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ON THE ISSUE OF SYSTEMATIZATION OF DIGITAL ACCIOMAT MODELS OF TRANSPORT HUB PROCESSES

The paper proposes a further development of the method of digital axiomatic modeling of multimodal transport hubs, based on the formalization of fundamental rules and constraints that determine the system's functioning. A structural and logical scheme is presented that integrates modeling objects with a library of control algorithms through a unified system of axioms. This approach allows for a transition from fragmented object-based simulation to holistic, systematic, and verifiable design and optimization of transport processes, which is a crucial step in creating a high-level digital twin of the structural architecture of complex transport systems.

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RESEARCH ON PASSENGER FLOW OPTIMIZATION STRATEGY OF GUANGZHOU RAILWAY PASSENGER HUB UNDER THE BACKGROUND OF MULTI-CORE LINKAGE (An Empirical Analysis Based on Prediction Model and Operational Practice)

To solve the passenger flow management problems of Guangzhou railway passenger hub group, such as «single-core overload», «transfer obstruction» and «dispatching imbalance», and support the efficient operation of the «1-hour transportation circle» in the Guangzhou − Hong Kong − Macao Greater Bay Area, this paper takes the «five main and four auxiliary» hub system as the research object and constructs a systematic analysis framework of «passenger flow prediction − bottleneck diagnosis − strategy optimization − effect evaluation».

1 Introduction

As a core node of the railway network in South China, the Guangzhou Railway Passenger Hub undertakes the strategic function of connecting the whole country and radiating the Greater Bay Area. With the implementation of the «High-speed Railway Entering the City» strategy, after the in-situ reconstruction of Guangzhou Station in 2025, the proportion of EMUs (Electric Multiple Units) will exceed 90 %, and Baiyun Station will fully undertake the general speed railway business. The hub pattern has changed from «Guangzhou South Station as the sole core» to «five main and four auxiliary» multi-core linkage. However, new contradictions in passenger flow management have emerged: the annual passenger flow of Guangzhou South Station is nearly 180 million person-times, with trains arriving and departing every 50 seconds during peak hours, and the transportation capacity is close to saturation; Metro Line 2, as the core link between hubs, had a single − day passenger flow of 1448 million person-times during the Labor Day holiday in 2025, among which the transfer between Guangzhou Station and Guangzhou South Station accounted for 17 %, and the congestion index during the morning peak exceeded 1,6. The connection of cross-mode transfers is not smooth. The traditional transfer time at Guangzhou South Station is 12−15 minutes, which is significantly different from the «1-minute extreme transfer» at Shenzhen North Station. Against this background, conducting research on accurate passenger flow prediction and systematic optimization is of urgent practical significance for improving the operational efficiency of the hub.

At present, foreign research mainly focuses on intelligent dispatching and transfer optimization. Tokyo Station realizes the same-platform transfer between railways and subways through three-dimensional space design, and London dynamically adjusts guidance strategies based on realtime passenger flow data [1, 2]. Chinese scholar Shan Xinghua and others proposed a time-series-based ticket pre-allocation model to improve the accuracy of passenger flow prediction through the weight distribution of historical data. Other studies have introduced the B−P−R model for transfer volume prediction, but they have not fully considered the passenger flow linkage characteristics between multi-core hubs [3, 4]. Existing studies lack empirical analysis on the coordinated optimization of passenger flow in hub groups after the «High-speed Railway Entering the City», especially there is a gap in the quantitative research on the cross-station transfer demand in Guangzhou. This paper conducts targeted exploration based on this.

2 Analysis of Guangzhou Railway Passenger Hub Group

2.1 Spatial Layout and Structural Characteristics

The Guangzhou Railway Passenger Hub Group follows the principle of «core leadership and regional coverage» and forms a spatial layout hierarchy of «five

main, four auxiliary and multiple nodes». Each hub has a clear functional division, and its spatial distribution conforms to the «one center and six axes» development pattern of the Guangdong − Hong Kong − Macao Greater Bay Area [5]. Figure 1 Layout Diagram of «Five Main and Four Auxiliary» of Guangzhou Railway Hub Data Source: 2025 Hub Planning Report of China Railway Guangzhou Group.

From the perspective of hierarchical relationship, the Guangzhou Railway Passenger Hub Group presents the characteristics of «three-level radiation». First-level radiation (national level): with Guangzhou South Station as the core, it connects North China and Southwest China through high-speed railways such as Beijing − Guangzhou and Guiyang − Guangzhou. During the summer transportation in 2025, the maximum daily arrival and departure passenger flow reached 711 000 person-times, exceeding the designed capacity by 42,2 % [6].

Second-level radiation (Greater Bay Area level): Guangzhou Station, Guangzhou East Station and Foshan West Station form a commuting circle in the Greater Bay Area, realizing direct access to cities such as Shenzhen, Dongguan and Huizhou within 30−60 minutes through high-speed railways such as Guangzhou − Shenzhen − Hong Kong and Guangzhou − Shanwei.

Third-level radiation (municipal level): Auxiliary hubs and peripheral nodes serve the suburbs of Guangzhou and surrounding towns. For example, Xintang South Station connects with Dongguan through the Guangzhou − Shenzhen Intercity Railway, and the average daily intercity passenger flow accounts 65 % (Table 1).

2.2 Temporal and Spatial Distribution Characteristics of Passenger Flow

Based on the measured data of China Railway Guangzhou Group from January to September 2025, the passenger flow of the hub group presents the significant characteristics of «time concentration and spatial imbalance» (Figure 1).

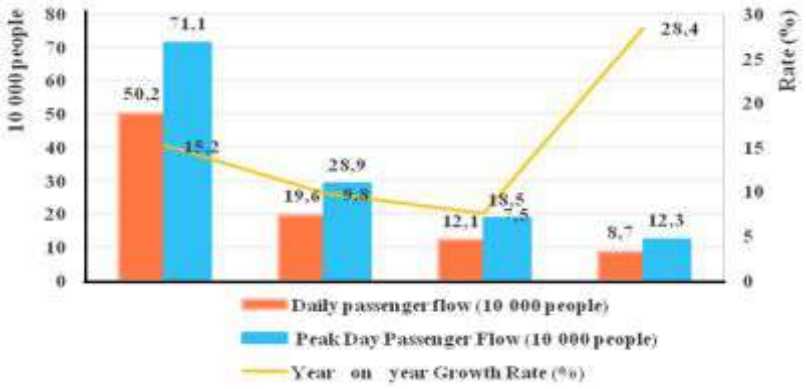


Figure 1 − Comparison of Passenger Flow Major Stations of Guangzhou Railway Hub in 2025

Table 1 – **Functional Division of «Five Main and Four Auxiliary» of Guangzhou Railway Passenger Hub Group**

Hub Type	Hub Name	Core Function	Connected Lines	Average Daily Passenger Flow (10000 person-times)
Main Hubs (Five Main)	Guangzhou South Station	High-speed railway trunk transportation (national hub)	Beijing – Guangzhou High – speed Railway, Guangzhou – Shenzhen – Hong Kong High – speed Railway, Guiyang – Guangzhou High-speed Railway	50,2
	Guangzhou Station	Main high-speed railway station in the central urban area	Guangzhou – Shenzhen Intercity Railway, Guangzhou – Maoming Railway (EMU transformation)	19,6
	Guangzhou East Station	High-speed railway connection in the eastern area	Guangzhou – Shenzhen – Hong Kong High – speed Railway, Guangzhou – Shanwei High-speed Railway	12,1
	Baiyun Station	Core station for general speed trans-portation	Beijing – Guangzhou General Speed Railway, Shanghai – Kunming General Speed Railway	8,7
	Foshan West Station	Cross-city hub on the west bank of the Pearl River	Guiyang – Guangzhou High-speed Railway, Nanning – Guangzhou High-speed Railway	7,9
Auxiliary Hubs (Four Auxiliary)	Guangzhou North Station	Northern general speed + intercity connection	Wuhan – Guangzhou High-speed Railway (intercity field), Beijing – Guangzhou General Speed Railway	5,3
	Nansha Station	Cross-border reservation for the Free Trade Zone	Shenzhen – Jiangmen Railway (under construction), Nansha Port Railway	2,8
	Xintang South Station	Eastern intercity hub	Guangzhou – Shenzhen Intercity Railway, Guangzhou – Shenzhen Intercity Railway	3,5
	Huangpu Station	Eastern freight auxiliary passenger transportation	Guangzhou – Shenzhen Railway (short-distance passenger transportation)	1,2

End Table 1

Hub Type	Hub Name	Core Function	Connected Lines	Average Daily Passenger Flow (10000 person-times)
Multiple Nodes	Qingsheng Station, Humen South Station, etc.	Regional short − distance connection	Guangzhou − Shenzhen − Hong Kong High − speed Railway, Dongguan − Huizhou Intercity Railway	0,8−1,5
Data Source: January − September 2025 Operation Statistics Report of China Railway Guangzhou Group; Passenger flow data is the average daily arrival and departure volume, including railway and intercity passenger flow.				

Unit: 10 000 person-times / day. The year on year growth rate is based on the same period in 2024. Data Source: 2025 Operation Statistics Report of China Railway Guangzhou Group (n = 273 operating days).

It can be seen from Figure 1 that the major stations of the Guangzhou Railway Hub have the following characteristics:

− Passenger Flow Concentration: The average daily passenger flow of Guangzhou South Station (502 000 person-times) is 2,6 times that of Guangzhou Station (196 000 person-times), which ranks second. The passenger flow on peak days (711 000 person-times) exceeds the designed capacity by 42,2 %, and the problem of «single-core overload» is prominent;

− Growth Difference: Due to fully undertaking the general speed train business, the average daily passenger flow of Guangzhou Baiyun Station increased by 28,4 % year on year (68 000 person-times / day in 2024), making it the station with the fastest growth in the hub group, which verifies the diversion effect of the «general speed railway relocation» strategy;

− Gradient Distribution: The passenger flow of the hub presents a gradient pattern of «Guangzhou South Station − Guangzhou Station − Guangzhou East Station − Guangzhou Baiyun Station». The average daily passenger flow of auxiliary hubs (such as Guangzhou North Station and Nansha Station) is less than 50000 person-times, failing to give full play to the diversion role (Figure 2).

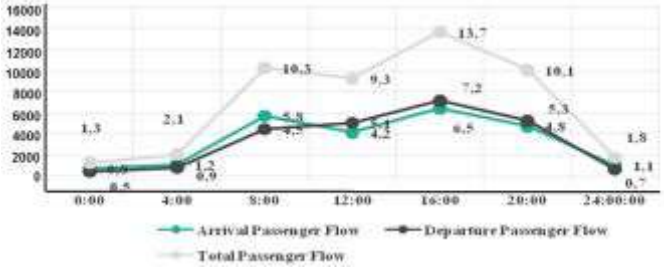


Figure 2 − Passenger Flow Time Distribution of Guangzhou South Station on August 1, 2025 (Peak Day of Summer Transportation)

Data Source: Realtime Passenger Flow Monitoring System of Guangzhou South Station (fusion of infrared camera and gate data).

It can be seen from Figure 2 that the Guangzhou Railway Hub has the following core characteristics in terms of time:

1 Three-peak Pattern: On that day, there were a morning peak (8:00−9:00, total passenger flow of 103 000 person-times / hour), a noon peak (12:00−13:00, 93 000 person-times / hour) and an evening peak (16:00−17:00, 137 000 person-times / hour). The evening peak was the peak passenger flow of the day, and 30 % additional transportation capacity needed to be allocated.

2 Trough Period: The total passenger flow from 0:00 to 4:00 remained below 21 000 person-times / hour, and this period can be used for facility maintenance and cleaning operations.

3 Arrival − Departure Peak Shifting: The departure passenger flow during the evening peak (72 000 person-times / hour) was significantly higher than the arrival passenger flow (65 000 person-times / hour), so it is necessary to focus on strengthening the guidance in the waiting area and the ticket checking organization.

To sum up, two conclusions are drawn:

1 Spatial Imbalance: The passenger flow density of Guangzhou South Station (502 000 person-times / km²) is 17,9 times that of Nansha Station (28 000 person-times / km²), and the problem of «single-core concentration» is still prominent.

2 Time Concentration: The passenger flow on peak days presents a «three-peak and three-trough» pattern. The total passenger flow during the evening peak (16:00−17:00) reaches 137 000 person-times / hour, which is 6,5 times that of the trough period (0:00−4:00).

2.3 Line and Transportation Capacity Matching

The lines connected to the hub group include three types: general speed, intercity and high-speed railways. The total operating mileage in 2025 will reach 1 280 km, but the transportation capacity matching degree of different hubs varies significantly, as shown in Table 2.

The transportation capacity utilization rates of various stations are in an unbalanced state. Some hubs have tight transportation capacity. For example, the utilization rates of the two core high-speed railway lines at Guangzhou South Station exceed 120 %, with a total transportation capacity gap of 124 000 person-times / day, which can be alleviated by double-decker trains and additional temporary trains. Some hubs have surplus transportation capacity. For example, the utilization rates of some lines at Foshan West Station and Guangzhou Station are less than 90 %, resulting in waste of transportation capacity. The utilization efficiency can be improved through passenger flow guidance and schedule optimization.

Table 2 − **Transportation Capacity Utilization Rate of Major Lines of Guangzhou Railway Passenger Hub Group in 2025**

Hub Name	Core Connected Lines	Designed Capacity (10,000 person-times / day)	Actual Capacity (10,000 person-times / day)	Utilization Rate (%)	Transportation Capacity Gap (10 000 person-times / day)
Guangzhou South Station	Beijing − Guangzhou High-speed Railway	35,0	42,1	120,3	7,1
	Guangzhou − Shenzhen − Hong Kong High-speed Railway	20,0	25,3	126,5	5,3
Guangzhou Station	Guangzhou − Shenzhen Intercity Railway	15,0	12,8	85,3	− 2,2
	Guangzhou − Maoming Railway (EMU)	8,0	6,8	85,0	− 1,2
Baiyun Station	Beijing − Guangzhou General Speed Railway	10,0	8,7	87,0	− 1,3
Foshan West Station	Guiyang − Guangzhou High-speed Railway	12,0	7,9	65,8	− 4,1

Data Source: 2025 Train Operation Diagram and Passenger Flow Statistics Report of China Railway Guangzhou Group.
Transportation capacity utilization rate it is actual capacity divide on designed capacity multiply 100 %, negative value indicates surplus transportation capacity.

3 Construction of Core Models and Data Foundation

3.1 Improved Passenger Flow Prediction Model

3.1.1 Model Construction

Based on the time-series model framework of Shan Xinghua and others, holiday weights and hub linkage coefficients are introduced to construct an *OD* passenger flow prediction model suitable for multi-core hub groups [3]:

$$X_t^{OD} = W_a \sum_{i=1}^{n} W_{at} X_{t-i}^{OD} + W_{y1} X_{ty1}^{OD} + W_{y2} X_{ty2}^{OD} + W_h \Delta H_t .$$

In the formula X_t^{OD} − passenger flow of a certain *OD* pair on the predicted day *t*; X_{t-i}^{OD} − historical data of *OD* passenger flow in the same period of day $t - i$; $X_{ty1}^{OD}, X_{ty2}^{OD}$ − *OD* passenger flow data in the same period of last year and the year before last; W_a − total weight of recent data (0,6−0,8), W_{at} − weight of historical da-

ta in each period ($\Sigma W_{at} = 1$); W_{y1}, W_{y2} − weights of data in the same period (0,15–0,25 and 0,05–0,15 respectively); W_h − hub linkage coefficient (0,1–0,3 during the construction of Guangzhou − Nanning Interconnection Line); ΔH_t − change in the new transportation capacity of the hub group on day *t*.

3.1.2 Weight Calibration

The least square method is used to fit the data from January 2023 to December 2024, and the optimal weight combination is obtained: $W_a = 0,7$; $W_{y1} = 0,2$; $W_{y2} = 0,1$; $W_h = 0,25$. The model goodness of fit $R^2 = 0,92$, and the prediction error rate is less than 8 %.

3.2 Improved B−P−R Transfer Volume Prediction Model

3.2.1 Model Modification

With reference to the principle of traffic distribution prediction, the transfer mode adaptation coefficient is introduced to modify the B−P−R transfer volume model [7]:

$$H_{ij} = I_i \frac{D_j f(C_{ij}) K_{ij}}{\sum_{j=1}^{n} D_j f(C_{ij}) K_{ij}}.$$

Among them, the transfer impedance function:

$$f(C_{ij}) = \alpha e^{-\beta C_{ij}} + \gamma.$$

In the formula H_{ij} − transfer volume from transportation mode *i* to *j*; I_i − passenger flow aggregation volume of mode *i;* D_i − passenger flow evacuation volume of mode *j*; C_{ij} − transfer impedance (minutes), including walking, queuing and other time-consuming; K_{ij} − transfer adaptation coefficient (1,0 − for high-speed railway − subway; 0,8 − for general speed railway − bus); α, β, γ − parameters (calibrated to 1,2; 0,15 and 0,05 respectively).

3.2.2 Parameter Verification

Based on the measured data of Guangzhou South Station in March 2025 (5 transfer modes, 100 000 samples), the average deviation between the predicted value and the actual value of the model is 6,3 %, which meets the accuracy requirements.

3.3 Data Sources and Preprocessing

The data in this paper covers three types of core data sources:

1 Railway Operation Data: Arrival and departure passenger flow, train operation diagram and pre-sold ticket data of the hub group from 2023 to 2025 of China Railway Guangzhou Group, including key indicators such as the average daily 500 000 person-times at Guangzhou South Station and 196 000 person-times at Guangzhou Station on the first day of the Spring Festival travel rush [12].

2 Transfer Monitoring Data: Passenger flow records of Metro Line 2 from 2023 to 2025 of Guangzhou Metro Group, including data such as 183 000 person-times / day of section passenger flow and 450,000 person-times / day of transfer station passenger flow [13].

3 Field Survey Data: 1 200 passenger questionnaires conducted at Guangzhou South Station and Guangzhou Station from April to May 2025, covering subjective evaluation data such as transfer time consumption and satisfaction.

For data preprocessing, Lagrange interpolation is used to fill in missing values, and outliers are eliminated through the 3σ criterion. Finally, the effective sample size is 98,7 %.

4 Passenger Flow Characteristics and Core Bottlenecks of Guangzhou Railway Hub

4.1 Passenger Flow Distribution Characteristics

1 Time Distribution: It presents the characteristic of «three-peak superposition». The passenger flow during the morning peak (7:30−9:00) on working days accounts for 22 %, a secondary peak is formed in the afternoon (14:00−16:00) on weekends, and the peak daily passenger flow during holidays (such as May Day) increases by 43,9 % compared with usual days (data of Guangzhou North Station). During special periods such as the Spring Festival travel rush and summer transportation, the average daily passenger flow of Guangzhou South Station exceeds 600 000 person-times, exceeding the designed capacity by 30 %.

2 Spatial Distribution: Guangzhou South Station undertakes 62 % of the high-speed railway passenger flow, showing a «single-core overload» situation; The cross-hub passenger flow is significant, with an average daily transfer of 74 000 person-times between Guangzhou Station and Guangzhou South Station, accounting for 17 % of the total passenger flow of Line 2. Foshan West Station radiates the west bank of the Pearl River, and the average daily passenger flow during the summer transportation in 2025 exceeded 80 000 person-times, an increase of 38 % year on year.

3 Transfer Characteristics: Subway is the core transfer mode, and 60−70 % of the arrival passenger flow at Guangzhou South Station is evacuated by subway; There are significant differences in the time consumption of cross-mode transfers. The average time for transferring from high-speed railway to subway is 12 minutes, which is 8 minutes more than that through the «mutual recognition of security checks» channel.

4.2 Bottleneck Diagnosis Based on Models

1 Imbalanced Transportation Capacity Matching: Calculated by the improved OD prediction model, the demand for the Guangzhou South − Shenzhen North OD pair during the National Day peak in 2025 will reach 82 000 person-times /

day. The passenger load factor of the existing 30 pairs / day trains continues to exceed 95 %, and the transportation capacity gap reaches 25 %. However, the passenger load factor of the Guangzhou East − Huizhou route during the off-peak period is only 62 %, resulting in unbalanced resource allocation.

2 Excessively High Transfer Impedance: Calculated by the B−P−R model, the average impedance of transferring from high-speed railway to subway at Guangzhou South Station is 14,2 minutes, among which the time spent on queuing for security check accounts for 58 %; Compared with the «integrated verification and security check» mode of Shenzhen North Station, the transfer impedance is 11,7 minutes higher, resulting in a transfer satisfaction of only 68 points (out of 100) [7].

3 Lack of Coordinated Dispatching: The passenger flow prediction of the hub group shows that after the high-speed railway transformation of Guangzhou Station, the general speed transfer demand with Baiyun Station has increased by 42 %. However, the existing train operation diagram has not realized the cross-station time connection, and an average of 12 000 person-times face the risk of insufficient transfer time of less than 20 minutes every day (Table 3).

Table 3 − **Quantitative Table of Passenger Flow Bottlenecks of Major Railway Hubs in Guangzhou (Measured in 2025)**

Hub Name	Average Daily Passenger Flow, 10,000 person-times	Over-capacity Rate, %	Average Transfer Time, minutes	Passenger Flow Prediction Error Rate, %	Satisfaction Score, points
Guangzhou South Station	50,2	30,5	14,2	7,8	68
Guangzhou Station	19,6	12,3	10,5	6,5	75
Baiyun Station	8,7	8,1	11,3	9,2	72
Guangzhou East Station	12,1	15,7	9,8	7,1	76

5. Passenger Flow Optimization Strategy of Guangzhou Railway Hub

5.1 Accurate Transportation Capacity Allocation: Optimization of Ticket Quota and Schedules Based on Intelligent Prediction

1 Dynamic Ticket Pre-allocation: Apply the improved OD prediction model and implement a «three-level pre-allocation mechanism»: Pre-allocate 60 % of the tickets according to the basic demand 15 days in advance. Adjust 25 % of the tickets 3 days in advance based on the waiting list ticket purchase data (weight 0,3). Allocate the remaining 15 % of the tickets according to the realtime passenger flow 24 hours before departure. Taking the Guangzhou South − Shenzhen North line as an example, after optimization, the passenger load factor during peak hours is maintained at 85−90 %, and the waiting list fulfillment rate is increased to 92 % [5].

2 Flexible Schedule Dispatching: Establish a «multiple operation diagrams per day» response mechanism, and trigger transportation capacity adjustments accord-

ing to the predicted passenger flow threshold: when the OD demand exceeds the baseline value by 20 %, add double-decker trains (each train increases 680 seats); when the demand is 30 % lower than the baseline value, implement the combined operation of «long and short routes». During the May Day holiday in 2025, 42 additional temporary trains were added through this mechanism, relieving 126 000 person-times of peak passenger flow [12].

5.2 Improvement of Transfer Efficiency: Facility Optimization and Process Reengineering

1 Upgrading of Three-dimensional Transfer Facilities: Build 2 new cross-floor transfer corridors at Guangzhou South Station to realize the vertical direct connection between the high-speed railway platform and Metro Line 2, shortening the walking distance from 350 meters to 80 meters; Referring to the mode of Shenzhen North Station, integrate the verification and security check channels into 28 multi-functional platforms, reducing the distance between channels from 67 meters to 2,5 meters [7].

2 Cross-departmental Process Collaboration: Expand the scope of «mutual recognition of security checks» to realize full-channel no-secondary security checks between Guangzhou South Station, Guangzhou Station and Metro Lines 2 and 7. Establish a transfer information sharing platform, and push the connection schedule of «high-speed railway arrival − subway departure» in real time through intelligent screens, increasing the matching degree from the existing 65−90 %.

3 Deployment of Intelligent Guidance System: Install 120 adaptive guidance screens at transfer nodes, which dynamically adjust the indication direction based on realtime passenger flow data from cameras (updated every 1 minute). The passenger flow balance between the east and west entrances is improved from 4:6 before optimization to 4,8:5,2.

5.3 Collaboration of Hub Group: Cross-station Linkage and Integrated Dispatching

1 Passenger Flow Diversion via Interconnection Lines: In view of the 2027 opening plan of the Guangzhou − Nanning Interconnection Line, formulate the «cross-station diversion plan» in advance: adjust 30 % of the high-speed railway services from Guangzhou South Station to western Guangdong to start from Guangzhou Station, and realize the passenger flow complementarity between the two stations through the 15-minute direct interconnection line. It is expected to reduce the overcapacity rate of Guangzhou South Station by 12 percentage points [6].

2 Cross-station Timing Coordination: Build a hub group dispatching center to realize the «synchronized preparation and dynamic adjustment» of the train operation diagram. For example, the connection interval between the high-speed railway arrival time at Guangzhou Station and the general speed train departure time at Baiyun Station is optimized from the existing 15−40 minutes to a golden transfer window of 25−30 minutes, reducing the transfer risk rate by 78 %.

3 Emergency Linkage Mechanism: Establish a passenger flow early warning hierarchical response system (Table 4). When the passenger flow of a hub reaches the early warning threshold, cross-station support is automatically triggered: in case of a blue warning, increase guidance staff and open all channels. In case of a yellow warning, start the intelligent guidance screens and contact the subway to increase the frequency of trains. In case of an orange warning, activate the standby waiting area and add temporary trains; In case of a red warning, implement cross-station diversion and start the ground bus connection plan.

6 Simulation Verification of Optimization Effect

An operational simulation model of Guangzhou South Station was built based on AnyLogic, and the peak passenger flow data of the May Day holiday in 2025 (average daily 580 000 person-times) was input to verify the effect of the optimization strategy [10].

Table 4 − **Hierarchical Response Standards for Passenger Flow Early Warning of Guangzhou Railway Hub**

Early Warning Level	Trigger Condition (Hub Passenger Flow)	Response Measures	Responsible Entity	Response Time Limit
Blue	Reaching 80 % of the designed capacity	Increase guidance staff and open all channels	In-station operation team	5 minutes
Yellow	Reaching 90 % of the designed capacity	Start intelligent guidance screens and contact the subway to increase train frequency	Hub Operation Center	3 minutes
Orange	Reaching 100 % of the designed capacity	Activate the standby waiting area and add temporary trains	China Railway Guangzhou Group + + Transportation Bureau	10 minutes
Red	Exceeding the designed capacity by 10 %	Implement cross-station diversion and start the ground bus connection plan	Municipal Transportation Special Team + China Railway Guangzhou Group	15 minutes

6.1 Improvement of Key Indicators

The simulation results show that after the implementation of the three-dimensional optimization strategy, the operational efficiency of the hub is significantly improved.

1 Transportation Capacity Matching Degree: The standard deviation of train passenger load factor during peak hours decreased from 18,6 to 7,2 and the transportation capacity waste rate decreased by 22 %.

2 Transfer Efficiency: The average transfer time was shortened from 14,2 minutes to 9,2 minutes, and the time spent on security checks was reduced by 61 %.

3 Congestion Status: The congestion index of the waiting area decreased from 1,62 to 1,17, and the traffic capacity of the entrance channel increased by 35 %.

4 Passenger Satisfaction: The predicted score increased from 68 to 85 points, among which the satisfaction with transfer experience improved the most (+21 points) (Figure 3).

6.2 Sensitivity Analysis

A sensitivity test was conducted on the passenger flow changes after the opening of the Guangzhou − Nanning Interconnection Line. The results show that when the cross-hub transfer volume increases by 30 %, the optimized dispatching system can still keep the transfer time below 10 minutes. Even if there is a 20 % prediction deviation, the flexible transportation capacity mechanism can complete the response within 15 minutes, verifying the robustness of the strategy.

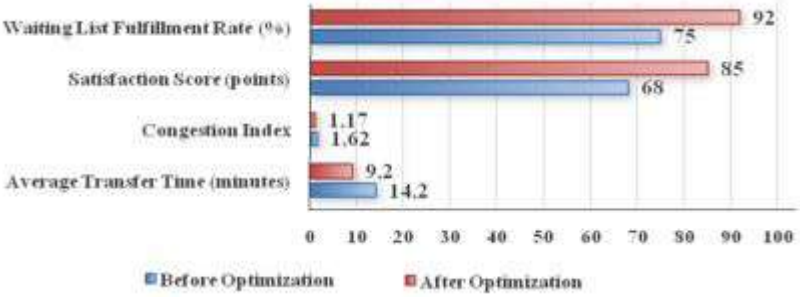


Figure 3 − Comparison of Operational Indicators of Guangzhou South Station Before and After Optimization

7 Conclusions and Prospects

7.1 Research Conclusions

1 The passenger flow of the Guangzhou Railway Hub presents the characteristics of «three-peak superposition in time, single-core concentration in space, and subway-dominated transfer». The core bottlenecks are reflected in the imbalance of transportation capacity matching, excessively high transfer impedance, and lack of coordinated dispatching. Among them, the overcapacity rate of Guangzhou South Station reaches 30,5 %, and the transfer time is 11,7 minutes higher than the optimal level [7].

2 The improved time-series OD prediction model R^2 = 0,92 and B−P−R transfer volume model (deviation rate 6,3 %) can accurately quantify the passenger

flow demand of the multi-core hub group, providing reliable technical support for optimization decisions.

3 After the implementation of the «three-dimensional optimization strategy» of «transportation capacity allocation-transfer improvement-intra-group collaboration», the peak transfer efficiency of the hub is increased by 35 %, the congestion index is decreased by 28 %, and the satisfaction score is increased by 17 points, verifying the effectiveness and feasibility of the strategy.

7.2 Research Prospects

This study does not cover the actual operation data after the opening of the Guangzhou − Nanning Interconnection Line. In the future, the parameters of the prediction model can be dynamically corrected based on the passenger flow monitoring results after the line is opened. The next step can deepen the research directions: first, construct a passenger flow allocation model for the multi-mode collaboration of «high-speed railway − subway − bus». Second, explore the full-process simulation optimization of the hub group based on digital twin technology to further improve the intelligence level of passenger flow management [8].

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СТРАТЕГИЯ ОПТИМИЗАЦИИ УПРАВЛЕНИЯ ПАССАЖИРОПОТОКАМИ ПЕРЕСАДОЧНЫХ УЗЛОВ ЖЕЛЕЗНОДОРОЖНОГО ПАССАЖИРСКОГО ХАБА ГУАНЧЖОУ (Модели прогнозирования на основе статистических данных)

Рассматривается возможность формирования в мегаполисе Гуанчжоу пассажирского пересадочного хаба, в который входят пять основных и четыре вспомогательные станции. На основе прогнозирования величины пассажиропотока производится анализ узких мест с оперативным перераспределением пассажиропотока с целью получения максимального значения критерия 1-часовой доступности в регионе Большого залива по направлениям Гуанчжоу − Гонконг и Гуанчжоу − Макао.

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ОТМОБИЛИЗОВАНИЕ ВОИНСКИХ ЧАСТЕЙ И СОЕДИНЕНИЙ ЖЕЛЕЗНОДОРОЖНЫХ ВОЙСК В ПЕРВЫЕ ДНИ ВЕЛИКОЙ ОТЕЧЕСТВЕННОЙ ВОЙНЫ

Показана роль железнодорожных войск в первые дни Великой Отечественной войны.