Comparative Study on the Application Effect of Intelligent Evacuation System and Traditional Evacuation System in Road Tunnel

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Abstract. Numerical simulation was conducted to analyze the evacuation pattern of different crowds under the mixed behavior mode by using a renovated cellular automaton model. Research on intelligent evacuation system was based on the basic principle of safety evacuation, the installation location of intelligent evacuation direction system, the tunnel space structure and typical fire scenarios, with comprehensive consideration of factors such as path length, exit width, population density and distribution of evacuated people. The effects of visual induction, auditory induction and dual induction on the evacuation process of intelligent evacuation system were studied by changing the range of guidance signals to population evacuation, and a method for intelligent dynamic identification evacuation path based on multi-parameter was obtained. The results of the simulation show that the intelligent evacuation system can offer a dynamic evacuation route via the real-time control of the guidance signals, such as the sound and light indicators, and instruct the people under the fire to choose the most feasible behavior pattern so as to enhance the efficiency of evacuation. Under the different behavior patterns, it would be possible to effectively reduce the evacuation time via the dual induction mechanism of the sound and the light if a crowd manages to choose the appropriate number, location and direction of the induction signals, and enlarge the impact range of those signals. In addition, the evacuation efficiency can be expected to be raised by controlling the working status of induction signals to provide people with dynamic evacuation route based on the intelligent dynamic identification algorithm.

1. Introduction

As of the end of 2018, there were 17738 highway tunnels in China, and the total length of which is 17236.1km [1]. There are more and more super-long highway tunnels and large-scale tunnel groups, which brought great convenience to the transportation, but also increased the difficulty of personnel evacuation in tunnel fire. The safe evacuation of people in tunnel fires is a complex system involving the interaction of three basic factors: tunnel structure characteristics, fire development process and human behavior. It is one of the hotspots in the field of tunnel operation technology and fire safety science. Domestic and foreign scholars have conducted research on personnel evacuation and intelligent evacuation systems. For example, the new intelligent emergency evacuation system adopts a centralized control system to convert the traditional nearby escape into a safe guided escape [2].
congestion propagation model based on real-time distribution of passenger flow is established [3]. Incorporate the control effect of the indicator into the population distribution prediction model to get closer to the real situation evacuation people distribution prediction model [4]. A subway intelligent evacuation system closes the marker light pointing to the exit of the danger zone according to the fire point location reported by the fire alarm system, and only lights the marker light pointing to the exit of the safety zone [5]. Dynamic model evacuation flow configuration enables continuous prediction of the temporal and spatial distribution of pedestrian flow [6]. The evacuation model is used to construct the evacuation route construction algorithm and the intersection traffic flow distribution algorithm to guide the escapers to evacuate to the safe area [7]. In addition, a number of fire evacuation models and personal evacuation behaviors have been conducted at home and abroad, including experimental studies and numerical simulation calculations [8, 9, 10].

It can be seen that it has become the consensus of researchers to avoid the evacuation of people to dangerous areas by setting intelligent evacuation indicators. However, how to optimize the overall evacuation efficiency by setting intelligent evacuation indicators is still a topic worthy of further exploration. The construction of the intelligent evacuation system, the interaction mechanism between the system and the evacuation behavior of the population, and the determination principle of the evacuation induction path need further research. Therefore, this paper comprehensively consider the internal structure of the building, the intensity of personnel, the psychology of evacuation personnel, the control of people flow, etc., establish a crowd safety evacuation model, study the new intelligent evacuation system, improve the safety evacuation efficiency, and have important academic value and practical significance.

2. Composition of Intelligent Evacuation System

The intelligent evacuation concept is a new evacuation concept based on the major defects of the traditional evacuation system. The core idea is to guide people to evacuate safe exits away from fire sources in an active, fast and accurate manner based on the exact location of the fire. The safe evacuation method of converting the “near evacuation” method into the premise of “away from the fire source and the principle of evacuation as the principle”, which greatly reduces the evacuation time and avoids blind escape. The composition of intelligent evacuation system is shown in Figure 1.

![Composition of Intelligent Evacuation System](image_url)

Figure 1. Composition of Intelligent Evacuation System

The intelligent evacuation system consists of fire detectors, intelligent evacuation controllers, intelligent emergency lighting and intelligent evacuation sign lamps, and other communication control devices. Based on the concept of “smart evacuation”, the application of advanced computer technology has made significant improvements to the traditional fire emergency lighting controller. The system realizes many functions such as window operation, building plane graphic editing and display, emergency evacuation of personnel accidents under non-fire conditions and so on. The intelligent evacuation system consists of intelligent emergency lighting controller, emergency lighting power supply, emergency lighting distribution electric device, emergency lighting and indicator light.
In the event of fire, after the intelligent evacuation controller receives the information from the fire detector, the intelligent evacuation system immediately generates the optimal evacuation route, and quickly starts the fire emergency sign on the optimal evacuation line along the evacuation channel to the safety exit. The direction flashes in turn to form an optical flow that allows the escaper to clearly see the optical flow and evacuate safely along the optical flow. When the system is applied to a highway tunnel, considering the particularity of the tunnel, the evacuation method of “keeping away from the fire source as the premise, evacuation in the wind and evacuation as the principle” is implemented. When the intelligent evacuation controller performs spatial decision-making and evacuation plans, it combines the direction of the fresh air supply and smoke exhaust system with the location information of the evacuation facilities, including the cross-holes and cross-holes of the road tunnel. The evacuation situation of the road tunnel fire is shown in Figure 2.

![Figure 2. Personal Evacuation in Highway Tunnel Fire](image)

### 3. Evacuation Model

#### 3.1. The Construction of the Evacuation Model and Basic Assumptions

The cellular automata takes a finite discrete state from each cell distributed in the regular grid and makes synchronous updates following certain local rules. Which is a discrete space-extensible dynamic system composed of a large number of simple and consistent individuals through local interactions. On the basis of the improved cellular automaton model, the auditory effect and visual effect coefficient are introduced to reflect the mechanism of the intelligent evacuation system in the highway tunnel for crowd evacuation.

When the number of person is \(m(m \geq 2)\) moves to the same target at the same time, the rejection probability \(r \in [0, 1]\) is introduced, and the relevant pedestrians remain motionless with probability \(r_1\), and move with probability \(1-r_1\), and each person’s motion probability is equal. The exclusion probability is defined by the Sigmoid function in the neural network. The model gives a quantitative relationship of friction, and the friction probability \(f\) is defined as:

\[
f = \theta \cdot V\]  

(1)

where \(V\) is the relative velocity; \(\alpha\) is the hardness coefficient, \(\theta\) is the Coefficient of friction.

Through the above processing, a quantitative description of the repulsive force and friction between people and people, and the evacuation of people can be obtained. The actual evacuation system is to follow the safety exit and set the high exit voice along the evacuation path, the low level evacuation illumination, and the ground or wall continuous guided light flow indicator light to indicate the direction, or directly use the sound and light alarm device to instruction the evacuation of people. The high-level exit voice is defined as auditory induction, and the low-level evacuation illumination and the continuous-oriented guided light flow marker light are defined as visual induction. The joint action of the two or the sound and light alarm device is called double induction, and the comprehensive evacuation of personnel is carried out. The degree of influence is defined as \(k \in [0, 1]\). When there is high visibility, the visual induction is stronger than the auditory induction. On the contrary, the
auditory induction is stronger than the visual induction, and the expression of the auditory induction and visual induction on the probability of motion is:

\[ p'_i = \frac{(k_a + k_v)}{p_i} \]

where \( k_a \) is auditory effect coefficient; \( k_v \) is visual effect coefficient; \( k_a + k_v = 1 \).

When \( k_a \) tends to 1, it is complete auditory induction, corresponding to the state of low visibility in the middle and late stages of fire, and vice versa is complete visual induction corresponding to the state of good visibility at the beginning of the fire.

3.2. Simulated Scene and Evacuation Mode

Let the simulation scene be a section in the tunnel. As shown in Figure 3, there are three safety exits. The exits of A and B are 2 m wide and the exit of C is 4 m wide. According to calculations, the number of people who should be evacuated is about 400.

![Figure 3. Schematic diagram of the plane layout of the simulated scene](image)

According to its familiarity with the tunnel, the evacuation behavior mode can be divided into the shortest path behavior mode 1, the inbound and outbound of consistent behavior mode 2, and the complete herd behavior mode 3. When people are unfamiliar with the surrounding environment and encounter emergency situations, their decision-making process is more affected by fear, which is characterized by a complete herd behavior pattern based on the direction of movement of most people in their field of vision. Set the evacuation grid to 0.5m × 0.5m, and the parameters of the evacuation model are selected as: \( \alpha = 1 \) (human exclusion), \( \alpha = 2 \) (human and wall exclusion), \( \theta = 0.3 \) (person Rubbing with people), \( \theta = 0.7 \) (wall and human friction). Full consideration of the actual crowd evacuation, the evacuation speed of personnel is related to the density of people around, and monotonously decreasing with the increase of population density.

When the evacuated individual moves to the evacuation exit, it is considered as evacuation success. Each step consumes 0.5 m/v. Under the condition of the mixed behavior mode, people are considered to be evacuated according to any of the three behavior patterns randomly assigned.

4. Analysis of the Role of Intelligent Evacuation System

4.1. The Effect of Visual Guidance on the Evacuation Process

In the intelligent evacuation system, taking \( k_a = 0 \), indicating the position, number and influence range of the evacuation guidance sign indicating the visual induction effect on the evacuated population. The complete herd behavior pattern 3 is being analyzed, when the evacuation indicator enters the visual range, its behavior pattern is directly converted to behavior pattern 1.

It can be seen from the analysis of Figure 4 that when the influence range of the evacuation guidance sign is small, more evacuation personnel unable to evacuate quickly because the evacuation guidance sign is not seen, and the overall evacuation time was delayed. On the contrary, when the influence range of the evacuation guidance sign is large, more evacuation personnel can select a reasonable evacuation path under the guidance of the evacuation guidance sign to save the evacuation time. Figure 6 also reveals that when the range of influence is extended to a certain extent, the impact on evacuation time will be lost. Therefore, it is important to optimize and illuminate a reasonable dynamic evacuation guidance indicator, which is one of the advantages of the intelligent evacuation
system. In the same way, we use the above method to simulate the influence of auditory induction on the evacuation process, and we will draw similar conclusions.

4.2. The Effect of Double Guidance on the Evacuation Process

Under the condition that $k_v=0.8$, $k_v=0.6$, $k_v=0.4$, and $k_v=0.2$, respectively, the evacuation of personnel is simulated based on the fact that the auditory induction in the real fire smoke is slightly larger than the visually guidance influence range. The simulation results are shown in Figure 5.

![Figure 4. Relationship between visual guidance and the number of people unevacuated](image1)

![Figure 5. Relationship between dual guidance and the number of people unevacuated](image2)

It can be seen from Fig. 5 that when the acoustic and light guidance markers are used together, the visually guidance weakening (from 0.8 to 0.2) and the acoustic guidance enhancement (from 0.2 to 0.8) are reflected indirectly. The importance of sound evacuation signs when fire smoke causes a decrease in visibility. Therefore, a double guidance mechanism is adopted in the intelligent evacuation system of the tunnel, which can greatly shorten the evacuation time and improve the evacuation efficiency.

4.3. The Effect of Double Guidance on Evacuation Process in Tunnel Fire

Let the fire happen near the exit A and make the following changes to the simulation calculation scenario. The evacuation guidance marker position is distributed close to the safety exit and along the evacuation path. The intelligent evacuation system can change the direction of induction of the evacuation guidance marker according to the smoke situation, that is, to point to a non-hazardous and nearest security exit.
Figure 6 shows the change in the direction of indication of the sound and light indicators when $k_v = 0.4$, and the comparison of the number of unevacuated personals by the intelligent evacuation system. Figure 7 shows the alignment of the traditional evacuation system for the number of unevacuated personals when $k_v = 0.4$. The position and number of sound and light indicators are unchanged and point to the original direction.

Comparing Figure 6 and Figure 7, it is easy to see that the intelligent evacuation system illuminates the number and location of the correct evacuation guidance markers, which can shorten the evacuation time and improve the evacuation efficiency.

5. Conclusions
The improved cellular machine model is used to simulate the evacuation process of mixed evacuation behavior patterns in three behavioral modes. The effects of visual induction, auditory induction and dual induction on evacuation process in intelligent evacuation system were studied. The influence mechanism of sound and light induction on the evacuation process of the crowd was analyzed, and the following conclusions could be drawn:

(1) When the highway tunnel fire occurs, the number, location and direction of lighting the correct evacuation guidance signs are an important way to ensure the rapid and effective evacuation of the crowd.

(2) The intelligent evacuation indicator with comprehensive consideration of path length, exit width and personnel density can more rationally plan the evacuation route. Dynamic identification of evacuation paths according to certain optimization rules will greatly improve the evacuation efficiency of the crowd, and the number of people unevacuated at the same time decreased by 16.7%.

(3) Extending the influence range of the evacuation guidance identification system by means of the dual guidance mechanism of sound and light is an effective way to shorten the evacuation time, which can reduce the evacuation time by 15.5%.

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