Research on Personnel Evacuation Selection Strategy Based on Virtual Reality Technology

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Abstract: In recent years, many cities have carried out the planning and construction of urban underground complexes integrating commerce, entertainment and transportation. Urban underground complexes are different from traditional ground high-rise buildings, with environmental characteristics such as deep burial, large single area, and limited evacuation exits, and when a fire is carried out for emergency evacuation. Therefore, how to carry out the research on the evacuation behaviour of personnel according to the environmental characteristics of urban underground complex has become an important problem that needs to be solved urgently at this stage. In view of this situation, this paper proposes to try to use virtual reality technology to study the evacuation behaviour and evacuation effect of personnel in the complex, and put forward corresponding optimization design suggestions. The use of VR technology for evacuation simulation testing and evaluation overcomes the problems of high cost and organizational difficulty in field evaluation and optimization; on the other hand, due to the high simulation of the real environment and the introduction of human subjective factors, it can make up for the shortcomings of the current method of using computer programs to simulate subway station evacuation to a certain extent.

Keywords: virtual reality experiments; underground complex; emergency evacuation; simulation experiments

1 INTRODUCTION

The emergence of underground space buildings is followed by the safety of buildings and the people in them. Due to the following disadvantages inside these underground space buildings: (1) The crowd is highly dense and the number of exits is limited. (2) The flexibility of emergency evacuation signs and early warning broadcasts is insufficient. (3) The practical flexibility of fire partition and fire shutter design is obviously insufficient. Then, once natural or man-made sudden disasters such as fire, earthquake, terrorist activities occur, external rescue is extremely difficult (HAGHANI 2014)[3], if there is no effective emergency prevention mechanism designed, effective and safe personnel evacuation strategy, the safety and property of people in underground space buildings may suffer very serious losses.

In recent years, the incidence of underground space building fire and fire situation in China and other countries in the world is still quite serious (WANG 2020), how to deal with the sudden accident of underground space construction and do a good job in emergency and disaster reduction, (Lei 2014)[8] is an important research content of building emergency management. Often for diversified functions often steel structure as the main load-bearing building, its space

EMIS 2023, February 24-26, Chengdu, People's Republic of China

DOI 10.4108/eai.24-2-2023.2330686

height is high, the space span is large, the number of exits is limited, can accommodate a large number of people dense underground space buildings, (Richard 2016)[11] its emergency evacuation signs and early warning broadcast can not play the role of efficient evacuation guidance, in emergency situations usually have huge safety risks. In order to reduce the catastrophic consequences of sudden accidents in underground space buildings (Eric 2017), reduce evacuation time and improve evacuation efficiency, in view of the necessity of using guide guidance strategy research for underground space buildings (KUBOTA 2021)[6], this paper conducts evacuation guidance strategy research based on agent model and simulation, innovates and optimizes the bottleneck problem of emergency evacuation guidance in underground space buildings, and achieves the expected effect of improving evacuation efficiency. This study can provide guiding suggestions for the safety management and emergency evacuation strategy of dense crowds in underground space buildings, which has important practical significance for improving the level of public safety in China.

2 VIRTUAL REALITY EXPERIMENTS

2.1 Data Acquisition

A total of 106 volunteers were recruited for the trial, all of whom were college students or teachers, including 64 men and 42 women, with an average age of 24.8 years.

The initial position of the subject is any point in the centre of the sunken square, and the system randomly determines the initial exit orientation for it. An emergency notice then began broadcasting, instructing people to evacuate. The subject can complete the evacuation process as soon as possible by observing the surrounding environment, selecting a suitable exit, and changing the direction of movement by controlling the handle. Each participant performed 6 tests in this scenario, and the initial position of each test was the same, but the availability of evacuation routes, the number of surrounding people and the distribution of surrounding people changed, and the test working conditions were designed as shown in Table 1.

Table 1: Design of experimental conditions

group	1	2	3	4	5	6
evacuate Number	1014	620	200	620	620	620
Exit is not available	-	-	-	1	2,5	1,2,5

The test equipment is a predominantly HTC VIVE virtual reality head-mounted display with a resolution of 640×800 pixels per eye. The test scene is a square in Wu jiao in Yangpu District, Shanghai, completed using Unity 3D model, as shown in Figure 1. The total area of this scene is 7300m^2, and there are five exits for the participants to choose from evacuating, as shown in Figure 2.

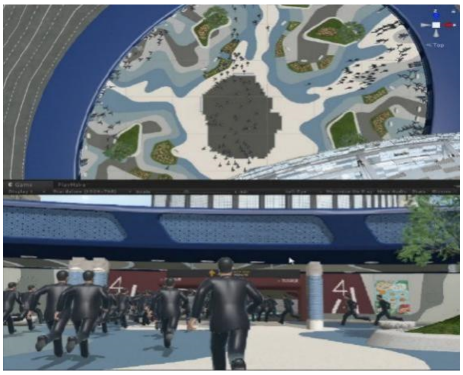

Figure 1: Virtual experiment scenario of crowd evacuation

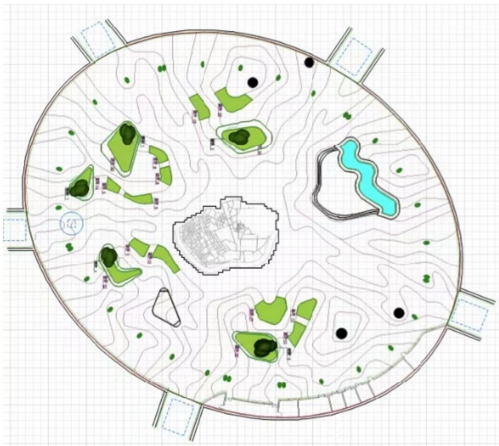

Figure 2: Exit layout of the evacuation scenario

2.2 Data Analysis

The purpose of the experiment was to explore the influence mechanism of individual export decision-making behaviour, and a total of 106 valid data were collected. Therefore, the selection result of the test on the exit was used as the dependent variable (response variable), and the availability of the exit in different scenarios, the number of virtual evacuees, the familiarity of the evacuees with the scene, the orientation of the initial exit of the evacuees, and the closest exit of the evacuees were used as independent variables (explanatory variables), and the correlation of the variables was shown in Table 2.

Table 2: Explanatory variables and proportions

Explanatory variable properties	Property details	Percentage
Gender	male	60%
	female	40%
Identify evacuation signs	Yes	95%

	No	5%
Identify emergency exit signs	Yes	59%
	No	41%
Identify no-pass signs	Yes	16%
	No	84%
Whether to change the route	Yes	68%
	No	32%
Whether you are familiar with the scene	Completely familiar with the scene	4.7%
	Familiar with the scene	26.4%
	Unfamiliar with the scenario	68.9%
Initial exit orientation	1,2,3,4,5	20%
Initial recent export	1,2,3,4,5	20%
Exit availability	3,4	24.5%
	1,2,5	17%
Number of virtual evacuees	620	57%
	1014,400, 200	14.3%

Through the above analysis of data characteristics, it can be seen that the type of response variable is multiclass, and the gender, line, sign recognition, initial exit orientation, closest exit, and channel availability in the explanatory variables are binary or multivariate categorical variables. All response and explanatory variables are disordered categorical except for scene familiarity. Therefore, this paper adopts the unordered multiclassification logistic model, reference (LIN 2020), and uses the maximum likelihood parameter method (KINATEDER 2018)[5] to perform fitting tests on the independent and categorically disordered variables. The results of the correlation test for the variables included in the final model are shown in Table 3.

Table 3: Final model likelihood ratio test

Effect	Model fit conditions	Likelihood ratio test		
	-2 logarithmic likelihood of the simplified model	chi-square	degree of freedom	Salience
Intercept	904.755a	0.000	0	0.000
Initial exit orientation	1075.709	170.954	16	0.000
Distance to the nearest exit	1001.629	96.874	16	0.000
Change course	918.660	13.905	4	0.008
Virtual people	922.409	17.653	8	0.024
Number of egresses available	1091.695	186.939	12	0.000

From the analysis of the multivariate logistic model, it can be seen that in the experiment in this paper, the initial exit orientation, exit availability, pedestrian density in the scene, and distance from the evacuation exit have significant effects on the selection of evacuation exit.

3 CROWD EVACUATION SIMULATION MODEL AND STRATEGY

This paper mainly uses the pedestrian library and process library in Anylogic 8.7.0 simulation software to establish the pedestrian evacuation environment model and pedestrian evacuation behaviour logic, and the following figure is a schematic diagram of the operation interface of the software.

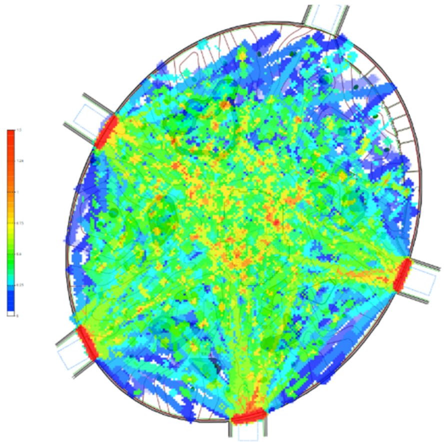

Figure 3: schematic diagram of the operation interface of the software

In Anylogic software (ARELLANA 2020)[1], each pedestrian is an agent who can make judgments based on the social force model based on the surrounding environment and their own characteristics, reflecting the dynamic behaviour of autonomous decision-making. The use of this software to model the agent of the pedestrian flow evacuation process is mainly divided into the following processes:

Create a new model. Click the New button on the main Anylogic interface to create a new model that converts information from the real world to the machine world.

Import the background image. Import the floor plan of the target object as a drawing file to the main window interface.

Build an environment model. Use the imported graphics as the background, redraw them using the space marker control in the Anylogic pedestrian library, complete the setting of obstacles and space positions, and set the parameters for each space marker space according to the actual situation.

Construct pedestrian behaviour patterns. After completing the construction of the environmental model, the corresponding elements in the simulation software are used to build a logical model of the pedestrian evacuation model, and the relevant parameters are set according to the actual situation.

Simulation analysis. Run the simulation model and complete the research of the actual problem through the statistics and analysis of the key data in the model.

3.1 Simulation Model Construction

3.1.1 Spatial Environment Modelling

Use the tool "wall" to draw the plaza, the boundary and the separation line of their internal areas, and select the scope and boundary of pedestrian evacuation; use the tool "rectangular wall" to draw obstacles such as pillars in the square, music pools, benches, etc., and set the area where pedestrians cannot walk; use "Goal Line" to set the source and destination of pedestrian generation; evacuation exits were set up in five directions using Line Services, and drawing tools were used to model the evacuation environment of sunken plazas at the MIAN inter face. In this study, the sunken square of Wu jiao in Shanghai was used as case study Figure 4.

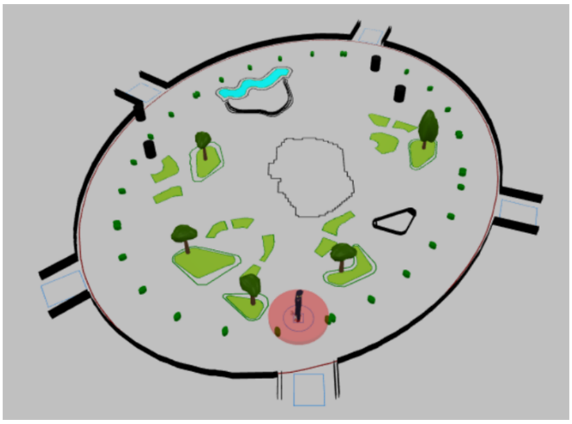

Figure 4: 3D diagram of Shanghai Pentagon Field simulation scene

3.1.2 Model of Human Movement

The personnel model mainly includes the rule system and the evacuation guide characteristic system. In order to accurately simulate the flow of people in the sunken square, (FENG 2021) the main parameters of the evacuees and evacuation guide agents are the density of people, the rules of evacuation, and the evacuation time. Anylogic is a simulation platform software that can realize multi-method hybrid model, this study is based on the system dynamics pedestrian library, agent, discrete and continuous events in Anylogic to model evacuated individuals, by setting up continuous or discrete action flowcharts and building blocks in pedestrian evacuation to write Java code to simulate the relevant parameters of actual moving objects. The agent in the simulation software is embedded with the classical social force model, which can more realistically reflect the various situations and parameters of the evacuation of personnel in the real scene, and can also vividly simulate the behaviour of real individuals, and can also interact with the external environment.

3.2 Boot Mode

3.2.1 Without Guidelines

Through Anylogic simulation software, there is no guide to guide, and the parameters of each evacuee agent when evacuating are defined as:

Evacuate Agent=<St, E, Y>

St refers to the collection of behaviour states of the agent in time t, E refers to the set of the agent's interaction with the external environment and behavioural events, and Y refers to the set of interactive actions realized by other agents under the stimulation of external events.

3.2.2 Bootstrapping Policy for Dividing Exits Equally

The flowchart of the Java Equal Allocation Exit Algorithm programmed in the Anylogic simulation software is shown (Jim 2020), and the steps are described as follows:

Search for the number of egresses and denote it as the set D= {1,2,3,4,5,6,7,8,9,10,11,12}.

Define the scale function new Custom Distribution (R=1:1:1:1:1:1:1:1:1:1:1:1).

Determine whether to achieve the equal distribution of evacuation according to the ratio of 1:1:1:1:1:1:1:1:1:1:1:1, yes, the output result is over; otherwise, return to the first step to start searching for an exit input calculation execution.

3.2.3 Shortest Path-based Bootstrapping Policy

In the event of an emergency such as a fire, it is not easy for evacuees to find the shortest evacuation path to escape, so it is necessary to consider the simulation of the shortest path guidance to help evacuees escape along the shortest path to the exit and achieve rapid evacuation. In order to achieve the goal, the shortest path optimization algorithm needs to be constructed during evacuation.

The detailed shortest path algorithm flow chart, and the steps are described as follows:

Set the longest path from evacuees to the exit to L max, where L max is any path.

The path of any exit in the set of exits from the subject is Ln, Ln is any path other than L max, and n is the natural number.

Compare L max with Ln, if Ln<=L max, then Ln is assigned to L max, continue to iterate over all paths in the set, and end the iteration after all path comparisons are completed.

Output the shortest path L min after the iteration is completed.

4 CONCLUSIONS

Comparing the evacuation results of the above guidance strategies can more intuitively reflect the evacuation effects of different evacuation guidance strategies. According to different pedestrian densities, the correlation between the change of the number of evacuees and the evacuation time of the above three evacuation guidance methods is shown in the figure 5.

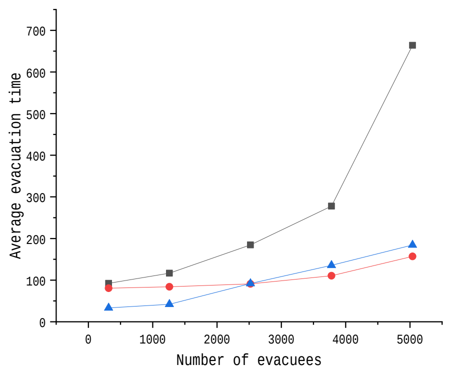

Figure 5: 3D diagram of Shanghai Pentagon Field simulation scene

It can be seen from the simulation and comparison results of the four evacuation guidance methods in the figure above:

The evacuated person without the guidance of the guide evacuated by himself, when the number of evacuees is less than 500 people, the evacuation time is close to the exit guidance evacuation, when the number of people is increasing, there is a certain congestion in the evacuation process.

Guide evacuation according to the bisecting exit algorithm, when the number of evacuees reaches 2520, the algorithm of bisecting the exit and the algorithm of the shortest path have the same evacuation efficiency, which can be seen in the case of the same evacuation density: when the evacuation density is large and the number of people reaches 3780, the bisecting exit algorithm leads to uniform utilization of each exit and less evacuation time.

When guiding evacuation based on shortest path optimization, when the number of evacuees is small, the evacuation time is shorter. When the number of evacuees increases, the shortest path guidance evacuation time increases significantly, resulting in uneven utilization of exits and serious congestion at exits. when the number of evacuees is less than or equal to 2520, and the evacuation efficiency is the same as that of the global shortest path algorithm when the number of evacuees is greater than or equal to 3780.

This study can provide guidance and suggestions for the safety management of dense crowd in underground space buildings and the formulation of emergency evacuation strategies. It can assist relevant departments to carry out building fire simulation drills and provide new solutions for disaster prevention optimization analysis.

It is possible that the evacuation guidance model of underground space buildings adopted in this study is relatively simple. In future studies, more underground space building cases can be established for in-depth verification in building fire protection design, emergency management and other aspects, such as libraries, large shopping square and terminals.

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