Optimization Scheme of Large Passenger Flow in Huoying Station, Line 13 of Beijing Subway System

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Abstract: This paper focuses on the distribution of passenger flow in Huoying Station, Line 13 of Beijing subway system. The transformation measures taken by Line 13 since operation are firstly summarized. Then the authors elaborate the facilities and equipment of this station, especially the node layout and passenger flow field. An optimization scheme is proposed to rapidly distribute the passenger flow in Huoying Station by adjusting the operation time of the escalator in the direction of Xizhimen. The authors adopt Queuing theory and Anylogic simulation software to simulate the original and the optimized schemes of Huoying Station to distribute the passenger flow. The results of the simulation indicate that the optimized scheme could effectively alleviate the traffic congestion in the hall of Huoying Station, and the pedestrian density in other places of the hall is lowered; passengers could move freely in the hall and no new congestion points would form. The rationality of the scheme is thus proved.

Keywords: Huoying station of Beijing subway system, passenger flow, escalator, queuing theory, system simulation, Anylogic.

1 Introduction

With the acceleration of urbanization in China and the increasing pressure on urban traffic caused by the increase of urban population, all the lines of Beijing subway system are seriously affected by the huge passenger flow.

Different countries have different strategies to alleviate the mass passenger flow of the subway system, with the operation mode, signal system, etc., as the principal manifestation [Cheng (2019)]. However, transforming the subway lines involves a great amount of resources, both financially and humanly, and the operation of the lines under transformation has to be suspended, which makes these transformation projects tremendous ones [Wu, Zapevalova, Chen et al. (2018)].

Line 13 of Beijing subway system started its operation in 2002. The daily passenger flow increases by 20%-50% each year, from 37,600 to 498,800 passengers each day, which

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means an increase by 1226% [Parkinson and Bamford (2016)]. Huoying Station of Line 13 of Beijing subway system, is connected with the depot and is the starting point of multiple trains. It is also functioning as the terminal station and switchback station of the shuttle train (half-route train). Huoying Station features a multiple and complicated turnout system: there are 21 groups of turnouts and 4 station tracks, which makes it one of the most complicated subway stations in Beijing, even the whole country, in the aspect of turnout structure.

Huoying Station is a typical exchange and switchback subway station, with 2 lines and 7 entrances/exits. The stations of Line 13 are ground stations with double-island platforms, and the stations of Line 8 are underground stations, with island platforms, as shown in Fig. 1.



Figure 1: Block diagram of Huoying station

The passenger flow in this station is composed of commuters, exchangers, etc., with an extremely obvious tidal distribution, in other words, there are very obvious morning and evening peaks. The complicated composition of the passenger flow results in differences in the utilization of the equipment and facilities, as well as differences in streamline familiarity. Queuing and congestion occur in high frequency at devices, such as ticket machines, gate machines and stair ports, making the organization of passenger transport more complex.

Huoying Station is located in the east of the interchange between Huangping Road and Shuangsha Railway in Changping District, Beijing. It neighbors Lishui Bridge in the east, Huilongguan in the west, Huangtudian Station of S2 in Jingzhang Railway in the south, and Tiantongyuan, the largest community of Asia, in the northeast. The passenger flow of Huoying Station is thus huge in peak periods. Most passengers in the morning peak period are going in the direction of Xizhimen, making the 4 escalator entrances to Xizhimen extremely crowded.

2 Proposition of optimization scheme for peak hours

Line 13 has adopted various measures to tackle the quickly increasing passenger flow in recent years, which are manifested in the renovation of stations, vehicle and operation mode, including redesign of the station to increase the number of entrances, upgrade and repair of vehicle, and shortening the departure intervals [Fujita (2017)]. All these measures have effectively distributed the quickly-increasing passenger flow of Line 13, with a tremendous cost as the price.

The large number of passengers lingering in the station hall makes the hall and the

interchange passages extremely crowded [Zhou, Plaisent, Zheng et al. (2014)]. To deal with this problem, the authors propose to suspend the operation of the escalator in this direction, and open vertical lifts for special passengers such as the disabled and the old during the peak hours. Whether this scheme would effectively distribute the passenger flow in this station, or would cause congestion in other areas needs to be simulated and tested in a reasonable and scientific way, with a sound theoretical basis [Goldkuhl and Cronholm (2015)].

3 Acquisition of field data

There are obvious passenger flow peaks in Huoying Station, taking the form of tidal distribution in the morning and the evening. Statistics of 10 working days' morning peak hours are chosen for this empirical research, with the positions located respectively at point A of the entrance, interchange passage, and the stair ports in the station hall. The statistics represent the number of passengers per hour. The statistics are shown in Tab. 1.

Table 1:	Statistics	of Huoying	station
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(ิล`	Number	of passengers	at interchange	nassage ner (marter
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Minute	Line 13 to Line 8	Line 8 to Line 13
8:15	713	2365
8:30	869	2446
8:45	629	1861
9:00	564	1803

Minuto	Number of outbound	Number of inbound
winnute	passengers	passengers
8:15	112	593
8:30	78	655
8:45	72	625
9:00	93	793

(b) Number of passengers at point A per quarter

(c) Passenger flow of stair ports in station hall

Stair port	Number of outbound passengers	Number of inbound passengers
To Dongzhimen, with escalators	1256	2208
To Dongzhimen, without escalators	1057	2132
To Xizhimen, with escalators	727	6842
To Xizhimen, without escalators	668	2895

4 Theoretical model validation

Queuing theory is a theory that studies the stochastic regularity of queueing phenomena in service systems. It focuses on the probability regularity of the quantitative index, in other words, the optimization of the system. The aim of Queuing theory is to provide a properly designed and effectively operating service system to maximize the benefits.

The Poisson process is a stochastic process used in queuing theory to describe customers' arrival law. In fact, it is a pure generative process, closely related to the Poisson distribution and negative exponential division in probability theory [Thaduri, Galar, Kumar (2015); Ma, Luo, Jin et al. (2018); Ma, Luo, Jin et al. (2017)].

The M/M/S/K system illustrates a queuing model with the characteristics as follows: the interarrival time subjects to a negative exponential distribution; the service time is of negative exponential distribution; the number of servers is S; the system capacity is K. When K=S, a loss-based queueing model is adopted; When k= ∞ , a waiting queueing model is adopted.

"Kendall" notation: X/Y/Z/W

where X is the interval time distribution of the passengers, Y is the distribution of service time, Z is the number of servers, W is the capacity of the system, i.e., the maximum number of passengers that could be held.

$M/M/1/\infty$ System:

A queuing model in which M stands for the interarrival time of passengers subjects to a negative exponential distribution; M is the service time and is of negative exponential distribution; the number of servers is 1; and the system capacity is infinitive (waiting model).

M/M/S/K system:

A queuing model in which the interarrival time of passengers subjects to a negative exponential distribution; the service time is of negative exponential distribution; the number of servers is S, and the system capacity is K. When K=S, a loss-based queueing model is adopted. When K= ∞ , a waiting queueing model is adopted.

System state: Also called queue length, refers to the number of passengers in the queuing system (the number of customers waiting in line plus the number of customers receiving services).

where Queuing length is the number of passengers waiting for service in the system, N (t) stands for System state of t (t \geq 0), pn (t) stands for the probability of an instant in state n, S stands for number of concurrent servers in the queuing system. λ_n stands for average arrival rate of the newly arrived customers when the system in is state n (the average number of passengers arrived within a time unit), μ_n stands for average service rate of the whole system when the system is in state n (average number of passenger that could be served within a time unit).

When λ_n is a constant, λ_n is represented as λ ; when the average service rate of each server is a constant, the server rate of each server is represented as μ , then when $n \ge s$,

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 $\mu_n = S\mu$ is available. Thus the average time interval of the passengers arriving successively is $1/\lambda$, the average service time is $1/S\mu$. Let $\rho = \lambda/S\mu$, then ρ is the service strength of the system.

The arrival and leave of the passengers of the subway conform to the Poisson distribution stream, thus the Poisson distribution of the queuing theory is applicable here. When the escalators open and close, we could regard the escalator system as a multi-channel $M/M/2/\infty$ system. The following results are obtained after calculation:

$$\lambda = 114, \ \mu = 65, \ \rho = \frac{\lambda}{\mu} = 1.75 \tag{1}$$

$$\rho_{\rm s} = \frac{\pi}{\rm s}\mu = \frac{114}{2\times65} = \frac{114}{130} < 1 \tag{2}$$

The probability of the entire escalator being idle is shown as follow:

- 1

$$P_0 = \left[\frac{(1.75)^0}{0!} + \frac{(1.75)^1}{1!} + \frac{(1.75)^2}{2!(1-1.75/2)}\right]^{-1} = 0.070$$
(3)

Average queuing length is shown as follow:

$$L_{q} = \frac{0.070 \times (1.75)^{2} \times 1.75/2}{2! (1 - 1.75/2)^{2}} = 6$$
(4)

Average queue length is shown as follow:

$$L = L_{\rm q} + \rho = 6 + 1.75 = 7.75 \tag{5}$$

Average sojourn time is shown as follow:

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$$W_{\rm q} = \frac{L_{\rm q}}{\lambda} = 6/114 = 0.05 \tag{6}$$

Average waiting time is shown as follow:

$$W = \frac{L}{\lambda} = 7.75/114 = 0.07\tag{7}$$

All the service indices increase compared with those of Tab. 2 after the escalator is closed, thus the validation of the optimization scheme is proved [Thomas (2014); Ma, Luo, Li et al. (2017)].

Item	With the escalator opened	With the escalator closed
Probability of being idle	0.070	0.403
Average queue length	6	5
Average queuing length	7.75	2.27
Average sojourn time	0.05	0.02
Average waiting time	0.07	0.02

Table 2: Service indices of the escalator after closed

5 Software simulation

Anylogic is a widely used simulation tool to model and simulate discrete, continuous and hybrid systems, among which Pedestrian Library, based on the social force model, is the basis of pedestrian simulation. Pedestrian Library could be used to build pedestrian buildings or streets because it could effectively visualize pedestrian process. Pedestrian Library is widely used in the simulation of pedestrian facility and equipment layout. These are the reasons why Anylogic is chosen in this research.

5.1 Survey of node layout and streamline

The layout of facility/ equipment nodes, streamline conflict nodes and facility/equipment selection nodes is briefed in the following node layout and adjacency diagram in Fig. 2.



Figure 2: Layout diagram of Huoying station

5.2 Scheme of system simulation

The authors implemented simulation experiments on the initial and optimization schemes and compared the distribution of the passenger flow in the station based on the two schemes, to verify the feasibility and validity of the optimization schemes. Based on the initial and the optimized layout schemes of Huoying Station, the authors created corresponding simulation environments with Anylogic and described the corresponding modules of the feasibilities and equipment. The module properties and streamline directions are set according to the actual conditions of the passenger flow in Huoying Station. A simulation model is set up after relevant parameters and the data of the dynamic simulation of passenger flow are put in, and the passenger flow distribution in the station hall, as well as the utilization balance of the facilities and equipment are calculated accordingly. The simulation results are analyzed based on the above calculation. The procedure of simulation analyzation is illustrated in Fig. 3.



Figure 3: Flowchart of simulation comparison

5.3 Setting up of simulation model

(1) Environmental modeling

Firstly, the hall plan of Huoying Station is drawn with the help of AutoCAD. The dimensions of the gate machines, columns, escalators and other facilities and equipment are set according to the data acquired, and the structure of the hall is imported. The passenger flow of each streamline of the station is set according to the data acquired from the field survey (Tab. 1). It is important to note that the simulation time is 60 minutes.

(2) Behavior modeling

The passenger flow of Huoying Station is subject to the actual measurement. At the same time, in order to better simulate the pedestrian path, detour and other traffic behaviors, path modules are set in some areas.

5.4 Simulation estimation of the initial scheme

The initial condition of Huoying station is simulated with Anylogic based on the layout field data. Priority is given to the process of passenger flow in each streamline of Huoying Station. The layout of simulation scene and the logic module setup are illustrated in Fig. 4.



(b) Logic modules

Figure 4: Initial simulation interface

In the simulation process, adding a module of pedestrian density map would make it possible to real-time observe the distribution of passenger flow in each area of the station, and get an intuitive picture of the density of passenger flow in the up-bound escalators. The distribution of passenger flow of the original scheme could be obtained after the simulation is stable, as shown in Fig. 5. Fig. 5 illustrates that the bottleneck of passenger flow distribution could be found in the entrance of the escalator leading to Xizhimen, and the distribution of passenger flow of the initial scheme is uneven because of the unbalanced layout of facilities and equipment of the station. Thus, serious congestions

could be found in the station and it is difficult for passengers to walk smoothly [Vipparthy, Madhu, Ramakrishna et al. (2015)].



Figure 5: Pedestrian density map

5.5 Simulation evaluation and comparison of the optimization scheme

The layout of optimized simulation logic module is shown in Fig. 6 [Takikawa (2016)].



Figure 6: Optimized simulation interface

(1) Analysis of pedestrian density

The optimization simulation model is run and a simulation map of the distribution of passenger flow is obtained after the simulation is stable, as shown in Fig. 7. Comparing Fig. 7 with Fig. 5, we find that the bottleneck spot at the entrance of the escalator existing in the initial scheme is successfully relieved by the optimized scheme, the pedestrian density in other areas is comparatively lower, and the pedestrians are moving smoothly. Thus the optimization scheme has greatly relieved the congestion of the passenger flow, and pedestrians are moving more smoothly.



Figure 7: Pedestrian density

(2) Distribution of passenger flow

The distribution of the passenger flow in the station hall of Huoying Station is put out by simulation, as shown in Fig. 8.



Figure 8: Distribution of passenger flow (a: initial b: optimized)

The above simulation data has proved the rationality of the proposed optimization scheme, which has been adopted by the Third Branch Company of Beijing Subway Company in Huoying Station.

6 Conclusions

The authors of this article propose an optimization scheme to adjust the operation time of the escalators in peak hours in Huoying Station, and verify the scheme with Queuing theory. The validation of the scheme is simulated and proved with Anylogic. This scheme, which has been adopted by Huoying Station, contributes to the distribution of passenger flow in the station. The overall idea of this research would be beneficial to solve similar problems existing in public places with a severe passenger congestion.

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