual accident situations are put forward through the presentation and application of theories and models.

(2) This article basically reproduces the entire process of crowd evacuation under gas accidents and secondary accidents. Under the conditions where it is almost impossible to complete the experiment, the pedestrian library modeling of system simulation was selected, the role of key variables was set and realized, and new ideas for evacuation research were provided.

(3) This article focuses on analyzing the impact of early warning and the presence or absence of groups on evacuation results, and clarifies the importance of early warning and individual evacuation. It is pointed out that accident early warning should seize important time windows and meeting the flexibility of time is the direction of future efforts. Evacuation should maintain individual evacuation as much as possible to avoid herd mentality. Therefore, emergency drills and education should be carried out to create a good and scientific social atmosphere.

2. Emergency evacuation model based on accident scenarios

2.1. Accident scenario construction

To construct major accident scenarios, it can provide certain background support for accident prevention and emergency response. Since similar accidents often have similar occurrences, development processes and patterns, the nature of events and risks they have are relatively similar, coupled with the condensation and analysis of a large number of accident cases that have occurred in the past, it is more conducive to reflecting the commonality of accident occurrence and development. The essential laws provide important basis for the construction of emergency management system and the preparation of emergency plans.

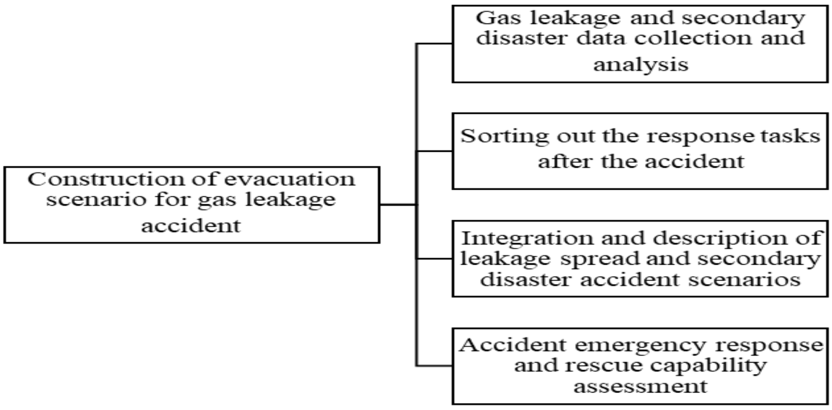

Figure 1. Gas leakage accident evacuation scenario elements

In order to clearly show the accident scenario focusing on emergency evacuation when a gas leakage accident occurs, an emergency evacuation scenario model for gas leakage accidents was established based on the emergency scenario construction of the China Academy of Safety Science and Technology, as shown in Figure 1. Combined with the frequent occurrence of gas accidents, firstly, typical accident data were studied and analyzed to obtain common characteristics of accidents; Since this study is based on the discussion of emergency evacuation after clearing risks, the second item in the original construction method, "event-centered evaluation and convergence", was changed to "response task sorting", this step mainly focuses on crowd evacuation. The response task is to evacuate from the accident injury area to a safe area as quickly as possible. In this process, we must try our best to ensure personal safety, ensure evacuation efficiency, and minimize the harm to people caused by the accident; On the basis of the first two items, the accident scenarios are integrated, common problems and common accident types are found, and described; finally, common emergency response capability loopholes are evaluated, and emergency evacuation countermeasures are proposed accordingly.

The specific content of evacuation scenario construction for gas leakage accidents should include:

(1) Collection and analysis of urban gas leakage and secondary disaster data: The background of the accident mainly includes time, location, related buildings and departments involved, etc. Analysis of design, installation, maintenance and monitoring requirements for urban gas systems, as well as guidance on emergency response and disaster management;

(2) Summary of response tasks after the accident: Determine the response tasks after the accident, including emergency notification, alarm, evacuation, aftermath, and post-accident reconstruction. Formulate the responsibilities and action plans of relevant departments and personnel to ensure that various tasks can be carried out in an orderly manner;

(3) Integration and description of leakage spread and secondary disaster accident scenarios: According to the characteristics of urban gas leakage, a scenario description of leakage spread and secondary disaster accidents is constructed. Taking into account factors such as different leakage sources, leakage rates, and environmental conditions, describe the process and scope of influence of leakage diffusion;

(4) Accident emergency response and rescue capability assessment: Evaluate the emergency capabilities of urban gas systems, including the reliability and effectiveness of equipment and measures such as leak detection, alarms, and emergency shutoffs. Assess the capabilities of emergency rescue agencies and personnel, including training, equipment and organizational capabilities to respond to gas leaks and secondary disasters.

2.2. Pedestrian evacuation theory based on social force model

The pedestrian evacuation model is constructed based on the Social Force Model (SFM). The classic social force model was proposed by Helbin et al.[20]. This model means that during the purposeful walking process, pedestrians will be affected by the driving force of the pedestrians themselves (the destination of the pedestrians walking), the repulsion or attraction between pedestrians (between pedestrians The comprehensive impact of the mutual influence) and the repulsive force between pedestrians and obstacles (pedestrians will inevitably encounter obstacles during walking, which will affect their walking speed, direction, etc.), which well reflects the impact of pedestrians on walking. Changes during the process, because of this, SFM is widely used to simulate and analyze pedestrian movement characteristics.

The equation of SFM is as follows[21]:

$$m_\alpha = \frac{d\overrightarrow{w_\alpha}}{dt} = \overrightarrow{F_{\alpha(t)}} + \xi \tag{1}$$

$$\overrightarrow{F_{\alpha(t)}} = \vec{F}_\alpha^0(\overrightarrow{v_\alpha}, v_x^0\overrightarrow{e_\alpha}) + \sum_\beta \overrightarrow{F_{\alpha\beta}}(\overrightarrow{e_\alpha}, \overrightarrow{r_\alpha} - \overrightarrow{r_\beta}) + \sum_B \overrightarrow{F_{\alpha B}}(\overrightarrow{e_\alpha}, \overrightarrow{r_\alpha} - \overrightarrow{r_B}) + \sum_i \overrightarrow{F_{\alpha\iota}}(\overrightarrow{e_\alpha}, \overrightarrow{r_\alpha} - \overrightarrow{r_\iota}, t) \tag{2}$$

In equation (1), m_α is the particle mass of the SFM object, $\overrightarrow{w_\alpha}$ is the desired speed, and $\overrightarrow{F_{\alpha(t)}}$ is the comprehensive force, that is, the "social force". The terms on the right-hand side of equation (2) contain the driving, repulsive, and attractive forces required for particle action. ξ represents the fluctuation term, which represents random changes in behavior.

The power of desire determines the power that drives people to reach their destination, that is, the driving force of pedestrian movement, represented by $\vec{F}_\alpha^0$; In the same way, the repulsive force includes the repulsive force between pedestrians and between pedestrians and obstacles, as well as the attractive force between pedestrians, which are represented by $\overrightarrow{F_{\alpha\beta}}$, $\overrightarrow{F_{\alpha B}}$ and $\overrightarrow{F_{\alpha\iota}}$ respectively.

Research on crowd evacuation in different environments such as airports, shopping malls and subway stations has a series of research results using and improving SFM. In order to solve the problem of insufficient consideration of factors in the traditional social force model, an improved social force model was proposed. The improved model takes into account the panic of pedestrians during the evacuation process, the attraction intensity of external factors[22], emotional factors of the crowd[23], etc. It can better simulate the real pedestrian flow trajectory. It can be seen that the social force model can be well transferred to the evacuation of crowds in gas accidents in public buildings.

2.3. Emergency evacuation model

A system of factors influencing crowd evacuation effects was established based on gas leakage accidents. From a systemic perspective, focusing on the factors of the main evacuation buildings and the crowd themselves, a system of influencing factors for crowd evacuation shown in Figure 2 was constructed.

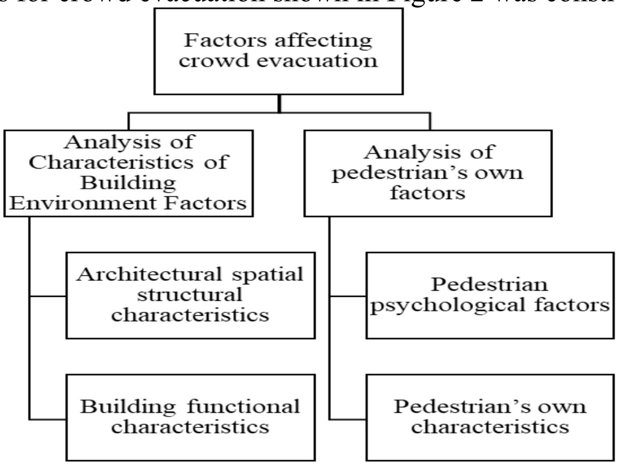

Figure 2. Influencing factors of crowd evacuation

Based on this, the selection and setting of parametric variables in the subsequent accident simulation process, the construction of the accident building model, and the change range of human evacuation speed are determined, so as to establish an evacuation model that is closer to reality and has practical significance. Based on the fire and explosion accident caused by gas leakage, the modeling process of using Any Logic pedestrian library is as follows:

(1) Insert the background image of the building involved in the accident into the main of Any logic to form a basic outline;
(2) Create the physical environmental conditions required in accident-involved buildings;
(3) Apply the pedestrian library to create a crowd evacuation logic chain;
(4) Change parameters to obtain comparison results;
(5) Quantitative analysis of evacuation result data.

3. Gas leakage accident emergency evacuation case

The aforementioned accident scenario construction model and pedestrian evacuation modeling process were applied to the "6·13" major explosion accident case in Shiyan City, Hubei Province, China. Focusing on the group setting, human reaction time, overall time consumption and path selection during the evacuation process, accident simulation and emergency evacuation improvement and optimization are carried out, thereby providing certain reference for emergency evacuation work in gas leakage accidents.

3.1. A brief analysis of the "6·13" major explosion accident in Shiyan

A brief analysis of the cause of the accident is shown in Figure 3:

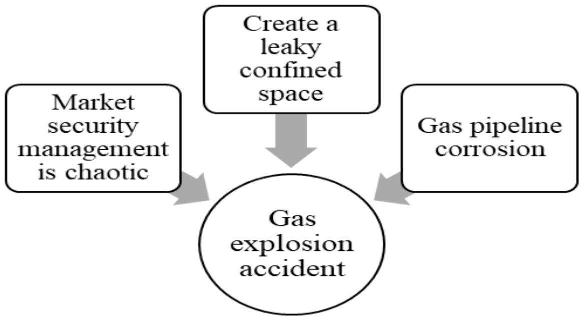

Figure 3. Schematic diagram of accident cause analysis

The gas pipeline leakage accident can be roughly divided into five stages as shown in Figure 4:

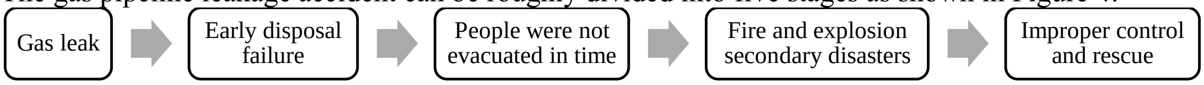

Figure 4. Gas Leakage Accident Phase 5

3.2. Pedestrian evacuation process model construction

In this accident, pedestrian flow was mainly divided into two stages. The first stage is when pedestrians walking normally before the accident enter the store where the accident occurred and conduct various activities. The second stage is to initiate evacuation immediately after the accident occurs, with the purpose of escaping from the building. Therefore, the pedestrian evacuation process is established according to this setting. It should be noted that the number of pedestrians is determined with reference to the local population density, the time of the accident, the accident investigation report, and the functional division of the building involved in the accident to form a reasonable number of people. The setting is designed to explore the positive or negative impact of factors such as evacuation path selection, reaction time, and presence of groups on evacuation, and is not limited to the actual situation of the accident.

The building involved in the accident is a two-story building, and the stairs on the first floor are wider. Therefore, when constructing the evacuation model, taking into account the specific circumstances of the accident and the practical significance of the research, only the stairs in the middle and on both sides of the building were set up. In the "Code for Fire Protection Design of Buildings", when determining the design value of the density of people in stores and business hall buildings, the quantitative relationship between the calculated area of evacuated people and the actual area of the building is generally (0.5-0.7):1[24]. The actual total area of the two floors of the building involved in the accident in the simulation scenario is approximately 2,000 square meters. Based on the selected case location and the actual situation, the corresponding coefficient is 0.5. According to the formula：

$$\boldsymbol{A = \alpha \cdot K} \tag{3}$$

Among them, A is the effective building area for calculation, α is the actual building area, and K is the calculation coefficient. The effective building is 1000m^2. The minimum personnel density ranges from 0.30 to 0.60 people/m^2. It can be roughly obtained that there are 600 people of various types in the building involved in the accident. Let them be evenly distributed on the first and second floors of the building involved in the accident, that is, the number of evacuees on each floor is 300, and carry out evacuation simulation based on this number.

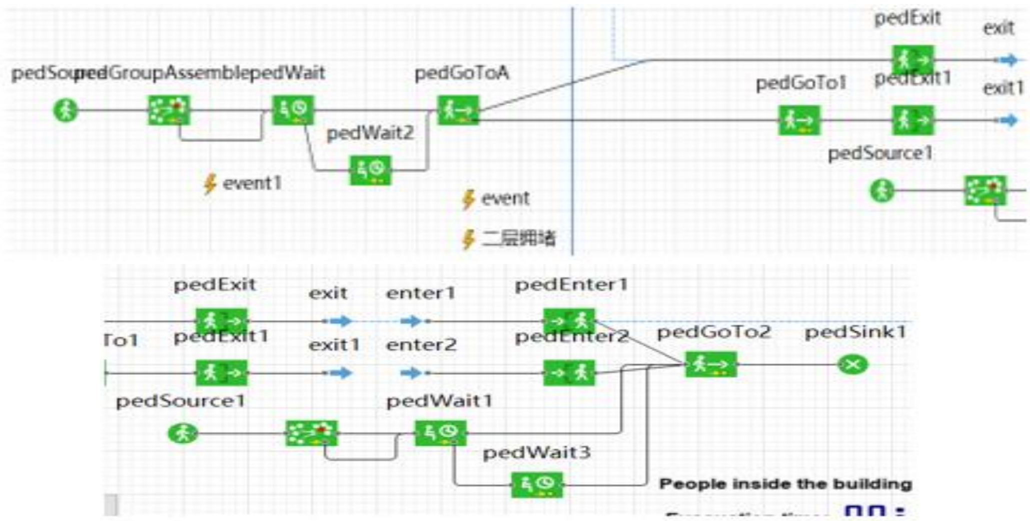

Figure 5. Logic diagram of evacuation model

As shown in Figure 5, it is the established pedestrian evacuation logic diagram. “pedSource” is the starting evacuation personnel on the second floor. The main function of this control is to generate a certain number of pedestrians. Pedestrians enter the second floor of the predetermined building and start random activities. Through the attraction of the attractor, the crowd arrives at the predetermined location before the accident and waits for the accident time to arrive; “pedGroupAssemble” is a control that divides groups. Through the setting of this control, evacuated pedestrians can be divided into individual evacuation or group evacuation composed of several individuals.

"PedWait" and "pedWait2" set the free movement time for pedestrians after entering the building and the reaction time for people to realize that evacuation is about to begin. Among them, "pedWait" is to show the free activities of pedestrians after entering the commercial building, such as finding goals, completing goals, and finding seats; "pedWait2" is the reaction time of pedestrians from the moment the accident or evacuation warning order is issued. This value is an important adjustable parameter that can reflect pedestrian evacuation capabilities, which in turn reflects the degree of acceptance of safety emergency education and emergency evacuation drills, as well as pedestrian safety knowledge and abilities. According to relevant research, after a fire accident, only about 30% of people will immediately make judgments and responses about emergency evacuation, and the remaining 70% will not respond immediately, with a delay of 48 seconds to 178 seconds[25], It is not only related to the person’s training factors, but also related to age, disease and other factors, which is relatively complicated. Based on the case used in this article, the accident occurred in a comprehensive building in a market. There were many elderly people and children, and the reaction time of the crowd was relatively long. Referring to the approximately normal distribution, a small proportion of people react very quickly before evacuation. Therefore, in this simulation, three groups with uniformly distributed human reaction times are set as 48 seconds to 60 seconds, 60 seconds to 120 seconds, and 120 seconds to 178 seconds, and the time variables of these three groups are studied and discussed respectively. “pedGoToA” is the process of the crowd looking for the exit, and the search for the exit is based on the principle of proximity, and the person consciously chooses the nearest exit to himself, and the corresponding function statement needs to be inserted here.

The function of the “pedGoTo1” control is to set the source point of the accident-related building accident to become an area that blocks the passage of evacuated people after a period of time after the accident, that is, the congestion area.

Pedestrians will make corresponding choices to change the path, and complete the choice of the shortest path that is different from the previous shortest path through the insertion of the function selection . If it still fails, repeat the previous logic until it passes.

"PedExit" and "pedExit1" respectively describe how normal uncongested evacuating pedestrians and congested pedestrians complete the evacuation of the second floor and enter the first floor through the stairs. "exit" and "exit1", "enter1" and "enter2" specifically describe the process of entering the first floor from the second floor. At this time, the evacuation of the second floor has basically been completed. “pedEnter1” and “pedEnter2” describe the process of pedestrians on the second floor entering the first floor, that is, exiting the merchants on the second floor, passing through the corridor, finding the nearest stair exit, and going to the first floor through the stairs. Pedestrians on the second floor gathered on the first floor, and then completed the evacuation process from the first floor to the outside of the building involved in the accident. The pedestrian evacuation process on the first floor is similar to the above, except that there is no process of going downstairs, so the details will not be repeated.

3.3. Emergency evacuation simulation

Table 1. Simulation group division

No	Evacuation group	Reaction time
1	Individual	48s-60s
2	Individual	60s-120s
3	Individual	120s-178s
4	Group of 2-5 people	48s-60s
5	Group of 2-5 people	60s-120s
6	Group of 2-5 people	120s-178s

At the beginning of the experiment, the number of people to be evacuated in the building was 600, and the evacuation time was 00:00 seconds; Pedestrians to be evacuated have appeared from outside the building, entered the building, and began to find their respective locations through the attractor;

At this time, the set evacuation time has arrived and pedestrians have begun to evacuate. As shown in Figure 6, the evacuation time has reached 1 minute and 54 seconds, and 465 people remain inside the building;

Figure 6. Crowd evacuation schematic diagram

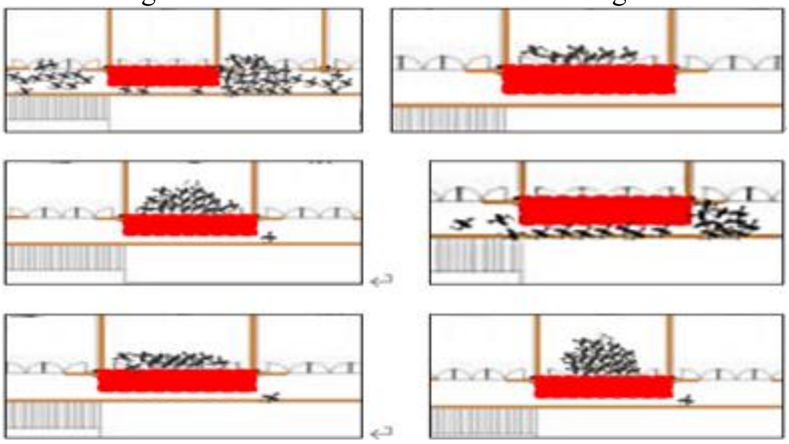

Figure 7. Crowd congestion diagram

Figure 7 shows the pedestrian congestion situation in the accident center in six simulations (from left to right, from top to bottom, 1-6 in order).

In the first experiment, when the emergency evacuation process lasted 90 seconds, congestion occurred in the accident center, which affected pedestrian evacuation efficiency;

In the second experiment, the relevant personnel failed to respond in time before the door was blocked and were unable to escape. As a result, they were unable to escape from the room at the center of the incident, and the remaining 7 people failed to evacuate successfully;

In the third experiment, the remaining 19 people failed to evacuate;

In the fourth experiment, a slight congestion occurred in the accident center, and all 600 people in the building were successfully evacuated;

In the fifth experiment, a total of 13 remaining people failed to evacuate;

In the sixth experiment, a total of 23 people remained and failed to evacuate.

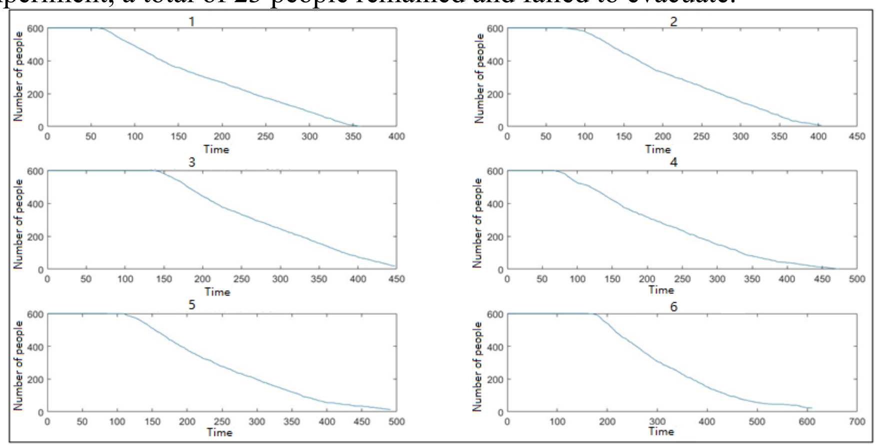

Figure 8. The trend line chart of the number of people to be evacuated

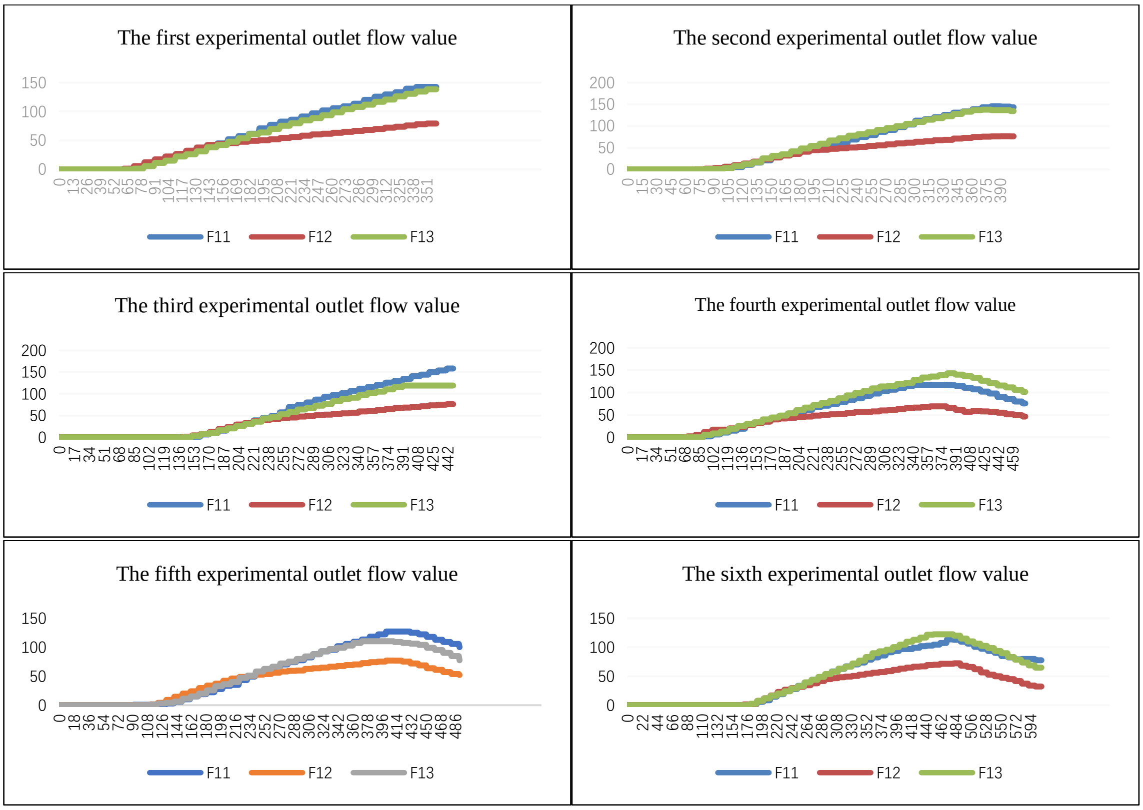

Figure 9. Evacuation of each outlet flow value change trend line chart

The remaining number of people to be evacuated from the six simulation experiments and the changing trend of the flow of people at the three exits on the first floor are shown in Figures 8 and 9 respectively. The horizontal coordinate of Figure 9 is the cumulative value of the number of evacuees and the vertical coordinate is the time. F11, F12, and F13 represent the three stairway entrances in the building.

(1) The first run: All 600 pedestrians completed emergency evacuation from dangerous buildings, which took a total of 6 minutes and 0 seconds.
(2) The second run: A total of 593 people were evacuated, which took a total of 6 minutes and 44 seconds. The completion time of this evacuation was delayed by 44 seconds compared with the first experiment.
(3) The third run: A total of 581 people were evacuated. Compared with the previous two experiments, this evacuation took longer to complete.
(4) The fourth run: All 600 people were successfully evacuated, which took a total of 7 minutes and 54 seconds.
(5) The fifth run: A total of 587 people were evacuated, which took a total of 8 minutes and 11 seconds.
(6) The sixth run: People have almost no emergency evacuation drills and safety emergency education, so reaction times are generally evenly distributed between 120 seconds and 178 seconds; Other parameters are set according to the above baseline and are the same as those related to previous runs. It took 10 minutes and 10 seconds to complete the evacuation of 577 people.

3.4. Emergency evacuation scenario data analysis

The relevant data obtained from the operation of the above emergency evacuation scenario model are summarized and displayed as follows:

Table 2. Simulation data summary

No	Evacuation time/s	Number of people evacuated	Exit traffic peak F11,F12,F13
1	360	600	142.4, 79.2, 138.4
2	404	593	145.6, 76.2, 137.6
3	448	581	158.4, 76.2, 119.2
4	474	600	117.6, 69.3, 143.2
5	491	587	127.2, 77.1, 110.4
6	610	577	113.6, 72.3, 122.4

Among them, the time to complete the evacuation in the first three and last three times increased in sequence, and the number of people who successfully evacuated decreased in sequence. The increase in evacuation time from the fifth experiment to the sixth experiment was particularly obvious. In addition, the first three groups of experiments were compared with the last three groups of experiments one by one, which is equivalent to changing only the variable of presence or absence of groups. However, compared with the former, the evacuation time of the latter was significantly longer than that of the former by more than one minute or even longer, indicating that Individual evacuation is theoretically more efficient; The first and fourth groups successfully evacuated the most people, evacuating everyone in the entire building. In other words, when a gas accident occurs, the faster people respond, the more conducive to successful evacuation, and also the success of emergency self-rescue.

Regarding the outlet peak flow, F11 is generally higher than F13, and both F11 and F13 are generally higher than F12. The former is mainly caused by the congestion at the center of the accident; the latter shows that during the evacuation process, a considerable number of people will ignore the objective fact that there are many exits and choose to run to exits with more pedestrians, reflecting the universality of herd mentality.

4. CONCLUSION

(1) The presence or absence of groups has a great impact on evacuation efficiency, evacuation speed, and evacuation completion during the evacuation process of buildings after a gas leakage accident. Individual evacuation shows better evacuation results. For the same number of people, individual evacuation takes less time and the evacuation speed is faster, which is more conducive to the smooth development of accident emergency rescue and reduces the accident casualty rate. Therefore, the public should not behave excessively in an emergency, but should analyze rationally and evacuate in an orderly manner in accordance with site prompts and on-site commands.

(2) The setting of early warning is completed by using the time interval of the event. The earlier the warning, the shorter the time interval between the occurrence of the accident and the start of crowd evacuation, and the higher the success rate of emergency evacuation. However, no early warning was issued during the accident examples selected in this article. In fact, this is also the case for most accidents. This is also an important reason why accident casualties are so serious. Therefore, it is very important to monitor the status of hazard sources in key places, conduct fault diagnosis of equipment and facilities with high risk factors, and conduct regular inspections. This will help to issue correct early warning information, increase the probability of successful evacuation, and reduce accident losses.

(3) The variable crowd reaction time is the key variable in this experiment. There are many factors that affect the length of people's reaction time, such as the degree of exposure to emergency evacuation drills, people's safety and emergency awareness, people's psychological quality, the role of the parties responsible for the relevant accidents, the role of the accident emergency rescue team, etc. The faster people respond, the better the above factors work, the better the crowd evacuation effect, and the more people can be successfully evacuated. Therefore, relevant parties (government departments, enterprises, etc.) should take effective measures, focusing on safety emergency training and drills, supervision of key industries and places, etc., so that pedestrians can respond quickly.

Acknowledgements

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