Simulation for Service Facilities and Passenger Flow Organization Optimization on Railway Terminal

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Abstract—This paper takes railway terminal as research object, considers the diversity of passengers, and uses Anylogic software based on the social force model to build a dynamic simulation model of inbound walking path for complex passenger flow. Beijing West Railway Station is taken as an example, and equipment utilization balance degree (EUBD), passenger density (PD), average walking time (AWT), passenger queue length (PQL) are selected to evaluate, and optimization suggestions are put forward. Research shows that increasing the number of security inspection equipment, escalators can significantly improve the efficiency of passengers entering the terminal, and the average walking time at the entrance on the northwest and middle side of the second floor is reduced by 73.83%, 65.99% respectively.

1. INTRODUCTION
The railway terminal integrates various transportation methods such as railway, subway, bus, taxi, and handles passenger transport businesses. The service facilities and passenger flow organization affect the working efficiency of railway terminals directly. Therefore, it is of great significance to study the service facilities and passenger flow organization of railway terminal.

Most of the existing researches focus on the simulation analysis of local areas of subway stations or railway terminals. Chen Liyang [1] carried out simulation research on the layout of facilities in the hall of Beijing Metro Zoo Station, and used the flow density and average travel time to evaluate; Huang Wencheng [2] modeled and simulated the platform of Jianguomen subway station, and proposed that the width of the transfer stairs should be appropriately widened; Nie Guangyuan [3] simulated the pedestrian passage of Xizhimen subway station in Beijing, and gave the recommended passage width under different passenger flow conditions; Gong Yushu [4] simulated the process of passengers entering the station at the elevated level, and proposed to increase the number of service facilities to improve the efficiency; Xue Yanqing [5] carried out a simulation analysis of the passenger flow on the first underground floor of the Beijing South Railway Station, and provided an optimal scheme of the reasonable allocation and management of service equipment; Zhao Wenrui [6] used Anylogic simulation to analyze whether the number of existing service facilities in the waiting room best matched passenger demand in peak hours; Wen Nianci [7] used Arena software to simulate the south station of Nanjing railway station, and evaluated from three aspects: facility correlation, passenger average stay time and boarding comfort.

The above researches enrich the pedestrian simulation, but only considers the relationship between passenger behavior and facility layout in local area, and lacks the evaluation and analysis for the whole
area, and the inbound passenger flow of the whole area is more complex, so taking the whole railway terminal as the research object and considering the diversity of the passenger flow, the paper establishes a dynamic simulation model of the inbound walking path for complex passenger flow. And Beijing West Railway Station is taken as an example, equipment utilization balance degree (EUBD), passenger density (PD), average walking time (AWT) and the passenger queue length (PQL) are considered as evaluation indicators, and then an optimization scheme is proposed.

2. ANALYSIS OF PASSENGER FLOW COMPLEXITY IN RAILWAY TERMINAL

The complexity of passenger flow in railway terminal is reflected in the following aspects:

1. Multi-directional of inbound passenger flow. The railway terminal is the connecting and transferring place for the traffic inside and outside the city. It undertakes the transfer functions between various transportation modes. Passengers can choose various transportation means to arrive at the terminal. Due to the different operating characteristics of different transportation means, passengers will arrive at different position.

2. Dynamic space-time queuing of inbound passengers. When a large number of passengers enter, some equipment, such as stairs, escalators, security inspection equipment, etc., will be severely congested.

3. The complexity of passenger walking path. The railway terminal is generally the combination of underground and ground space with multiple entrances. When passengers enter, they often need to pass through multi-layer space and make multiple choices. The diversity of choices makes the walking path complicated.

3. MODEL ESTABLISHMENT

3.1. Simulation principle

Anylogic software is used. The core of Anylogic pedestrian simulation is based on the social force model. It is a continuous micro-simulation model, assuming that the pedestrian's walking behavior is influenced by the pedestrian's own driving force rather than the external force. According to the pedestrian's different walking purposes and the effect of the environment on him, the social force model considers three forces:

1. The pedestrian's own driving force: the "force" generated by the effect of individual subjective consciousness on his walking behavior, expressing the pedestrian's hope that he can walk at the expected speed.

2. Interpersonal force: The "force" generated by pedestrians' desire to keep a certain distance between others.

3. Force between person and boundaries: The force generated by pedestrian's keeping a certain distance with boundaries, which is similar to the interpersonal force.

The social force model is shown in Eq. (1).

\[
\frac{dr_a}{dt} = v_a \\
\frac{dv_a}{dt} = f_a(t) + \xi_a(t) \\
f_a(t) = f^0_a(v_a) + \sum_{i} f_{ai}(r_{ai}, v_{ai}, v_i) + \sum_{i} f_{ai}(r_{ai}, r_i, t)
\]

Where \( r_a \) is space position vector, \( v_a(t) \) is pedestrian speed, \( f_a(t) \) is the social force, \( \xi_a(t) \) is the disturbance term reflecting random action deviation, \( f^0_a(v_a) \) is the acceleration force, \( f_{ai}(r_{ai}) \) is the force between person and the boundaries, \( f_{ai}(r_{ai}, v_{ai}, v_i) \) is interaction between pedestrian and others, and. \( f_{ai}(r_{ai}, r_i, t) \) is the Attraction effect.
3.2. Simulation process
The simulation process mainly includes three parts: data collection, model establishment and evaluation and optimization of simulation results, as shown in Fig. 1.

(1) Data collection. It mainly collects terminal’s basic information and passenger related information, the former includes the plane layout and the service time of all kinds of service facilities, the latter mainly includes the number of passengers arriving and the walking path.

(2) Model establishment. First, combining the internal layout of the railway terminal and the relative position relation of various equipment and facilities, the paper draws plane layout in Anylogic software. Second, according to the investigation, the logic relationship of passengers entering is drawn and the parameters of relevant facilities and equipment modules are input. Finally, the effect evaluation indexes are set.

(3) Evaluation and optimization of simulation results. According to the results, the railway terminal is evaluated and analyzed, and corresponding optimization Suggestions are put forward. Then the simulation is conducted again, and the results before and after optimization are compared to verify that the optimization scheme could improve the service efficiency of the railway terminal.

4. Case Study

4.1. Establishment of dynamic simulation model of passenger walking path
BeijingWest Railway Station is taken as an example. There are 9 entrances, 5 in north square and 4 in south square, and 5 exits located on the first underground floor and the second underground floor, respectively. And there are 102 manual ticket checking gates, 55 automatic ticket checking machines, 41 security in total of 67 manual ticket windows, and 132 automatic ticket machines. And it is equipped with complete transfer facilities. Underground subway line 7 and line 9 are interchanged at the same platform, and bus hubs and taxi dispatch stations are situated in the north square and south square.

4.1.1. The logic relationship of passengers entering
The logic relationship of passengers entering is an important part in the model establishment. Based on the four-floor model of BeijingWest Railway Station, the real process of passenger entering is reflected in the logic frame diagram and all kinds of facilities and equipment are connected, it is shown in Fig. 2. passenger flow include ground passenger flow and underground passenger flow, the former refers to passengers arriving by buses, taxis and cars, while the latter refers to passengers arriving by subway.
4.1.2. Parameter settings.
The parameters mainly include model parameters and passenger parameters, between which the model parameters describe the characteristics of the facilities and equipment in BeijingWest Railway Station.

| Equipment                          | Capacity(per/h) | Simulation parameter |
|-----------------------------------|-----------------|----------------------|
| Automatic ticket machines         | 120             | Exponential(2)/min   |
| Automatic ticket checking machines| 720             | Exponential(12)/min  |
| Manual ticket windows             | 300             | Exponential(5)/min   |
| Security inspection equipment     | 360             | Triangular(8,12)/s   |

Passenger parameter is used to describe the passenger behavior, mainly including the number of passengers, passenger speed and so on. Passengers arrive at the station by different transportation means and choose different entrances. The arrival of subway passengers follows the uniform distribution, while other passenger flows follow the Poisson distribution. The specific parameters are shown in Table II and Table III.

| Means of transportation | Subway | Bus | Taxi | Car |
|-------------------------|--------|-----|------|-----|
| Proportion              | 52.1%  | 24.5% | 11.5% | 11.9% |

| Entrance                                | Passenger number(per/h) |
|-----------------------------------------|-------------------------|
| North entrance on the first floor        | 1444                    |
| North expressway passage on the first floor | 768                    |
| North entrance on the second floor       | 1152                    |
| Northeast entrance on the second floor   | 576                     |
| Northwest entrance on the second floor   | 482                     |
| South entrance on the first floor        | 4608                    |
| Southwest expressway passage on the first floor | 288                    |
| Southeast entrance                      | 291                     |

Passenger walking speed is an important parameter representing passenger traffic characteristics, composed by step length and step frequency. The specific parameters are shown in Table IV.
TABLE IV. THE NUMBER OF PEOPLE ENTERING EACH ENTRANCE

| Gender | Average speed | Initial speed | Comfort speed |
|--------|---------------|---------------|---------------|
| Male   | 1.3           | [0.5, 1.5]    | [0.8, 1.3]    |
| Female | 1.2           |               |               |

4.2. Analysis of simulation results

4.2.1. Analysis of equipment utilization balance degree (EUBD).
EUBD refers to the ratio of passenger number of the equipment with the highest utilization rate to the average passenger number of all similar equipment. It can effectively measure the coordination degree between facility layout and passenger flow distribution. It can be calculated that EUBD of security inspection equipment and automatic ticket machines at entrances is 1.71 and 1.98 respectively. According to relevant data, the appropriate interval of EUBD is (1, 1.2) in general, indicating the equipment utilization is seriously unbalanced. The reason is the uneven distribution of passenger flow, and the root cause is that some security inspection equipment and automatic ticket machines fail to meet the demand of large passenger flow.

4.2.2. Passenger density (PD) analysis
As can be seen from Fig. 3, PD at the escalators and staircases on each floor is relatively high, and PD at security inspection equipment and automatic ticket machines is mostly red, which indicates serious queue and congestion. The analysis shows that the number of these equipment is insufficient and cannot meet the passenger’s demand.

4.2.3. Analysis of average walking time (AWT)
AWT is the average time taken by all passengers from arriving at the terminal to entering the waiting room (excluding waiting time other than queuing and walking). In this paper, AWT at different entrances is taken as the research object, as shown in Fig. 4.
As can be seen from Fig. 4, AWT gradually increases with time. This is because passengers will queue when the number of passengers arriving exceeds the capacity. And AWT in the south square is generally higher than that in the north square. Although the number of passengers in the north and south squares is roughly the same, the number of entrances in the south square are less than that in the north square, passengers in the south square converge at the three entrances, in which case, passenger flow cannot be effectively dispersed.

4.2.4. Analysis of passenger queue length (PQL) in different service facilities
As can be seen from Fig. 5, there are great differences at different entrances. A lot of passengers queue in northwest entrance on the second floor, southwest expressway passage on the first floor, north entrance on the second floor and south entrance on the first floor, the number is growing linearly. The main reason is that the number of security inspection equipment at these entrances is insufficient.

As can be seen from Fig. 6, PQL in South 1 ticket office and South 2 ticket office shows a linear growth trend, while PQL at other automatic ticket machines increases slightly but generally tends to be stable. The analysis shows that there are a few automatic ticket machines in the South Square, which cannot meet the demand.
4.3. Simulation optimization

According to the above analysis, there are different congestion in escalators, security inspection equipment and automatic ticket machines. Due to the continuous promotion and application of railway e-ticket, the automatic ticket machines will be replaced. Therefore, this paper puts forward the following scheme mainly from the improvements of security inspection equipment and escalators.

(1) Increase the number of security inspection equipment in northwest entrance on the second floor, southwest expressway passage on the first floor, north entrance on the second floor and south entrance on the first floor. According to PQL at the four entrances and AWT, it is proposed to add 1-2 security inspection equipment at each of the four entrances.

(2) Increase the number of escalators on the second and first floor underground, and arrange the station staff to effectively guide the passenger flow. According to PD in the second and first floor underground, it is proposed to add one escalator in every place of the second and first floor underground.

The optimized PD, PQL and AWT are shown in Fig. 7, Fig. 8 and Table V.
The comparison between Fig. 3 and Fig. 7 shows that the overall PD in Beijing West Railway Station has declined, the PD at each escalator and PQL at the security inspection equipment at each entrance have also been decreased, indicating that the optimization scheme is effective. However, it can be found from Fig. 7 that PD in the south square is still higher than that in the north square. And it is calculated that EUBD of security inspection equipment is 1.60, indicating that the utilization imbalance still exists. The analysis shows that although the number of passengers entering two squares is approximately equal, there are fewer entrances in the south square, making the equipment pressure at each entrance of the south square higher, while the equipment pressure at the north square is lower. Further research can be conducted on whether the equipment utilization at each entrance can be more balanced by means of passenger flow induction.

By comparing Fig. 5 and Fig. 8, after optimization, PQL in the northwest entrance on the second floor, southwest expressway passage on the first floor, north entrance on the second floor and south entrance on the first floor has been significantly reduced and gradually stabilized.

It can be seen from Table V that after optimization, AWT at each entrance has been reduced, among which, AWT in the northwest entrance on the second floor is reduced by 73.83%, and AWT in the north entrance on the second floor is reduced by 65.99%, significantly improving the efficiency of passengers entering.

| Entrance                                      | Before improvement | After improvement | Time saved(%) |
|-----------------------------------------------|--------------------|------------------|---------------|
| North entrance on the first floor             | 6.8                | 6.3              | 7.41          |
| North expressway passage on the first floor   | 11.03              | 5.49             | 50.17         |
| North entrance on the second floor            | 5.73               | 1.95             | 65.99         |
| Northeast entrance on the second floor        | 14.49              | 3.79             | 73.83         |
| Northwest entrance on the second floor        | 7.31               | 6.36             | 13.03         |
| South entrance on the first floor             | 14.26              | 11.55            | 18.99         |
| Southwest expressway passage on the first floor | 14.14              | 12.72            | 10.04         |
| Southeast entrance                            | 15.84              | 14.94            | 5.68          |
5. CONCLUSION
This paper establishes a dynamic simulation model of inbound walking path for complex passenger flow and take BeijingWest Railway Station as an example. The results show that:

(1) After optimization, the overall PD is reduced, PD at each escalator and PQL at the security inspection equipment at each entrance are also decreased, and AWT is reduced, among which, AWT in the northwest entrance on the second floor is reduced by 73.83%, and AWT in the north entrance on the second floor is reduced by 65.99%.

(2) After optimization, EUBD of security inspection equipment is reduced, but the utilization imbalance still exists. And further research can be conducted on whether the equipment utilization at each entrance can be more balanced by means of passenger flow induction.

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