Advances in Computer, Signals and Systems (2023)
Clausius Scientific Press, Canada

DOI: 10.23977/acss.2023.070907
ISSN 2371-8838 Vol. 7 Num. 9

Study on the Simulation and Optimization of Pedestrian Flow in Metro Stations Based on Anylogic

Tingli Wang

School of Economics and Management, North China Electric Power University, Beijing, 102206, China

Keywords: Rail Transit, Simulation Experiment, Anylogic, Queue Optimization

Abstract: Metro stations, as the distribution center for metro passengers, queuing and congestion are very serious during peak commuting hours or when there is a sudden influx of passengers. Based on the example of Yuzhi Road Station of Beijing Metro Line 8, this paper analyzes the characteristics of passenger flow distributed in the station, using Anylogic to simulate the behavior of pedestrians and trains in and out of metro stations, the data of security queues and the average speed of pedestrians are calculated to analyze the rationality of the design of metro stations, and to propose the optimization of the number and speed of the security queues, and to check the optimization effect through modeling simulation and data statistics to provide reference for the operation management of metro stations and to avoid pedestrian congestion. Using Anylogic software to simulate the behavior of pedestrians and the entry and exit of trains in the subway station, the data of security queues and the average speed of pedestrians are calculated to analyze the rationality of the design of metro stations, and to propose the optimization of the number and speed of the security queues, and to check the optimization effect through modeling simulation and data statistics to provide reference for the operation management of metro stations.

1. Introduction

In recent years, with the development of China's economy and the expansion of the scale of urbanization, the urban underground railway system has been developing rapidly due to the advantages of punctuality, efficiency and large transport volume [1]. As the distribution center for metro passengers, metro stations have high passenger density and complex flow lines, if timely guidance, flow restrictions and other control measures cannot be taken, pedestrians in the station will be too dense, which not only increases the risk of accidents, but also fails to quickly achieve safe evacuation[2].

With the continuous progress of design concepts and technologies, dynamic pedestrian simulation of metro stations has become an essential part of the design of important metro stations. In order to improve the design of a station, the first step is to establish the station model in the pedestrian simulation software. After inputting the necessary parameters for simulation, the data from the simulation results should be analyzed to identify any shortcomings or bottlenecks in the station scheme. This analysis can help to improve the overall station design scheme. Scholars apply simulation software such as Anylogic to simulate and analyse the organisation and evacuation of passenger flow in rail transit from different angles.

Zang et al. (2022) proposed optimisation strategies for the design of metro station halls based on the Anylogic software platform by constructing a simulation model of the metro station and counting the congestion location and congestion level [3]. In recent years, there are many scholars to transfer station as the object of research, for the urban metro station passenger flow organisation problems, the transfer station pedestrian movement is affected by many factors. Bosina et al. (2017) analysed walking speed influences, summarised available walking speed measurements, determined the degree of influence caused by different categories of influences on walking speed, and gave reference values for walking speed for different factors in the same category of influence [4]. Goyal et al. (2020) studied pedestrians on stairs in metro stations in Delhi, India. To analyze the factors that affect pedestrian speed and flow on stairs in three Delhi metro stations [5], Li et al. (2020) also proposed a microscopic pedestrian simulation based on a social force model to simulate the passenger boarding and alighting modes on metro platforms as a way to explore the impact of passenger behaviour on alighting efficiency under different passenger flow conditions. Aiming at the problem of passenger flow congestion and evacuation in urban metro stations [6]. Qin et al. (2020) set up a fire scenario through simulation, changed the flow in the station, and analysed the evacuation under different states [7]. Yang et al. (2022) simulate the evacuation paths of pedestrians in underground stations to optimise the movement patterns and path selection behaviours of pedestrians in underground stations and to improve the efficiency and safety of underground evacuation systems [8]. Li et al. (2011) carried out evacuation simulation for emergency evacuation of metro station, and analysed the influence of bottleneck locations such as staircases, gates and exits on personnel evacuation during evacuation [9]. Lei et al. (2012) simulated the pedestrian evacuation process considering the facilities and planning in the metro station, analysed the impact of relevant facilities on the evacuation time, and proposed an optimal design [10].

This paper takes the Yuzhi Road metro station as an example, through the analysis of the station's public area layout, access to the station and the arrangement of other factors, and using the Anylogic software to carry out dynamic simulation, examining the reasonableness of the design of the station scheme, analysing the passenger flow at the station and proposing optimization proposals for the security check queue, so as to provide a reference for the optimization of the metro station scheme.

2. Simulation Example and Model Construction

2.1 Introduction to Simulation Examples

Yuzhi Road metro station is one of the metro stations along Beijing Metro Line 8, and is designed as a two-level underground station with side platforms. The station is located in the vicinity of markets, hospitals and other crowded public buildings, with high pedestrian traffic during peak hours.

Based on the field investigation of the Yuzhi Road metro station and combining relevant information, this paper sets the following assumptions:

(1) Passenger traffic is generated at an even rate during the simulation period;

(2) Neglecting the process of entering the station by purchasing tickets, i.e., assuming that during the simulation period, all passengers enter the station by swiping codes or metro cards;

(3) Neglecting the process of passengers entering and exiting the station using hydraulic helicopters, i.e., assuming that during the simulation period, all passengers choose escalators to enter and exit the station;

According to the above assumptions, this paper adopts pedestrian simulation to abstract the behaviour of entering and exiting the station, establishes the simulation model of Yuzhi Road metro station, and describes the logical relationship between pedestrians entering the station, queuing up for the train, taking the train, and exiting the station in the metro station.

2.2 Metro Pedestrian Anylogic Modelling

2.2.1 Determination of Simulation Objectives

The basic principle of system simulation is to create a simulation model centred on the simulation goal, and to simplify the established model as much as possible to improve the modelling efficiency under the premise of ensuring that the simulation goal is achieved. This paper mainly focuses on modelling and simulation of pedestrian flow in the metro, with specific simulation objectives:

(1) Simulation and modelling of pedestrian behaviour;
(2) Simulation and modelling of rail trains;
(3) Analysis and optimisation of queuing times for security checks at different entrances;
(4) Counting the average speed of pedestrian flow;
(5) Switching between 2D, 3D, logical and statistical view modes.

2.2.2 Model Element Definition

Elements from the Pedestrian Library and the Process Modelling Library are used to model pedestrian behaviour, and the definitions and types of each element are shown in Table 1 below.

Table 1: Pedestrian Library and Process Modelling Element Definitions

Type	Name	Instruction
Ped Source	pedSourceAD	Pedestrians entering the station at AD Gate
	pedSourceB	Pedestrians entering the station at B Gate
	pedSource	Pedestrians alighting in the direction of National Art Museum of China
	pedSource1	Pedestrians alighting in the direction of Zhuxinzhuang
Ped Service	pedService pedService6	Security Service
	pedService5 pedService7	Inbound Service
	pedService2 pedService3	Queuing Service
	pedService4 pedService1	Outbound Service
Ped Escalator	pedEscalator pedEscalator1	Pedestrians descending by escalator
	pedEscalator2 pedEscalator3	Pedestrians travelling up by escalator
Ped Area Descriptor	PedAreaDescriptor pedAreaDescriptor1	Pedestrian queuing area
Select Output	selectOutput	Choose descending lifts in different directions
	selectOutput	Choose outbound service in different directions
Ped GoTo	pedGoTo	Pedestrians going to different exits
Ped Sink	pedSink	End of pedestrian flow

Elements from the track library and the process modelling library are used to model the metro train, and the definitions and types of each element are shown in Table 2 below.

Table 2: Definitions of Track Database and Process Modelling Elements

Type	Name	Instruction
Train Source	trainSource, trainSource1	Orbital process flow, generating trains
Train MoveTo	trainMoveTo,trainMoveTo2	The train is moving forward
	trainMoveTo,trainMoveTo3	Train moves after stopping
Train Dispose	trainDispose trainDispose1	One out of the model
Delay	Delay, delay1	Train stops

2.3 Pedestrian Library Simulation Modelling

To model pedestrian behavior using Anylogic's pedestrian library, two aspects need to be considered: environment modeling and behavior modeling. In this article, we follow the steps below to create a model:

1) A new Anylogic model is created and imported into the base map. This paper then uses the spatial marking tool to outline the pedestrian activities area. Anylogic's 3D object database can be used to simulate inquiry counters, ticket vending machines, and other objects.

2) Secondly, this paper uses the "target line" tool to mark the pedestrian entry and exit points in the spatial marking of the pedestrian library. Also, the "Line Service" tool is used to represent the security check channel and ticket gate. The number of services, queues, and service types can be adjusted according to the properties of each tool.

3) In order to model pedestrian behavior, this paper uses connections between modules in the pedestrian library. We select different modules according to the passenger flow and use the connection between modules to simulate the real passenger flow data.

4) Finally this paper creates models in different layers to depict pedestrian behavior between different floors. This paper utilizes Anylogic's layer tool to create a two-layer model consisting of B1 and B2. The B1 layer is a single-layer model that focuses on pedestrian behavior such as entering the station through entrances, undergoing security and ticket checks, boarding and disembarking lifts, and exiting the station. On the other hand, the B2 layer is a two-layer model that involves pedestrians descending the escalator and waiting for the car in front of the shielded door of the underground. The pedestrian queues in front of each shielded door are represented by the "line service".

2.4 Orbital Library Simulation Modelling

The track library provided by Anylogic can be used to simulate the situation of trains entering and exiting the platform as well as the train formation. The specific modelling process is as follows:

2.4.1 Environment Modelling

To accurately depict the layout of Yuzhi Road metro station, this paper utilizes two tracks to represent the metro tracks leading to National Art Museum of China and Zhuxinzhuang respectively. These tracks are named "railwayTrack" and "railwayTrack1" and are used to simulate the side platform of the underground station.

2.4.2 Behavioural Modelling

The behavioural modelling of the metro train is shown in Figure 1, where "trainSource" and "trainSource1" represent the train sets going to the National Art Museum of China and

Zhuxinzhuang respectively.

Figure 1: Modelling of metro train behaviour

In behavioral modeling, the concept of "delay" is used to indicate the time a train stops. The delay time is usually set to 30 seconds, which is the time it takes for the train to come to a complete stop. When the train stops, a code is set which enables the pedestrians in the "pedAreaDescriptor" of the waiting area to board the train. At the same time, the pedestrians on the train get off and the "pedSource" is increased. This connection between the track library and the pedestrian library is established by the code.

2.5 View Area Switch

In order to make the model effect more clear and intuitive, through the view area tool to integrate the 2D view, 3D view, Logic view and Statistics view, and enable the fast switching between views, as shown in Figure 2 above, the orange labels represent different view areas, the variable "selectedViewArea" represents the selected view area, and the "navigate" function is set to switch the view to the currently selected area. By clicking on the 2D, 3D, Logical and Statistical buttons, we can easily switch between different views and demonstrate the effects of the model.

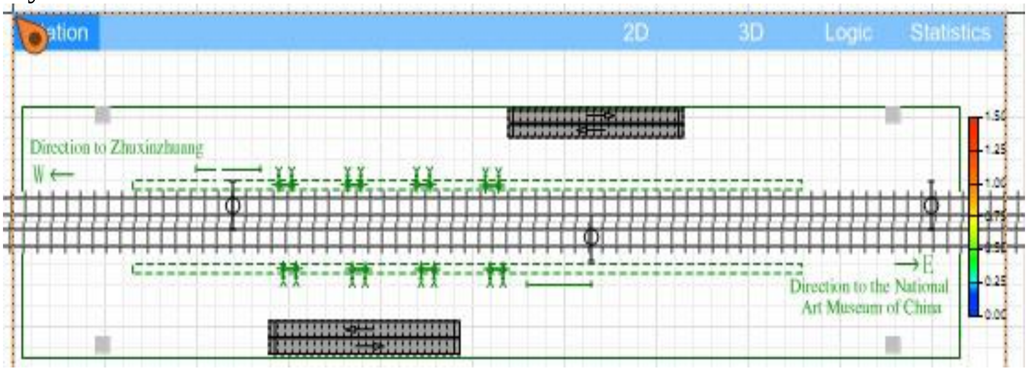

Figure 2: View Area Navigation Bar

3. Pedestrian Flow Modelling in Metro Stations

3.1 Demonstration of Simulation Model Run Results

According to the Anylogic simulation process mentioned above, the station model is built in the simulation modelling software, and the modules such as entrances and exits, ticket machines, gates, and up/down escalators are set up in Yuzhi Road metro station, and the data such as the passenger flow at each entrance/exit of the station, the passenger flow for boarding and alighting of trains of the two lines, interchange passenger flow, the number of trains, and the stopping time are set up. This paper uses the "Time Line Chart" tool to model stations, including exit security check queuing times and average metro passenger speeds.

The parameters are set as follows: security check delay time is uniform(3.0, 5.0); station service delay time is uniform(2.0, 3.0); train arrival event "event" cycles every 3 minutes to indicate that the train arrives at the station every 3 minutes, stays there for 30 seconds, and generates 25 pedestrians. After running the model, the perspective is shown in the following figure 3 and 4.

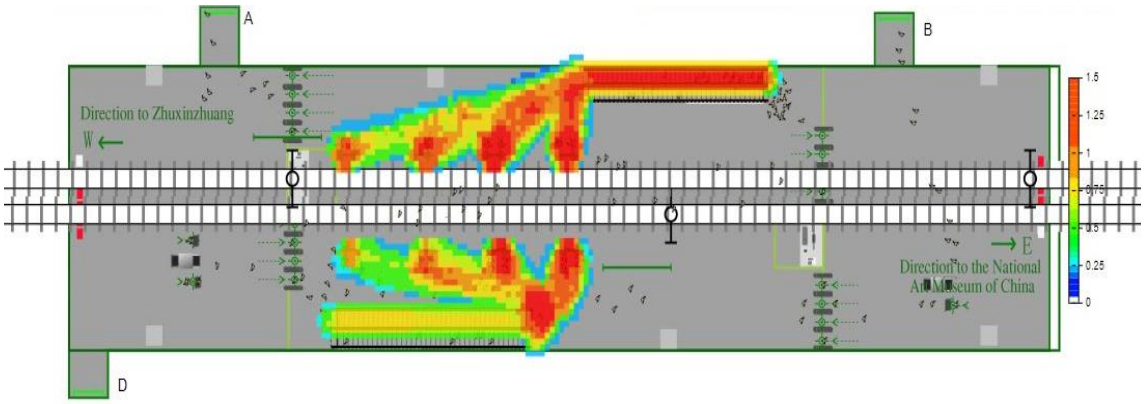

Figure 3: 2D view of model running effect

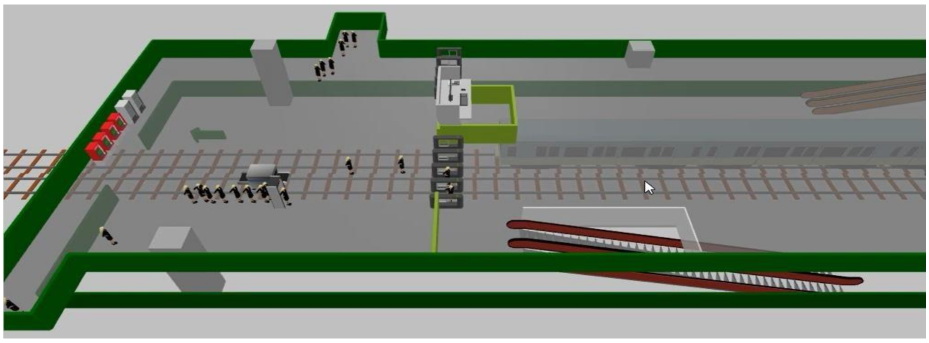

Figure 4: 3D view of model running effect

The effect of the metro pedestrian behaviour model and train set model is shown in Figure 5 below.

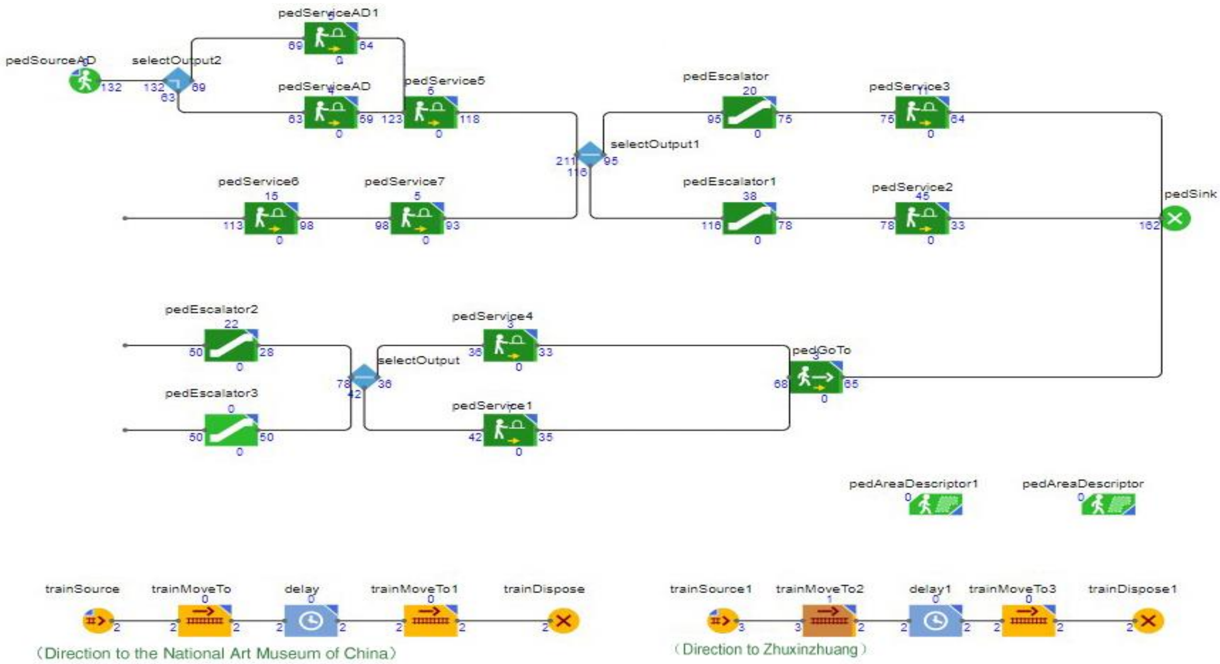

Figure 5: Behavioural model operation effect

3.2 Statistical Data Analysis of Simulation Models

3.2.1 Analysis of Queuing Times for Security Checks at Different Entrances

To analyze the changes in the number of people waiting in the security check queue at Gate AD and Gate B, this paper uses the timeline graph tool provided in Figure 6. This tool will enable you to track the number of people in the queue over time. With the increase of time, the pedestrian flow increases at each security checkpoint, and due to the longer security check time, the number of people in the security check queue increases gradually, and after reaching a certain value, the number of people in the queue gradually stabilizes. The peak number of people in the security check queue at the gate of AD is about 20 people, and the peak number of people in the security check queue at the gate of B is about 15 people, and since the security checkpoint at the gate of AD contains the number of people entering the station from the two entrances of A and D, the number of people in the queue is more than the number of people at the gate of B.

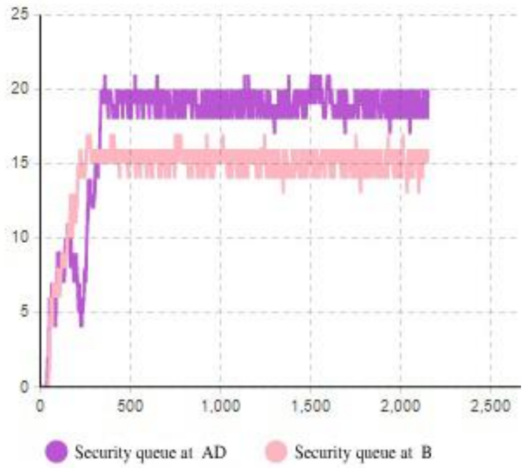

Figure 6: Security Check Queuing Time Analysis

The increase in the number of queuers over time is also reflected in the 3D view, as shown in Figure 7 below for the number of people queuing up for security check at the AD port, there is a crowded queue of pedestrians, which is consistent with the data situation of queuing statistics, and can be further optimised for the queuing up of the security check queue and the time of the security check.

Figure 7: 3D effect of the number of security checkers at the AD gate

3.2.2 Statistics on the Average Speed of Metro Passenger Flow

Calculate the average speed of the passenger flow, run and form a time line graph, as shown in Figure 8 below. It can be seen from the figure, with the increase of time, the average speed of the passenger flow is a declining trend, due to the existence of long queues for security checks at all entrances, so that the pedestrian speed slows down, coupled with the increase in the number of pedestrians, so that the average speed of pedestrians is a declining trend.

Figure 8: Average Speed Statistics of Passenger Traffic

3.2.3 Simulation Model Optimisation & Results

Due to the large number of people queuing for the underground security check, when optimising the underground simulation model, for the AD port security check, one queue line is added to alleviate the pressure of the number of people in the security check, and at the same time shorten the time of security check, and the delay time of the security check service is set to uniform(2.0, 3.0); For the security checkpoint at Gate B, since the number of people entering the station at Gate B is small, the security checking time is shortened and the service delay is changed to uniform(2.0, 3.0), which improves the efficiency of security checking and reduces the number of people in the queue. After increasing the security queue and adjusting the delay time and running the model, as shown in Figure 9 below, the queue of pedestrians in the security check at the AD gate is significantly reduced.

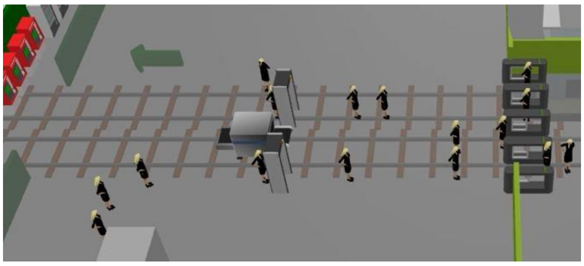

Figure 9: 3D simulation demonstration of optimised AD gate security queues

Re-generating the statistical graph, the number of people in the security check queue at port AD and port B is shown in Figure 10 below, it can be seen that by diverting the number of people from the other security check point in AD, the number of people in the security check queue at AD is significantly reduced, the peak number of people in the queue is reduced from the original 20 people to a maximum of 5. The number of people in the security check queue at B is increased slowly compared to the original model, and the number of people in the queue is finally stabilised at around 15, which is not too much different from the pre-optimisation period. By comparing the number of people queuing at the two security checkpoints, it can be seen that increasing the security queue brings better optimisation than increasing the speed of the security check, and if the number of people queuing at the metro security checkpoint is too large, the number of people queuing can be reduced by increasing the security checkpoint queue to avoid crowdedness.

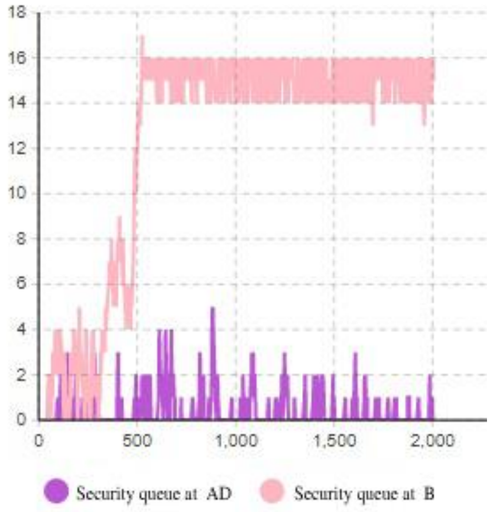

Figure 10: Security Check Queue Statistics after Optimisation

After adjusting the security queue and increasing the security speed, the average speed of the pedestrian flow was counted and it was found that the average speed of the pedestrian flow was improved compared to the optimisation, as shown in Figure 11.

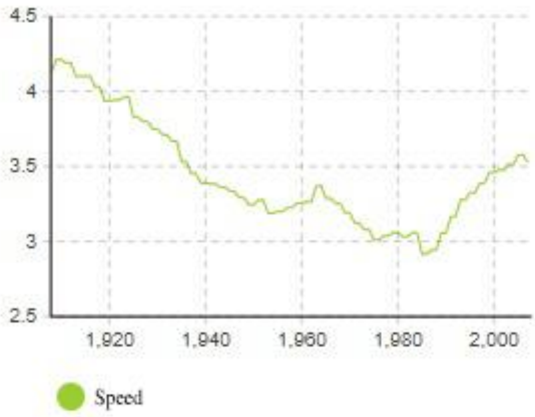

Figure 11: Average Pedestrian Speed Statistics after Optimisation

4. Conclusion

This paper first discusses the basic functions of Anylogic simulation software and introduces the simulation process of Anylogic software. By analyzing the characteristics of the underground Yuzhi Road metro station platform and simulating the layout diagram, we calibrated key parameters within the settings to create a realistic simulation of pedestrians entering and exiting the station, undergoing security checks, queuing for trains, and trains entering and exiting the station. This simulation model helped us to generate data and charts, which can be used to optimize the process of security check queuing at the underground station. Eventually, it was concluded that optimising the security queue line had a greater impact on the number of people in the queue than optimising the speed of the security check, and that an increase in the security queue line would more significantly reduce the pedestrian queue and avoid crowd congestion.

Although we have built a more complete model, there are still some places to be improved: (1) model details optimisation, due to Anylogic has a limit on the number of model elements, we can combine with java code to simulate richer scenarios in the later stage, and we can further optimise the details of the ticket machine, straight ladder, transfer and other scenes. (2) Data import, the pedestrian data in this paper is uniformly generated, which can be analysed in conjunction with the actual pedestrian entry data to make the simulation effect more realistic, and the model optimisation based on the real data is also more informative.

References

[1] Gao R. Proposed programme for the development of urban rail transport technology (2010-2015). Urban Rail Transit. 2010. 23(06):p. 3-8.

[2] Lei W, Li A, et al. Simulation of pedestrian crowds' evacuation in a huge transit terminal subway station. Physica A: Statistical Mechanics and its Applications, Physica A: Statistical Mechanics and its Applications, 2012, 391(22): 5355–5365.

[3] Loufei Z, Mingyuan L, Yinshan W. Research on Design Optimization of Subway Station Transfer Entrance Based on AnyLogic. Procedia Computer Science, 2022, 208.

[4] Bosina E, Weidmann U. Estimating pedestrian speed using aggregated literature data. Physica A: Statistical Mechanics and Its Applications, 2017, 468:1-29.

[5] Goyal T, Kahali D, Rastogi R. Analysis of pedestrian movements on stairs at metro stations. Transportation Research Procedia, 2020, 48:3786-3801.

[6] Li Z, Ma J, et al. A study on passengers' alighting and boarding process at metro platform by computer simulation. Transportation Research Part A: Policy and Practice, 2020, 132:840-854.

[7] Qin J, Liu C, Huang Q. Simulation on fire emergency evacuation in special subway station based on Pathfinder. Case Studies in Thermal Engineering, 2020, 21 (prepublish).

[8] Xiaoxia Y, Rui Z, Fuquan P, et al. Stochastic user equilibrium path planning for crowd evacuation at subway station based on social force model. Physica A: Statistical Mechanics and its Applications, 2022, 594.

[9] Yifan L, Chen M, Jie J, et al. Analysis of crowded degree of emergency evacuation at "bottleneck" position in subway station based on stairway level of service. Procedia Engineering, 2011, 11.

[10] Lei W, Li A, Gao R, et al. Simulation of pedestrian crowds' evacuation in a huge transit terminal subway station. Physica A: Statistical Mechanics and its Applications, 2012, 391(22).