Subway fire evacuation simulation model

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Abstract—**Fire is an increasing cause of casualties in modern life. Many people are killed in fire accidents every year. The worst thing is that people can hardly detect where and when a fire will occur. Thus it is difficult to know which evacuation path is effective and safe in advance. In this article, a new system is introduced to simulate evacuation plans in fire accidents in both 2D and 3D, which helps people decide where they should go when a fire breaks out. This system is implemented in agent-based modeling, which makes it more intelligent and flexible.**

Keywords-emergency evacuation; virtual reality; agent-based model

I. INTRODUCTION

Nowadays, there are two main research methods focused on subway evacuation: subway security-firedrill and numerical methods, such as simulation or statistical methods. Using volunteers to do the full-scale evacuation demonstration can help people to get familiar with the place and react faster when accidents happen. However, for research purposes, it has many ethical, practical and financial difficulties. It has been reported that 378 volunteers in total (that's 6% of participants) were injured from 1972 to 1991 in Britain. Moreover, since the volunteers are not under a real emergency situation, judgments made by crowds may not be reliable. Thus the whole trials actually provided little useful information.

Due to these flaws, computer based numerical models were introduced because they are economical and repeatable. Currently, there are some matured tools that works well in the simulation of specific emergency environments. Exodus is a suite of software from University of Greenwich, used for hazards propagation and individual evacuation simulations. It can be used for building, maritime or aircraft environment simulation. When integrated with vrEXODUS, a 3D simulation platform, it can provide an interactive 3D view of simulation. Fire Dynamics Simulator (FDS) with Evacuation is a combination of fire-driven fluid flow model provided by FDS and agent-based evacuation module. User can set up fire accidents and monitor the movement. Other tools, such as JASMINE, SMARTFIRE and FLUENT etc., also provide a good fire or smoke diffusion model.

All the tools above are mainly focused on accident spread prediction, like fire and smoke; however, they pay less attention to people's behavior in emergency. As sensors are pre-placed in buildings, the dangerous zone can be evaluated more accurately. With similar components among each other, metro stations are generally less complicated than tall-buildings. It makes the interactions between people and people as well as people and environments more important in both construct planning and evacuation simulation.

In this article, we introduce eXIT, a platform used for evacuation simulation for metro stations. It also serves as a toolkit which can build a metro station model within a short time. The eXIT can factually simulate passengers’ behavior and intensity of fire at the scene of the fire and conclude accordingly the best evacuation path. We build a sample based on JiedaoKou metro station to show the platform in section2. Conclusions and other issues are discussed in section3.

II. OVERVIEW

Our system consists of 2d and 3d platforms. Combining 2d platform and 3d platform has lots of advantages in restoring the real scene. 3d model is the core display platform. Users can change different angles to observe passengers’ evacuation behavior in 3d platform. 2d model is the core platform for computing. All algorithms are calculated in the 2d platform. Users are able to have an overview of the metro model intuitively by depression angle.

Emphasizing on human’s behaviors in emergency situations, we introduce a new idea-Particle Swarm Optimization (PSO) based on agent. In metro evacuation scenes, there is a direct link between human’s behavior and evacuation path. Thus, our platform centralizes the computing resource in simulating human’s interaction. Our methodology has five characteristics:

—Vraisemblance: Our research is based on authentic data, real passengers’ data and real data of metro structure.

— Comprehensiveness: Our research is based on sophisticated physical engine, which complete many details of our model.

— Interactivity: User can set simulation parameter according to their need, even if the simulation has begun.

— Visuality: 2D and 3D platforms make the simulation more realistic.

—Interoperability: User can import the experimental data as xml, and use this data in another simulation platform.

When researchers analyze a fire environment in subway, they prefer to observe the scene of accident from multi-angles. The multi-angles mode provides user with stronger operability and high fidelity. Nonetheless, the old 2d platform is not sufficient to meet people's need.

In comparison, our system imports the 3d platform. As it is well known for, the 3d platform plays an important role in virtual reality. However, 3d model is not widely used at present due to its complexity. Hardly can a non-professional user build a useful 3d model within a short period of time, and only few people use 3d evacuation model. To solve this problem, our system provides 3d model editing part. User can freely build 3d model using existing material library.

Another difficulty is how to combine the 2d and 3d platforms. In our system, when a 3d model is finished, the system can automatically generate a planform of model and import into 2d platform. By this time, the path calculation system starts to work.

After background calculating, the system imports the path result into 3d platform and automatically allocates human model, establishing an integrated virtual environment. As shown below, we establish the JiedaoKou 3d subway model.

Fig 1: Example of model library

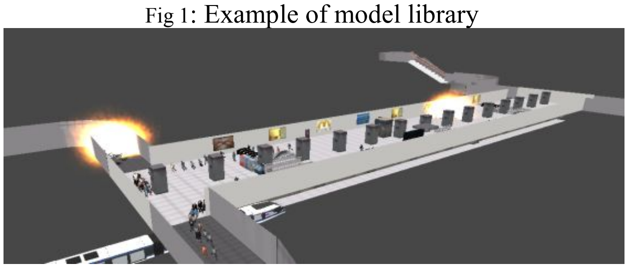

Fig 2: 3d model of JiedaoKou Station after fire accident

This system also pays attention to many details. For instance, the platform precisely simulates onset of fire accident and the movement of train. Besides, user can observe the connection of two floors and distinguish different people's action at short range, both of which can hardly be observed in old 2d model. Compared with other evacuation platforms, our system focuses on establishing the 3d scene to improve scene accuracy.

The 2d platform, as a top view model, can equip users with easy access to observing and analyzing evacuation path of passengers in subway. It meets all computation requirements so that people use it to simulate the real evacuation scene. Besides, it is easy to import the real data, by which the model is strengthened. In order to make good use of real data, we adopt a agent-based model, investing different character attributes to different figures, such as young people, elders, kids and so on. We simulate the real human's size, gender ratio and travelling speed in order to show an intuitive reflects of people's actions. When users modify the gender ratio and age ratio, we can see that the evacuation time change accordingly.

Another advantage of agent-based model is that user can easily observe the core data of evacuation. In our system, each individual has its own evacuation path and records about his evacuation situation. User can trail this path to locate every agent from the beginning of an accident to the end. Unlike traditional analysis for evacuation, which merely focuses on mass behavior and ignores individual actions, our system contains more details on an individual level.

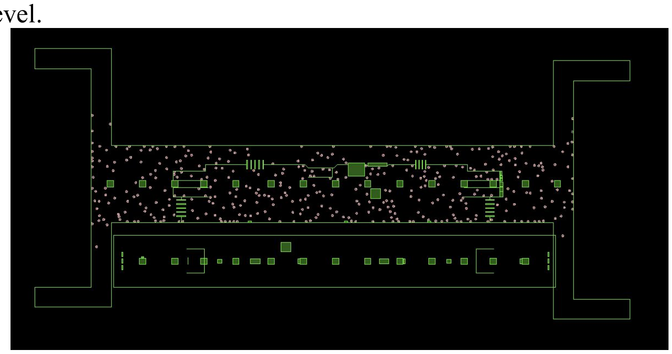

Fig 3: 2d model of JiedaoKou Station

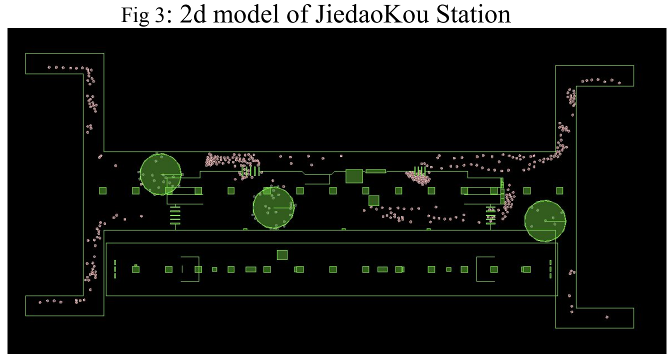

Fig 4: 2d model of JiedaoKou Station after fire accident

In our 2d platform, user can observe and report humans' kinematic parameters, such as direction of movement, bounding box, contact points and so on. When the simulation ends, the system generates a report and sends it to the 3d platform where all the information is shown.

Our 2d platform also contains model editing. It is a significant breakthrough among similar systems, since user can adjust in real time. After user imports the auto-generated planform into our 2d model, the evacuation simulation begins. User can draw and edit the dynamic evacuation scene, such as wiping a barrier or changing one's path manually, which takes effect on real-time path optimization. What's more, user is capable of designing the scale and number of fire accident. Only when users draw the scene of accident by themselves can they seek the best escape route easily. To enhance persuasion, we will provide an experiment to show our editing part in the next section.

III. EXPERIMENTAL RESULT

The code for the building design of metro provides us an official accidental evacuation computing method of station.

$$T = 1 + \frac{(q_1 + q_2)}{0.9 * \left[a_1 * (n-1) + a_2 * b\right]}$$

In this formula, where T is the time of evacuation, q_1 the passengers staying in the subway, q_2 the passengers staying in the station, a_1 trafficability of escalator, a_2 trafficability of stairs, n the number of escalator, b the width of stairs, m the people's response time and (n-1) represents the fact that one escalator maybe broken. 0.9 is a reduction factor of escalators and stairs. This code also rules that all passengers should be evacuated within 6 min when fire accidents happen.

Afterwards, user can edit the model environment manually to observe the passing rate and time in the same exit until finding the best construction of subway. Provided that people reconstruct the subway according to this simulation, the passengers can evacuate from the accident at faster speed than before.

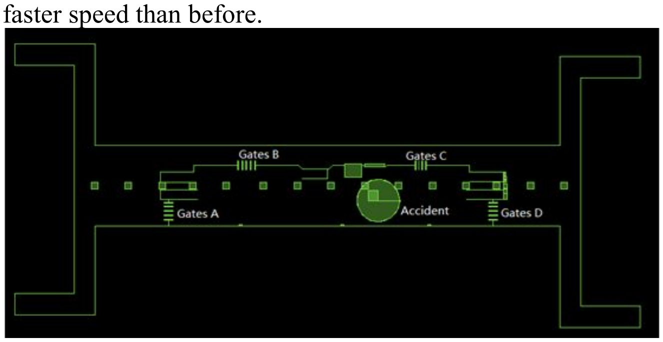

Fig 5: exit marking

We use JiedaoKou station as our test model and use our system to verify whether this station reaches the official standard or not. We assume that there are six hundred people in this station at the same time and, after twenty seconds, four fire accidents unfold sequentially. Our system records the passing rate and passing time of each exit. Besides, we use a series of experiments to show the evacuation position with different number of passengers.

What's more, we highlight the most serious blocking area. As shown below, lots of people crowd together in front of the upper right exit. Passengers have to pay more passing time to evacuation from this exit than other exits. In this way, we know that some structural problems exist in the upper right exit.

We also record the change of passing rates in each exit. From the graph, we know that rowding always happens in the first third of evacuation time. Comparing the data of four gates, we can see that passing rate of gate C is the slowest. This also shows a structural flaw of gates C.

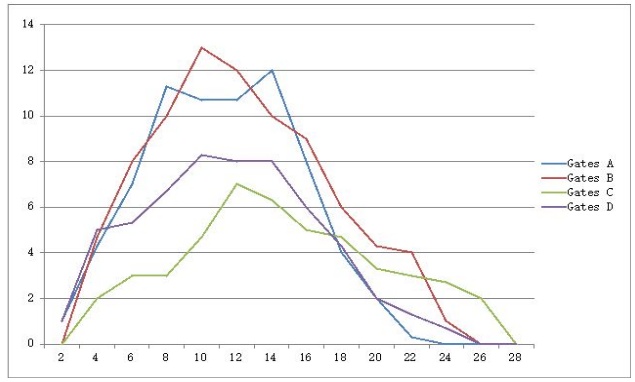

Fig 6: evacuation flow chart

If the fire disaster occurs in the left half-court, it will increase the burden of left exits, leading to safety loophole. To solve this problem, we decide to add a temporary wicket on the right. As shown in Figure X, we can see that the new exit really takes great effect.

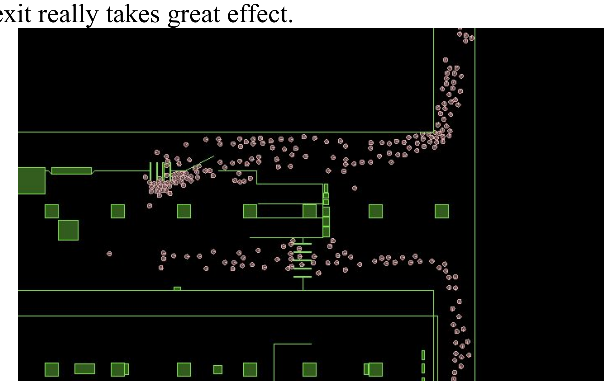

Fig 7: add a wicket

Thus, we apply nother experiment to verify the accuracy of our model and seek the best way to evacuation. We design a new exit as the last experiment did and add some separations. Japanese scholar Daichi Yanagisawa makes a point that placing separations in exit can improve passing rate. As shown below, this new way can provide order and improve passing rate. The new passing rate is more than 0.5% compared to the old passing rate and the block time is less than nearly 200s. This result aligns with Daichi Yanagisawa's viewpoint. After testing, we record evacuation time, passing rate and blocking time.

This table shows that JiedaoKou station may have design flaws, which leads to potential safety hazard. All passengers can hardly evacuate from station in 6 min. If there is a fire accident, casualties is very likely to happen. According to our experiment, the most crowded part is top right exit. The blocking time is more than 6 min. To solve this problem, we try to remove a part of barrier on the right. From the experiment result, this change takes great effect. Both evacuation time and passing rate achieve significant improvement. However, it is not the best improvement method. When we add some separations in new gates, the evacuation situation is further improved. This theory provides a new idea for subway construction.

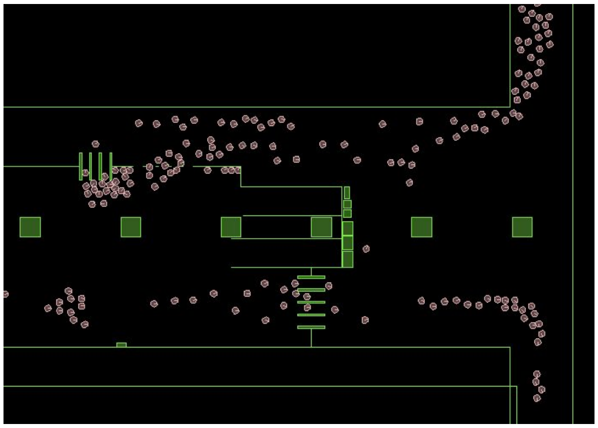

Fig 8: add separations

IV. CONCLUSION

In this paper we have introduced the eXIT subway evacuation simulation platform. Current evacuation simulation software focuses more on accident propagation prediction model but less on simulating human behavior than ours in emergency environment. We build agent-based model and take the hazard area, the barriers and people around into consideration. eXIT also provides a complete toolkit to build an interactive subway model floor and the corresponding functions to generate planar graph for each floor. In this way, our model is suitable for many different scenes. Users can monitor the evacuation process both in 3D and 2D (each floor).The experiments also show that our simulation meets Daichi Yanagisawa’s experiment result of human evacuation in real environment.

Current version of eXIT has simplified the hazard area by fixing the area’s shape and size. Some types of accident require diffusible hazard area calculation such as toxic gas or smoke which will propagation according to the environment. These models will be added in the future versions of eXIT.

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Table1: Data of people agent

	Travel speed(m/s)	Run speed(m/s)	Climbing speed(m/s)	Shoulder breadth(m)	Chest depth(m)	Age distribution
Man	1.55	4.65	2.15	0.506	0.301	0.42
Woman	1.45	4.35	1.95	0.478	0.300	0.4
Elder	0.8	2.4	1.28	0.442	0.293	0.08
kid	1.6	4.8	1.84	0.265	0.223	0.1

Table2: the result of a series experiments

Total People	Total Inner	Gates A		Gates B		Gates C		Gates D		DEAD
		Sec.	Num.	Sec.	Num.	Sec.	Num.	Sec.	Num.	
200	114	17.7	24	15.3	36	20.2	21	16.8	25	8
400	158	18.8	36	19.8	65	24.5	27	19.3	42	18
600	277	20.5	71	22.3	84	27.1	44	22.6	52	26
800	334	38.7	78	42.6	102	40.2	48	32.0	73	33

Table3: Experiment result

	Evacuation time(s)	Blocking time(s)	Passing rate(people/s)	Casualty rate
First time	423	378	1.42	4.2%
Second time	308	193	1.95	3.4%
Third time	298	154	2.01	3.1%