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Research on rational utilization of ticket selling and checking facilities in rail transit stations

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Abstract: For a long time, there have been problems such as unreasonable allocation and unbalanced use of ticket selling and checking facilities in the station. Therefore, combined with the research results, this paper summarizes the layout of ticket selling and checking facilities and the passenger traffic characteristics and arrival rules of urban rail transit are exposed. In addition, the queuing theory and discrete event simulation method are applied to establish the evaluation index system of the queuing system and configurate quantity of automatic ticket checking machine. With the help of AnyLogic simulation software, the queuing system is further simulated and evaluated with micro examples, and the layout optimization of brake is discussed from the perspective of economic configuration and balanced use.

1. Introduction

The station is the key point in the urban rail transit system. Reasonable layout of ticket selling and checking facilities is essential to improve the service of the station. It should not only meet the functional needs of passenger flow in and out of the station during peak hours, but also avoid the waste of resources. Scientific configuration and selection of the selling and checking facilities and its layout, reasonable use of these facilities based on the characteristics of passenger flow distribution, to the greatest extent possible to reduce passengers in and out of the station congestion and queuing phenomenon and balancing brake machine efficiency all have the vital significance in improving the operational management efficiency, effectively organizing the station passenger flow, giving full play to the equipment capacity, improving the operational management level and service quality of the station and so on.

2. Ticket selling and checking facilities in rail transit

2.1. Ticketing facilities

Ticketing facility is a functional facility providing legal traffic service voucher for pedestrians, mainly including automatic ticket machine, semi-automatic ticket machine and manual ticket window.

The requirements of Ticket Vending Machine (hereinafter referred to as TVM) are determined by such factors as the proportion of one-way Ticket passengers, the service capability of TVM, the acceptance of various ticketing methods by passengers and the ticketing policy of the operator, and so on. In some areas, the design manual makes additional provisions for the configuration of TVM: 3 m queuing space is reserved before TVM, and there are at least 2 TVMS in each location. In addition, based on the consideration of configuration space, 50% expansion capacity should be reserved [1]. There is no specific configuration standard for manual ticket Windows, and 1-2 are generally configured according to the real-time passenger flow of subway stations.

2.2. Automatic ticket checking facility

In urban rail transit, according to the different arresting body and arresting way, ticket brake can be divided into three roller brake (three-bar type), wing brake (leaf type), swing brake, translation brake, turn brake and so on. Among them, three-bar type and leaf type are widely used, with Shanghai subway and Beijing subway as the main representatives respectively.

Automatic ticket gates are generally arranged between the paid area and the non-paid area of urban rail transit stations, which are divided into inbound ticket gates, outbound ticket gates and two-way ticket gates [2]. Most of the entrance gates are close to the entrance and ticket selling facilities for passengers to enter the pay area from the non-pay area. Exit gates are always located in the right or close to the exit escalator entrance, guiding passengers to exit quickly. The two-way gate can be combined with the actual passenger flow direction to be opened to relieve station pressure during stations. The entrance and exit station gate units are suitable for separate layout. When the space of the station hall is limited, it can also be arranged side by side and separate passengers in different directions by diversion rail. Automatic ticket gate is an active facility, and its influence on the passenger flow of the station is mainly reflected in the layout position, open quantity and passing capacity of the gate. The reference value for the design of maximum passing capacity of ticket selling and checking facilities in the *subway design code*, and there are the following provisions for the layout of brakes [3]:

(1) The setting of automatic ticket checking machine is no less than 3 channels per group; (2) It is advisable to set up standard two-way automatic ticket checking machine in the station with obvious passenger flow direction; (3) Each independent payment area shall have at least one two-way wide channel automatic ticket checking machine, and the net distance of the wide channel automatic ticket checking machine shall be 900mm.

The number of entrance and exit brakes shall be calculated according to the passenger flow in peak hour:

$$N = \frac{MK}{m} \tag{1}$$

Where: M -- peak hour’s inbound passenger flow (upstream and downstream) or total outbound passenger flow;

K -- over-peak hour coefficient, generally 1.2-1.4; M -- the ability of each brake machine to pass the ticket per hour.

2.3. Security check and brake orientation

The relation between station security check and gate orientation can be divided into parallel layout and vertical layout [4].

(1) when security check orientation and brake toward vertical, it is the vertical layout. The passenger flow in the vertical layout has a bend Angle, and the utilization rate of the near end brake is obviously higher than that of the far end brake. The incoming passenger flow tends to gather and queue here, causing serious congestion. When the entrance gate is far away from the security check, the sight of passengers is blocked, and they cannot get the information of the faulty gate in time.

(2) when security inspection and brake towards parallel, it is the parallel layout. In parallel arrangement, the passenger flow line of the station is smooth without turning, and the view ahead is open, so that the congestion can be timely judged and the efficient path can be selected.

2.4. Security check and ticket purchase priority

For the security check near the entrance, direct connection channel or escalator station, the ticket selling area is generally set between the security check and the brake; For stations with a large area of non-payment area in the station hall, TVM and manual ticket Windows are generally arranged relatively or vertically. After purchasing tickets, passengers and card-hold passengers will gather into a queue for security check and enter the station, which is conducive to the organization of passenger flow distribution.

2.5. Brake machine layout

Beijing subway station brake machine layout mainly includes linear layout and corner layout. In the case of linear layout (FIGURE1), passengers mostly choose the near end brake the shortest path based on the visual field perception in the flat peak period. During rush hour, passengers will avoid the congestion brakes in addition to taking into account the distance of the route. Rows layout (FIGURE3) is a kind of linear layout, whose space is used more balanced, balancing the needs of the station layout and tidy and the space for passengers to line up so as to close the gap between the actual distance and the visual perception of passengers on the way from the security check to the escalator entrance in the payment area, in figure 3, "d" means the distance of brake machine vertical direction adjustment, four schemes have the following details:(1) plan ‘a’ and ‘b’ are arranged in two rows. A mainly considers the distance between passengers and the escalator after entering the station by swiping the card, and arranges the gate further from the escalator in front; B mainly considers that when passengers visually inspect the front gate, they will make a decision based on the shortest path. Therefore, the gate far from passengers on both sides is placed in front; (2) in plan ‘c’, the brakes are uniformly arranged into three rows. When the inbound flow line is perpendicular to the brake, the far end of the brake is placed in front and the near end of the brake in the back, so as to increase the ticket checking space for passengers; (3) plan ‘d’ is progressive layout, which increases the queuing space, disperses the queuing passengers and broadens their vision.

When the inbound flow line is perpendicular to the brake, the angle arrangement (FIGURE2) can reduce the flow of passengers in and out of the station mixed to avoid the head-on vertical conflict, and provide buffer space for passenger flow to get out of the station. When passengers that are in or out of the station pass through the same channel with a folded angle arrangement, orderly flow lines can be formed rapidly and spontaneously.

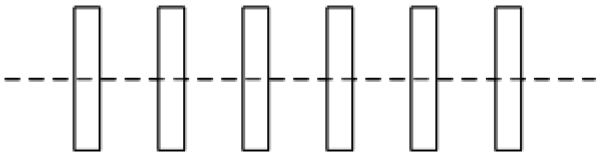


Figure 1. Linear-set brake

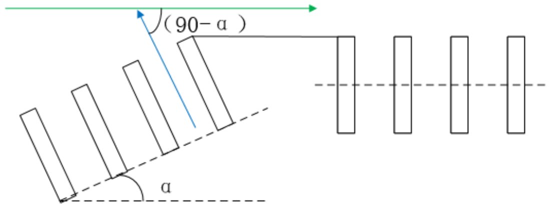


Figure 2. Angle-set brake

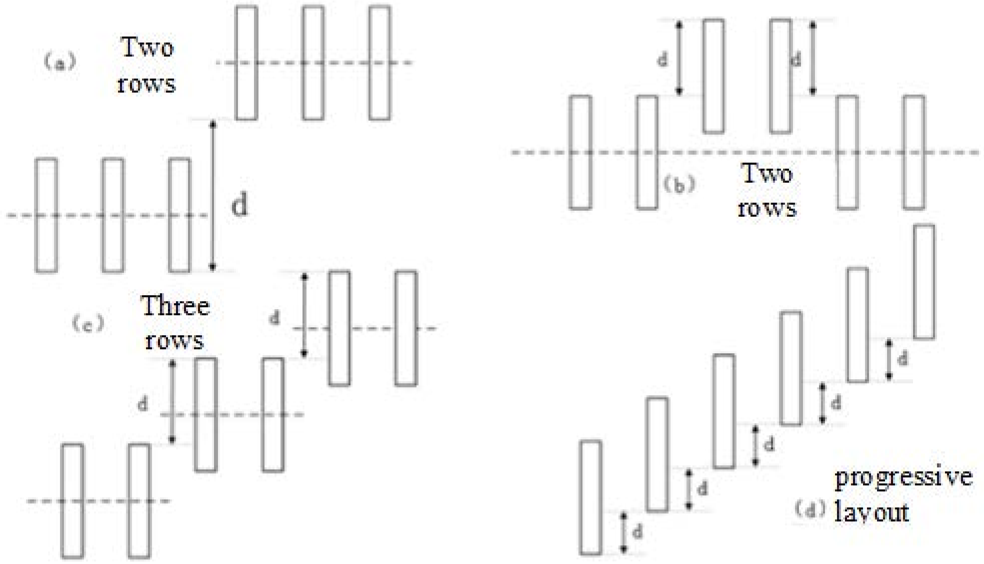


Figure 3. Brake in rows

3. Characteristics of passenger flow in urban rail transit stations

3.1. Passenger traffic characteristics in ticket selling and checking facilities

It is a random process for passengers to arrive at the station, which shows the following traffic characteristics at the ticket selling and checking facilities:(1) passengers can purchase tickets or enter the station with a card. There is a streamline clustering before and after security check. Due to limited service facilities in the peak period, passengers will wait in the non-payment area, especially in the security check area; (2) the flow of passengers in and out of the station is fixed and the function of required facilities is single. The range of free choice is small, therefore. Due to the transmissibility of human behavior, the individual behavior of passengers in front will affect the access route for subsequent arrival of passenger groups; (3) when passengers pass through the gate, the traffic flow in different directions will channelize into several independent and non-interfering traffic flows, so that passengers can enter the station in an orderly manner; (4) combining with the survey data of Station A, it is concluded that the speed of 68% of passengers passing through the gate is concentrated at 0.4-0.6m/s, and the average speed is 0.56m/s, which is lower than the walking speed under normal environment; (5) when passengers are not urgent, they tend to walk at the most comfortable speed and avoid obstacles such as railings and pillars.

3.2. Passenger arrival distribution.

The arrival of passengers includes inbound arrival, outbound arrival, which are different due to the different land use and customer sources around the station. They can be divided into four types: residential type (single peak), office type (single peak), commercial type (double peak) and hub type (no peak) [5], as shown in FIGURE4. The abrupt change of residential and office passenger flow is obvious, and the characteristics of inbound and outbound passenger flow between them are opposite.

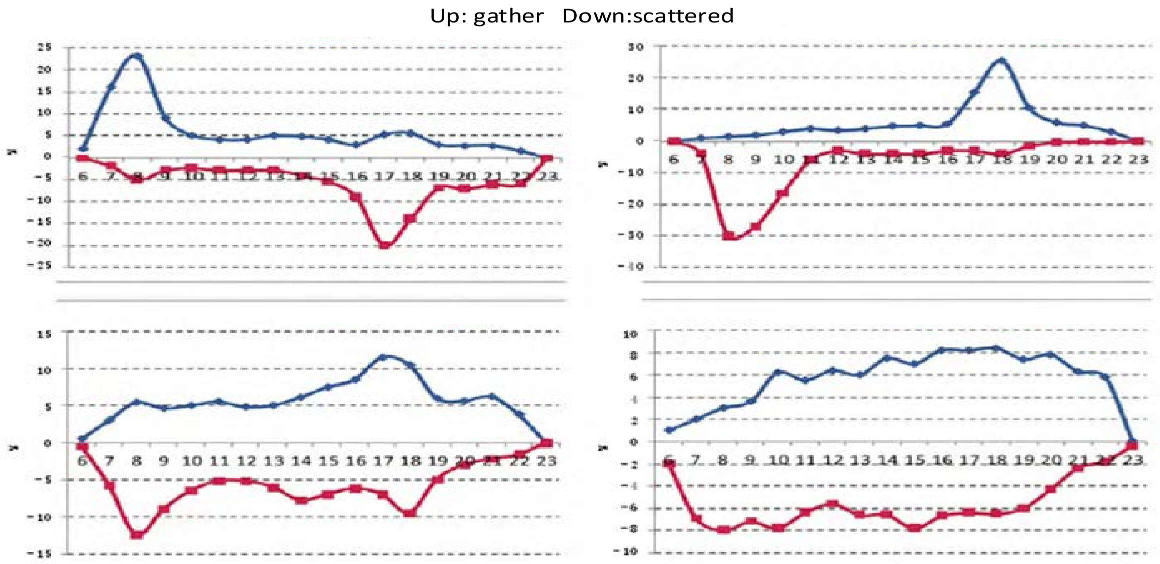


Figure 4. The time distribution characteristics of passenger flow in different types of urban rail transit stations

4. Automatic ticket checking queuing system.

Automatic ticket checking is a typical multi-channel non-loss queuing service system with several ticket checking machines. Each check-in machine can only serve one passenger at a time. After each service, the head passengers of the line at the service desk begin to receive the service. When the arrival rate of passengers is greater than the service rate of ticket check-in machine, the passengers queue [6]. In the queuing system of many-to-many service stations, the arrival of passengers and the service time of service stations obey some random distribution rules.

Simulation input: (1) total number of service stations s (s>1); (2) simulation time (unit: seconds);

For arriving passengers, there are the following instructions: (1) if there is an idle service desk, the idle service desk is randomly selected to provide service, and the "status" of the service desk changes from idle to busy; (2) if there is no free service desk, select the shortest queue and wait in line according to FIFO rule (if the number of people in the queue is the same, it will be randomly selected), and record the queuing time. The number of people in the queue increases by 1.

Simulation results output, for each service desk, output:(1) the total number of persons served; (2)

passenger queue number; (3) average queue length of passengers L

$$L = \sum_{\mathrm{i=1}}^{\mathrm{N_{p,k}}} \frac{\mathrm{L_{L,k,i}}}{\mathrm{N_{p,k}}} \tag{2}$$

Where: $N_{p,k}$: the number of passengers arriving at the KTH service desk within the simulation time; $L_{L,k,i}$: the check-in time that the ith passenger waits for.

Output the data of all passengers in the simulation process:(1) arrival time; (2) queuing time, no queuing output 0; (3) time of departure = time of arrival + time of queuing + time of receiving service.

The input flow of the queuing system of the automatic ticket checking machine can be described by the probability distribution of the arrival time interval of passengers. The passenger flow data in the survey is random, and the distribution type subject to it cannot be known in advance. The distribution hypothesis needs to be tested according to the sample.

Station A is A transfer station of three lines. According to the distribution of surrounding land, the passengers in and out of the station are mainly students, office workers and other commuter flows. The passenger composition is relatively simple, and the passenger flow is stable in weekdays. According to the analysis of the arrival interval of passengers at Entrance E, Station A for 5 consecutive minutes , only 14 arrival time intervals exceeded 5s, and most of the arrival time of passengers was between 0 and 3s, with a relatively dense flow of people. The 140 arrival time interval data are further sorted from large to small to analyze the rules of passenger input process. Trend can be seen that curve with negative exponential function, therefore, assumes that stops arrival time intervals passengers obey negative exponential distribution, using χ^2 fitting test.

(1)parameter estimation:

H_0: the probability density of T is：

$$f_T(\lambda) = \begin{cases} \lambda e^{-\lambda t}, t \geq 0 \\ 0, t < 0 \end{cases} \tag{3}$$

The function parameter λ is unknown, estimated by the maximum likelihood method is:

$$L(\lambda) = \prod_{i=1}^{n} \lambda e^{-\lambda t_i} = \lambda^n e^{-\lambda \sum_{i=1}^{n} t_i} \tag{4}$$

$$\Rightarrow \hat{\lambda} = \frac{n}{\sum_{i=1}^{n} t_i} = \frac{140}{299.4} = 0.465271$$

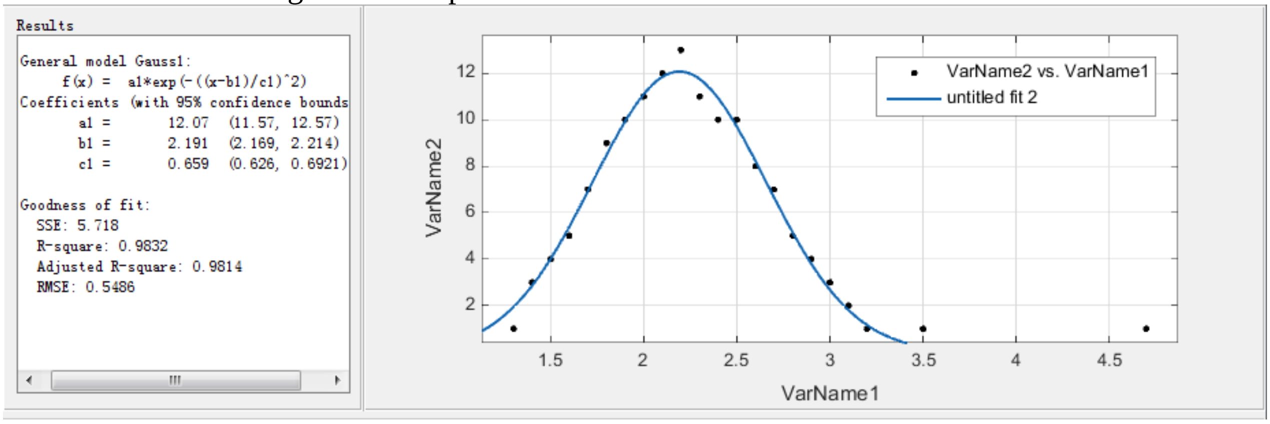
(2) hypothesis testing

In the H_0, T possible value of all the Ω for interval (0.2, 12.6] is divided into nine non-overlapping: between zones such as A1 = (0.2, 1.4], A2 = (1.4, 2.6], A3 = (2.6, 3.8], A4 = (3.8, 5.0], the A5 = (5.0, 6.2], the A6 = (6.2, 7.4], A7 = (7.4, 8.6], A8 = (8.6, 9.8], A9 = (9.8, 11]. Use χ^2 fitting test according to the calculation results, it is found that if H_0 is accepted at the significance level of 0.02, T is considered to obey the negative exponential distribution of parameter λ=0.465271 (that is, the mean time between arrival is 2.14929s).

The service rate of the automatic ticket queuing system is related to the number of passengers in the system. When the number of customers in the system k is no more than the number of ticket machines s, that is, $1 \leq k \leq s$, passengers are all in the service desk, the system service rate is $k\mu$; When the number of passengers $k > s$, the number of customers receiving service at the service desk is still s, and the rest of passengers are waiting in line for service, the system service rate is $s\mu$ [7]. It is defined that the time for passengers to receive service at the ticket gate is the sum of the time for ticket processing, gate opening and passengers passing through, which is mainly affected by the characteristics of passenger flow and should be determined according to the actual passenger flow in the station. The fitting analysis was performed on 138 groups of data of passengers passing through the brake for 5 minutes during the peak period at E of station A. The results are shown in FIGURE5. The time taken by passengers passing through the brake is normally distributed. Fit of R^2 is 0.9832, fitting function is:

$$f(x) = 12.07 \times e^{-\left(\frac{x-2.191}{0.659}\right)^2} \tag{5}$$

After the arrival time and service time distribution of passengers are determined, the simulation program of the queuing system at the Entrance E, Station A is written based on the multiple service stations of queuing theory model. Run the simulation program for many times after the number of service stations is changed. The output results are shown in table 1.



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General model Gauss1:
     f(x) =  a1*exp(-((x-b1)/c1)^2)
Coefficients (with 95% confidence bounds
       a1 =       12.07  (11.57, 12.57)
       b1 =       2.191  (2.169, 2.214)
       c1 =       0.659  (0.626, 0.6921)

Goodness of fit:
  SSE: 5.718
  R-square: 0.9832
  Adjusted R-square: 0.9814
  RMSE: 0.5486
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Figure 5. Fit the time of passengers pass the brake

The indexes are better when 3 entrance gates are configured. Considering the redundancy of facilities and equipment, it is optimal to configure 4 check-in machines at the station during the peak period to improve passenger satisfaction. Station A is located in the downtown area and its arrival distribution is office type. According to the survey, the weekday passenger flow of Entrance E is about twice as much as that of the weekend, and the ticket check-in machine can be equipped with 3 brakes at the weekend. In conclusion, considering the actual passenger flow characteristics, the application scheme of automatic ticket checking machine at different time periods at Entrance E, Station A is given, as shown in table 2.

Table.1. Simulation program running results.

Number of brakes	Counter number	Total number of passengers	Queuing percentage	Average passenger queue length	Average queuing time	Brake utilization rate
1	1	1551	99.9%	84	187s	96.52%
2	1	913	49.2%	0.74	0.94s	56.81%
	2	787	26.4%	0.71	0.46s	48.97%
3	1	602	19.1%	0.54	0.26s	37.46%
	2	572	4.5%	0.5	0.05s	35.59%
	3	541	1.8%	0.5	0.02s	33.67%
4	1	434	8.1%	0.5	0.10s	27.01%
	2	422	2.1%	0.5	0.03s	26.26%
	3	409	0.2%	0.5	0s	25.45%
	4	397	0	0	0s	24.70%

Table.2. Application scheme of automatic ticket check-in machine

Entrance	Weekend	Weekday(Monday to Friday)		
		5:30-17:00	17:00-20:00	20:00-24:00
E	3	3	4	3

5. Anylogic simulation

AnyLogic is used to simulate the ticket selling and checking facilities at the entrance and exit of the subway station, including the steps of setting up the environment, creating the behavior flow chart, running simulation and analyzing the results. After the completion of the simulation platform, the arrival rate of passengers was set at 1300 /h, and the simulation results at Entrance F, Station A were selected. The simulation results are shown in table 3. The simulation results are close to the actual data, so the simulation platform can better reflect the real state.

Table.3. Evaluation table of simulation effect of 'F' check-in brake

	Brake	actual	simulation	Error (simulation/actual -1)
passenger flow volume (person/h)	1	80	75	-0.06
	2	136	132	-0.03
	3	226	267	0.18
	4	243	259	0.07
	5	284	236	-0.17
	6	235	232	-0.01
	7	100	104	0.04

Table.4. The simulation results of 4 inbound brake machines

Brake	Number of passengers	Queuing percentage (%)	Average queue length	Maximum queue length
3	299	7.02	0.34	3
4	325	4.31	0.23	3
5	323	3.41	0.18	2
6	289	6.57	0.31	3

When four entrance brakes are configured, select no. 3, 4, 5 and 6 gates close to the security check for simulation. The number of passengers passing each brake within one hour and the queuing situation are shown in table 4. At this time, the spatial utilization imbalance of the brake is only 0.05, which is far less than the spatial utilization imbalance when 7 entrance gates are configured. Therefore, the scheme is feasible.

Set the gate area as the gate channel and passenger queuing area, and output the density of passengers in the gate area (person / m^2). The average passenger flow density and the maximum value are 0.537 person / m^{2}and 1.205 person / m^2 respectively. The overall service level is relatively high. However, when the passengers arrive in a concentrated way, the service level drops. Therefore, it is considered to change the layout of the brake and take the imbalance of the brake space utilization as the evaluation scheme. The screenshots of the simulation process and the analysis of the results are shown in FIGURE6 and table 5 respectively.

In plan 1 and 2, both sides of the brake shall be moved forward to balance the distance between the brake and security check. The simulation results show that the imbalance of brake space utilization increases significantly, and the average queue length and passenger flow density in the brake area increase with the increase of the forward distance 'd'. The simulation results time after time show that the number of passengers choosing brake no.5 is very small, mainly because the pedestrians choose the brake to avoid the blocking area as much as possible, the space of brake located at the edge is relatively open, so that the utilization rate is much higher than the middle gate.

No improvement effect can be achieved by moving forward No.3 and No.6 brakes. Then consider No. 5 and No. 6 brakes that are far from security check. The length of the brake is 120cm, the width is 30cm, and the width of the channel is 50cm. Set the range of movement distance d as 0.25-1.50, and change by 0.25 for each adjustment; When the brake units are arranged progressively, the range of movement distance d is set as 0.25 to 1.25, and each adjustment is 0.25. The comparative analysis can be concluded as follows:

(1) when the brakes are arranged in two rows, the imbalance of the utilization of the brakes increases with the increase of the moving distance d. It is found that the forward moving distance exceeds half of the length of the sluice gates, the space utilization imbalance stabilizes around 0.7.

The average queuing length and passenger flow density decrease with the increase of the moving distance d. Therefore, scheme 3 is recommended.

(2) in the case of progressive installation of the brake, there is no significant change in the space utilization imbalance and the average queue length of passengers, and the passenger flow density decreases significantly with the increase of the moving distance d. The analysis shows that the queuing passengers are scattered in a progressive arrangement. The recommended scheme 9 is to fine tune the longitudinal distance between adjacent gates and reduce the number of people in the queue.

Comparing scheme 3 with scheme 9, the latter is superior to the former in terms of evaluation indexes. The entrance gate is 6m away from the security inspection machine. In scheme 9, the maximum longitudinal movement distance of the gate machine is 0.75, and there is a buffer distance of more than 5m to disperse passengers. After comprehensive comparison, scheme 9 is recommended, i.e., progressive arrangement of brake units with row spacing of 0.25m.

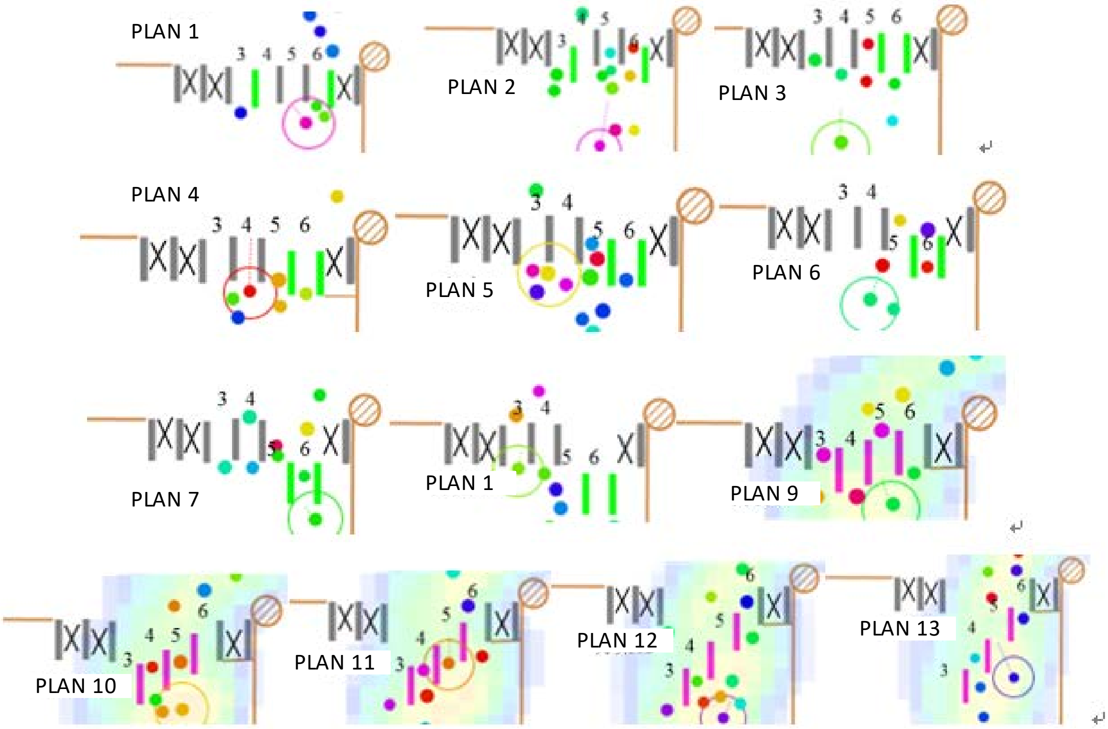

Figure 6. Improvement scheme for linear layout of brake machine

Table.5. Simulation results of station brake E

PLAN	Imbalance	Average queue length	Intensity	Plan analysis
1	0.571	0.234	0.637	Move No.3 and No.6 brake forward, d=0.25m
2	0.660	0.541	0.848	Move No.3 and No.6 brake forward, d=0.50m
3	0.175	0.304	0.566	Move No.5 and No.6 brake forward, d=0.25m
4	0.698	0.033	0.552	Move No.5 and No.6 brake forward, d=0.50m
5	0.634	0.078	0.548	Move No.5 and No.6 brake forward, d=0.75m
6	0.707	0.094	0.387	Move No.5 and No.6 brake forward, d=1.00m
7	0.715	0.119	0.346	Move No.5 and No.6 brake forward, d=1.25m
8	0.460	0.148	0.359	Move No.5 and No.6 brake forward, d=1.50m
9	0.104	0.156	0.459	Progressive arrangement of brake units, d=0.25m
10	0.108	0.238	0.466	Progressive arrangement of brake units, d=0.50m
11	0.175	0.299	0.308	Progressive arrangement of brake units, d=0.75m
12	0.169	0.234	0.282	Progressive arrangement of brake units, d=1.00m
13	0.154	0.250	0.278	Progressive arrangement of brake units, d=1.25m

6. Conclusion

Urban rail transit has become the most important public transport for residents in big cities, and new subway lines are built constantly. Therefore, it is particularly important to rationally arrange and use selling and checking facilities. From the perspective of reducing input cost and serving passengers, the station should make rational allocation and dynamic application of ticket selling and checking facilities to avoid excessive congestion or severe redundancy of facilities and ensure the service level and operation efficiency of urban rail transit stations. As a result, the transport capacity of urban rail transit has been improved.

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