

Research Article

Coordination and Optimization of Long-Distance Passenger Departure Timetable Connected to High-Speed Railway Station: Considering the Heterogeneity of Transfer Passengers Demand

Bing Zhang ¹, Dandan Zhou ¹, Nana Huang,² Xun Zhou,³ and Xunyou Ni¹

¹School of Transportation Engineering, East China Jiaotong University, Nanchang 330013, China

²Jinhua Municipal Design Institute Co., Ltd., Jinhua, China

³Jiangxi Comprehensive Transportation, Development Research Center, Nanchang, China

Correspondence should be addressed to Bing Zhang; zhangbing@ecjtu.edu.cn and Dandan Zhou; 2020138086100022@ecjtu.edu.cn

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Optimizing the departure timetable of long-distance passenger transport connected to high-speed railway stations can not only improve the attractiveness of long-distance passenger transport, reduce the loss of passengers, but also alleviate the pressure of passenger flow accumulation caused by uneven arrival of high-speed railways. Considering the demand heterogeneity of high-speed railway outbound transfer passengers and analyzing the characteristics of transfer travel time, a multiobjective optimization model with unequal interval departures is established. The model takes the minimum total cost and the highest transport capacity as the goal, with the constraints of the departure interval, the waiting time of the stranded passengers, the amount of passenger loss, etc., to optimize the adjustment of the departure interval and the number of departures for long-distance passenger transport and to answer it with the help of Matlab and Lingo software. The calculation results show that the optimized timetable strengthens the synchronous connection with the arrival of small peaks of passenger flow and improves the matching degree of transportation capacity and passenger flow demand. The total passenger transfer time after optimization is reduced by 10.53 h, and the transfer time per capita is reduced by 189.54 s.

1. Introduction

The optimization of transfers between high-speed railway stations and long-distance passenger stations occupies an essential part in urban traffic connections. How to meet the practical transfer needs of passengers between railways and highways has been the focus of research in recent years. Most of the passenger flow of long-distance passenger stations connecting high-speed railway stations comes from high-speed railway outbound passengers. When long-distance passenger transport adopts uniform departure intervals, there may be unreasonable resources allocation problems such as the poor match between the passenger flow of high-speed railway outbound transfer passengers and long-distance passenger transport capacity, a significant difference of long-distance bus load rate among different shifts, and long

waiting time of transfer passengers. Therefore, coordinating and optimizing the schedule of long-distance passenger transport is the key to solving the problems of load rate, capacity balance, and transfer efficiency.

As early as the 1970s–1980s, relevant scholars began to study the timetable compilation. For example, Newell [1] proposed the relationship between departure frequency and passenger arrival rate under bus capacity. Avishai [2] expounded the use of bus passenger data to develop bus departure schedules so that different departure options can be selected according to the specific requirements of the passengers. In recent years, the theory of departure interval optimization and vehicle scheduling has been further developed and deepened. The research object has also been expanded from conventional public transport to railway passenger transport, rail transit, and their interconnection.

The driving plan can maximize the demand of dynamic passenger flow by optimizing and adjusting the departure interval and number. Here are some research results of the summary and analysis.

Firstly, we analyze the schedule optimization study considering multiple transportation connections or multiple line interchanges. For example, Ma et al. [3] established a minimum model of the total passenger transfer time for urban rail transit interchange connecting buses and used a genetic algorithm to optimize the model for calculation. The results show that the optimization of the departure interval has a very obvious effect on the reduction of passenger transfer time, and the scheduling management is proposed to improve the operating efficiency of vehicles. Pei et al. [4] analyzed the characteristics of the waiting time of high-speed rail passengers switching to conventional buses and carried out distribution fitting and K-S test on passenger arrival time. Based on the probabilistic approach, an average passenger waiting time model considering the bus vehicle capacity limitation was established, and the validity of the model was verified through survey simulation. Guo et al. [5] developed a multiobjective integrated optimization model for the schedule and vehicle scheduling of pick-up buses at high-speed railway stations considering multiple constraints and designed a nondominated ranking genetic algorithm with an elite strategy to solve the model. Finally, the correctness and effectiveness of the model and algorithm were verified by taking the comprehensive optimization of the timetable and vehicle dispatching of a high-speed railway station pick-up bus line as an example. Wu et al. [6] and Guo et al. [7] considered the passenger transfer coordination timetable optimization model under multiple lines and the path selection behavior of the network train timetable optimization model. They studied how to adjust the time when the trains of different lines arrive at the transfer station to shorten the waiting time of the passengers. Cao et al. [8] provided a new solution to the synchronous and coordinated railroad scheduling optimization (SCSO) problem by determining the departure times of public transportation networks and performed model simulations based on the synchronous and coordinated scheduling optimization genetic algorithm (SCSO-GA) with local search strategy (LSS). Huang et al. [9] discussed three models in an incremental manner to optimize the last train schedule that includes multimodal coordination. These models were formulated as mixed-integer linear programming through a linearization technique to find the optimal schedule solution. Example test results show that the proposed models are effective in improving the coordination among last trains within the light rail network and between light rail and connecting modes. Cai [10] built an optimization model for the departure time of urban rail trains at a hub station based on the law of incoming passenger flow and an optimization model for the timetable of urban rail trains based on the connection of railway passenger hubs and simulated them with the actual data of Shenyang Metro Line 1 connected to Shenyang Station. The experimental results show that optimizing the train schedule is of great significance for reducing the waiting time of passengers on the whole line and speeding up

the operation efficiency of railway passenger transport hubs. Gao [11] established a bus schedule optimization model for intersecting lines and a bus schedule optimization model for common lines, taking into account the influencing factors, passenger waiting time, and vehicle departure interval, and also designed a genetic algorithm to solve the model. An empirical analysis of the schedule optimization problem of a certain three common lines in Changchun City was carried out, and the results show that the model has a good optimization effect.

Then, the analysis considers the departure schedule optimization study for a single mode of transportation or a single line. For example, Avishai et al. [12] considered two situations of nonequilibrium departure and balanced departure, studied the influence of different bus types on the full load rate and energy consumption, and established a bus schedule optimization model. The method of creating a timetable was applied to a real case in Auckland, New Zealand, validating the approach of the model. de Palma and Lindsey [13] put forward the optimization design method of departure schedule for a single line when passengers have different expectations for trip times and time delay cost under the premise of a certain number of public transport vehicles. Zhu et al. [14] proposed a two-level model to solve the schedule design problem of urban rail lines. The upper-level model aimed to determine the distance between trains, and the time for passengers to arrive at their departure stations was determined by the lower-level model. Example verification results show that the two-tier model performs well in reducing the total passenger cost and that the segment loading rate of trains in the optimized schedule is more balanced than the equidistant schedule. Xu et al. [15] constructed a schedule optimization model considering constraints, such as time-varying passenger flow demand, departure interval, and train full load rate, and innovatively solved it by genetic algorithm with computer simulation for urban rail transit large and small interchange trains. The results show that the optimized schedule can effectively reduce the crowdedness of passengers during the peak period and improve the balance of the full load rate of each train. Wu et al. [16] proposed a single-objective mixed-integer programming model to maximize the number of total transfer passengers benefiting from smooth transfers and also designed a preprocessing method to reduce the solution space of the proposed model. Numerical results show that the reduced model can be efficiently solved by branch-and-bound algorithms and that the preprocessing method can potentially be applied to large-scale transit networks. Chen et al. [17] considered heterogeneous transfer walking time and developed three mathematical models for the optimization of the last bus schedule. Finally, the embedded branch-and-cut algorithm of CPLEX is applied to solve these models. And the validity of each model is verified by Shenzhen metro network. Wu [18] developed a multiobjective optimal energy consumption schedule model for load balancing and designed a particle swarm algorithm based on simulated annealing to solve the model for the time-varying passenger demand. The results show that the optimized timetables effectively improve the overall performance of the timetables

by simulating the actual route data and passenger swipe data. From the perspective of passenger interchange, Ning [19] took into account the difference of interchange passengers' walking speed and the difference of interchange passengers' perception of the platform waiting time and studied the coordination and optimization of interchange station schedules, which is important to improve the convenience of interchange and station service level. Ning et al. [20] constructed a schedule co-optimization model based on flexible departure interval with the objective of maximizing the total number of interchange co-riders in the network and also designed a genetic algorithm to generate the optimization solution. The results of the case study show that the genetic algorithm has good solution performance, and the method can quickly generate network interchange co-timetable solutions, improve the efficiency of interchange nodes, and can meet the solution requirements of large-scale networks. Niu and Zhou [21] and Eva et al. [22] built the optimization model of train schedule under the condition of time-varying passenger flow demand and passenger detention and the optimization model of nonperiodic train operation under the condition of dynamic passenger flow demand. Other scholars (Guihaire and Haoj [23]; Petersen et al. [24]; Ibarra-Rojas et al. [25]; Schmid and Ehmkejf [26]) solved the optimization problem of unequal departure interval schedule by establishing a mathematical programming model.

In the above research, scholars have studied the optimization of departure timetables in different ways from different perspectives. Still, few have learned the optimization of departure timetables for long-distance passenger transport connected to the high-speed railways. Therefore, this paper studied the coordination and optimization of the long-distance passenger departure timetable of connecting high-speed railway stations based on considering the demand heterogeneity of outbound passenger flow and the balance of transportation capacity. It is hoped that the long-distance passenger transport and high-speed railway departure timetable can achieve a benign connection, reduce waiting time of passengers, improve the service level of long-distance passenger transport station, and enhance the evacuation capacity of the high-speed railway station to provide a reference for the high-quality urban public transport connection service of high-speed rail in and out passenger flow.

2. Transfer Time

2.1. Transfer Environment Setting. Taking the long-distance passenger station adjacent to the high-speed railway station as the research object, the high-speed rail passengers arrive at the station walk to the long-distance passenger station for transfer. The assumption of the transfer environment is as follows:

- (1) The study period is the peak passenger flow period during the Spring Festival travel period $[0, h]$. The passenger flow with transfer demand may appear that the number of arriving passengers exceeds the capacity of the coach.

- (2) The timetables of high-speed train arrivals and long-distance bus departures are known. The arrival time of the first high-speed railway is recorded as time 0. During the study period, the number of high-speed railway arrivals and long-distance bus departures is fixed, expressed in M and N , respectively.
- (3) Regardless of the impact of emergencies, both high-speed railways and long-distance buses operate strictly according to the timetable, and the daily passenger flow of the default route is relatively stable.
- (4) Assume that the high-speed rail arrives uniformly, and the number of arrivals is one each time. In contrast, the long-distance bus comes unevenly due to uncertain factors such as congestion, and the number of arrivals is random.

2.2. Definition of Transfer Time. Due to the nonuniform and instantaneous time of high-speed railway arrival and departure, its arrival passenger flow will show multiple small peaks over time (Xu and Huang, [27]). The two modes of transportation for high-speed railway and long-distance passenger transport are different platforms. The passenger transfer time defined in this article refers to the total time it takes for passengers to get off from a high-speed railway to board a long-distance bus, including the walking time of passengers at the entry and exit stations and the waiting time after arriving at the station.

After leaving the station, high-speed railway passengers generally need to walk through sidewalks and underpasses to arrive at the long-distance passenger station for transfer. Most of the previous studies have ignored the heterogeneity of passengers, and the default passenger arrivals are evenly distributed. However, the walking speeds of different individuals such as children, the elderly, and the young, the walking rates of passengers with time constraints, and the walking rates of passengers with leisure and shopping needs are different, and there may be other situations when additional passengers who transfer from the same high-speed railway may arrive at the station at various times, wait at other stations, and take other coaches. Passenger arrivals are unevenly distributed. This difference in individual and group needs cannot be ignored in fundamental analysis, and it is necessary to consider other situations to analyze the transfer time of passengers.

According to the above analysis, transfer passengers from the same high-speed railway station can be divided into "ready-to-go passengers" and "stranded passengers" due to different needs. The specific explanation is as follows.

Passengers who can successfully ride the latest long-distance coach without waiting are "ready-to-go passengers"; passengers who have missed the last bus due to the latest vehicle being fully loaded or have other needs must continue to wait for the second coach are "one-time stranded passengers."

Passengers who need to wait for the third coach due to the second coach's full load or other needs are "secondary stranded passengers."

Considering the actual situation and simplifying the research problem, it is assumed that most stranded passengers can successfully carry the third long-distance coach after waiting for most two long-distance coaches, and very few stranded passengers will be lost. $G(i)$ and $C(j)$ are defined as the high-speed railway arriving at the station in the i shift and the long-distance bus departing from the j shift in the $[0, h]$ period. $t_G^{(i)}$ and $t_C^{(j)}$ are arrival time and departure time of $G^{(i)}$ and $C^{(j)}$, respectively, where $i = 1, 2, 3, \dots, m$, $j = 1, 2, 3, \dots, n$, and the outbound passengers of the high-speed railway can only transfer the long-distance bus departing after the corresponding time. t_{GC} and t_W are the walking time and waiting time of transfer passengers. t_{GC}^1 is the total time for “ready-to-go passengers” to walk to the long-distance passenger station to successfully ride. t_{GC}^2 is the time for “one-time stranded passengers” to walk to the long-distance passenger station. t_W^2 is the waiting time of “one-time stranded passengers”. t_{GC}^3 is the time for “second stranded passengers” to walk to the long-distance passenger station. t_W^3 is the waiting time of “second stranded passengers.” The expression of total passenger transfer time is

$$T_P = t_{GC}^1 + t_{GC}^2 + t_W^2 + t_{GC}^3 + t_W^3. \quad (1)$$

The travel time analysis of transfer passengers after leaving the high-speed railway station is shown in Figure 1.

3. Multiobjective Coordination Optimization Model

The transfer connection between the high-speed railway and long-distance passenger transport depends on the coordination between bus dispatching and high-speed railway arrival time. First, this paper considers the heterogeneity of outbound passengers' demand and the characteristics of transfers. It analyzes the total number of passengers and the full time spent by different types of passengers from high-speed railway outbound to the long-distance buses. Second, the total cost of time to transfer passengers and the operating cost of the k^{th} passenger line are examined. Third, the match between the capacity of long-distance passenger transport and the transfer demand of high-speed railway outbound passenger flow is examined. Finally, with the minimum total cost and the highest transport capacity matching the objectives, a multiobjective coordinated optimization model with unequal interval departures is established.

3.1. Number of Transfer Passengers. In this paper, the waiting time difference of stranded passengers is increased to the total transfer travel time, the mantissa of the travel time distribution is increased, and the distribution parameters are adjusted to obey the favorable skew distribution. The principle of Weibull distribution can be used to deal with such common problems. Therefore, assuming that the travel time t of the transfer passenger follows Weibull distribution $t \sim W_{ei}(\lambda, \varphi, \beta)$, so cumulative distribution function $F(t; \lambda, \varphi, \beta)$ and probability density function $f(t; \lambda, \varphi, \beta)$ are distributed as follows (Zhang, [28]):

$$F(t; \alpha, \beta, \gamma) = \exp\left[-\left(\frac{t-\gamma}{\beta-\gamma}\right)^\alpha\right], h > t > \gamma > 0, \alpha > 0, \beta > 0, \quad (2)$$

$$f(\alpha, \beta, \gamma) = \frac{1}{\beta-\gamma} \left(\frac{t-\gamma}{\beta-\gamma}\right)^{\alpha-1} \exp\left[-\left(\frac{t-\gamma}{\beta-\gamma}\right)^\alpha\right],$$

where t is the travel time and α, β, γ are different parameters of the probability density curve.

Taking the time 0 as the starting point of the study period and counting with s , for the high-speed rail $G^{(i)}$ arriving at the i^{th} train, the number of people who need to transfer to the long-distance passenger line k is recorded as $X_{Gi}^{(k)}$ people. The probabilities of “ready-to-go passengers” and “stranded passengers” are recorded as $P_1^{(i)}$ and $P_2^{(i)}$, respectively, and the expression of the actual number of passengers is as follows:

$$R_1^{(i)} = X_{Gi}^{(x)} \times P_1 = X_{Gi}^{(k)} \times \int_{t_G^{(i)}}^{t_C^{(j)}} f(t) dt, \quad (3)$$

$$R_2^{(i)} = (1 - \tau) X_{Gi}^{(k)} \times P_2 = (1 - \tau) X_{Gi}^{(k)} \times \sum_{l=j+1}^{j+2} \int_{t_G^{(i)}}^{t_C^{(l)}} f(t) dt,$$

where $R_1^{(i)}$ is the actual number of “ready-to-go passengers” who are getting off the bus from high-speed rail $G^{(i)}$; $R_2^{(i)}$ is the actual number of passengers in the “stayed passengers” getting off the high-speed rail $G^{(i)}$; and τ is the passenger churn rate.

3.2. The Mathematical Model. Considering the situation of passengers stranded during the peak period, a multiobjective optimization model with unequal interval departures is established. The objective function is passenger transfer time, the total cost of passenger line operating costs, and the highest capacity matching. The decision variables are the departure time and the number of departures of long-distance buses.

3.2.1. Optimization Model of Departure Interval Based on Minimum Total Time Cost.

(a) The transfer time cost is represented by the product of the total time T_P spent by all transfer passengers and the average passenger time value V_{TP} which is related to the passenger's age, income, local economic status, and other factors. The expression is

$$V_{TP} = \left(\frac{G DP_{average}}{T_{year}}\right) * \alpha_t * \beta_c, \quad (4)$$

where $G DP_{average}$ is the per capita GDP value (Yuan/year); T is the annual working hours (Hour/year); α_t is the time value coefficient; and β_c is the cost adjustment factor.

Passengers who transfer from the high-speed railway $G^{(i)}$ outbound walk to the long-distance passenger station, and the expression of the transfer time of the “ready-to-go passengers” can catch the nearest long-distance coach after leaving the station is $t_{C-G}^{(j)}$.

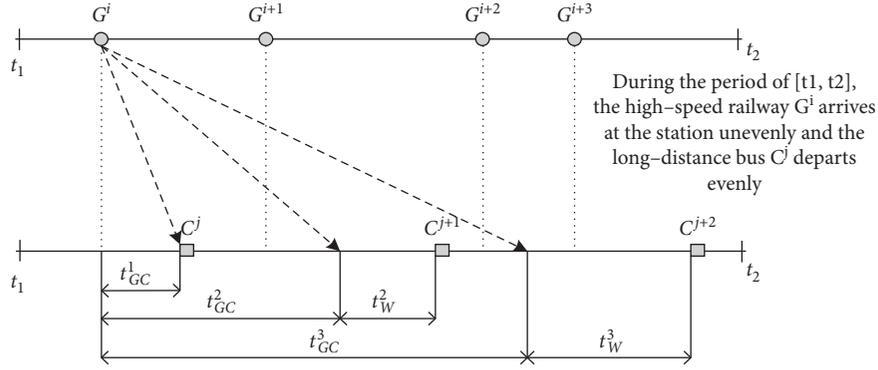


FIGURE 1: Analysis of travel time of transfer passengers.

“Stayed passengers” have to wait for a while after walking to the long-distance passenger station. The transfer time expression for the departure of a car C^l ($l = j + 1, j + 2$) is $t_C^{(l)} - t_G^{(i)}$, and the departure interval is $t_C^{(j+1)} - t_C^{(j)}$. The total transfer time of “ready-to-go passengers” and “stayed passengers” is represented by T_{P1} and T_{P2} , respectively, $X_G^{(k)}$ is for each departure to the station of the high-speed rail transfer to long-distance passenger line k demand for the number of people, and the expression is

$$\begin{aligned} T_{P1}^{(i)} &= (t_C^{(j)} - t_G^{(i)}) \times X_G^{(k)} \int_{t_G^{(i)}}^{t_C^{(j)}} f(t) dt, \\ T_{P2}^{(i)} &= (t_C^{(l)} - t_G^{(i)}) \times X_G^{(k)} \sum_{l=j+1}^{j+2} \int_{t_G^{(i)}}^{t_C^{(l)}} f(t) dt, \\ T_p &= T_{P1}^{(i)} + T_{P2}^{(i)}. \end{aligned} \quad (5)$$

- (b) The operating cost of the k -th passenger line is measured by the product of the total round-trip travel time T_K of the line and the time value V_{TK} of the passenger car in transit, where V_{TK} is related to the time value of transit passengers and the transit vehicle itself. The expression is as follows:

$$\begin{aligned} T_K &= a \left[\vartheta + \varphi + 2 \left(\sum_{d=1}^{D-1} r_d + \sum_{d=1}^D s_d \right) \right], \\ V_{TK} &= V_{TP} + S_k N_k (X_k - Y_k), \end{aligned} \quad (6)$$

where a is the number of departures of long-distance buses during the study period; ϑ is the preparation time of the vehicle at the departure station; φ is the rest time of the car at the terminal; r_d is the running time of the i th interval; s_d is the parking time of the car at the i th station. S_k is the average running speed of long-distance buses (km/h); N_k is the actual number of passengers carried by the passenger car (persons); X_k is the long-distance passenger transport price (yuan/person * km); Y_k is the unit transportation cost of long-distance bus (yuan/person * km).

According to the above analysis, the constraint target expression of the minimum total cost optimization model is

$$\min Z = V_{TP}(T_{P1}^{(i)} + T_{P2}^{(i)}) + V_{TK}T_K. \quad (7)$$

The constraints of the total cost minimum optimization model include full load rate constraints, departure interval constraints, stranded passenger waiting for time constraints, passenger flow loss constraints, passenger travel time constraints, arrival time constraints. The specific constraint expressions are

$$\left\{ \begin{array}{l} I_{\min} \leq \sum_{i=1}^m X_{G_i}^{(k)} \leq I_{\max} \\ A_{\min} \leq t_C^{(j+1)} - t_C^{(j)} \leq A_{\max} \\ 0 \leq t_W < t_C^{(j+2)} - t_C^{(j)} < h \\ 1 < \frac{R_2}{X_G^{(k)} - R_1} \leq 0.95 \\ 0 \leq t_G^{(1)} < t_C^{(1)} < h \\ 0 < t_C^{(j)} - t_G^{(i)} < t_C^{(j)} \end{array} \right\}, \quad (8)$$

where I_{\min} and I_{\max} are the minimum and maximum total load rate of long-distance passenger transport, respectively; A_{\min} and A_{\max} are the minimum and maximum time intervals for long-distance passenger departure; t_W is the waiting time for stranded passengers; R_1 is the actual number of “ready-to-go passengers” who got off from the high-speed train; R_2 is the actual number of “stranded passengers” who got off the high-speed train; $X_G^{(k)} - R_1$ is the total number of stranded passengers; $t_G^{(1)}, t_C^{(1)}$ are the first high-speed railway and long-distance bus, respectively.

3.2.2. Optimization Model Based on the Number of Departures with the Highest Matching Capacity. The highest transport capacity researched in this paper is the most increased coordination between the passenger flow of high-speed railway transfer to a long-distance bus and the passenger flow that long-distance passenger lines can carry. From the above definition, we can see that for each high-speed railway $G^{(i)}$ that arrives at the station, the number of people who need to transfer to the long-distance passenger line k is recorded as $X_G^{(k)}$ (per/h). The factors that affect the capacity of long-distance passenger transport mainly include departure interval, rated number of passengers, and total load rate. The formula for calculating the distribution capacity of the long-distance passenger transportation is

$$C_n = \sum_{k=1}^n \frac{60}{I_k} \eta_k \bar{B}_k, \quad (9)$$

$$\bar{B}_k = \frac{MP_m + LP_l}{M + L}, \quad 0 < L < M, \quad (10)$$

where C_n is the passenger transport capacity of n operating lines (per-tim/h); I_k is the average departure interval of vehicles used on line k (min); η_k is the average total load rate of a line k (%); \bar{B}_k is the rated average number of passengers carried by bicycle on line k (per/veh); M, L are the number of medium and large passenger vehicles operating on line k , respectively; P_m, P_l are the rated number of passengers of medium and large passenger cars, respectively.

Therefore, the calculation formula of the transportation capacity matching degree Y in the study period is

$$Y = \frac{\sum_{k=1}^n X_G^{(k)}}{\psi C_n}, \quad (11)$$

where ψ is the proportion of high-speed railway to long-distance passenger transport as a proportion of total long-distance passenger traffic.

The ideal condition for the matching of transport capacity is $0.9 > Y > 0.86$. When the transportation capacity is not within this range, the departure plan needs to be adjusted. The calculation formula is

$$N_k = \frac{X_G^{(k)} - C_k}{Cap}, \quad (12)$$

where C_k is the passenger transport capacity of k operating lines (per-tim/h); N_k is the number of vehicles increased or decreased in the k th passenger line ($N_k > 0$ is increased, and $N_k < 0$ is reduced); Cap is the transportation capacity of long-distance passengers during peak hours.

4. Solving Algorithm

The vehicle scheduling problem belongs to the NP-hard problem, and an optimal algorithm can be used to solve the optimal value.

The optimal model based on the number of departures with the highest matching capacity is a linear programming problem, which is solved with the help of Lingo software. The specific solution will not be described in detail in this article. Based on the optimization model of the departure interval with the most minor total cost, there are many constraints. This paper uses Matlab software to solve it with a genetic algorithm.

Assuming that during the study period $[0, h]$, there are n long-distance buses are departing according to the departure time, the departure time is recorded as $t_C^1, t_C^2, t_C^3, \dots, t_C^m$, and the departure time of the m th long-distance bus is t_C^m . The genetic algorithm analysis and implementation process are as follows:

Step1. Individual codes generate initial populations. In the research period $[0, h]$, m individuals are randomly generated as the initial population $t_C^1, t_C^2, t_C^3, \dots, t_C^m$. Since the chronological order of vehicle departures in ascending order can improve the subsequent calculation efficiency, a random number is generated in $[0, h_p]$ as t_C^1 , and a random number in $[h_p, 2h_p]$ is generated as t_C^2 .

Step2. Calculate the fitness value. The fitness value is the total travel time of all transfer passengers. Since the fitness function is suitable for solving the maximum value of the model, this paper converts the opposite number of the objective function into fitness. The fitness function expression is as follows:

$$fitness(t) = - \sum_{i=1}^n X_G^{(k)} \left[(t_C^{(j)} - t_G^{(i)}) \times \int_{t_G^{(i)}}^{t_C^{(j)}} f(t) dt + (t_C^{(l)} - t_G^{(i)}) \times \sum_{l=j+1}^{j+2} \int_{t_G^{(i)}}^{t_C^{(l)}} f(t) dt \right]. \quad (13)$$

Step3. Choose an operation. Calculate the probability of chromosome individual i being selected in each selection. Use the roulette wheel selection method to choose

chromosomes with better fitness and randomly generate a uniformly distributed random number as the selection pointer, as shown in the following formula:

$$pi(i) = \frac{1}{fitness(i)} * \sum_{i=1}^n \frac{1}{fitness(i)}. \quad (14)$$

If $pi(0) + pi(1) + \dots + pi(i-1) < \varepsilon < pi(0) + pi(1) + \dots + pi(i-1) + pi(i)$, the i^{th} individual can be inherited to the next generation.

Step4. Cross-operation. The crossover operation used the discrete crossover method. Based on a random pairing of individuals, randomly set the position of the intersection, and then exchanged part of the chromosomes in the paired individuals with each other. If the variable is after the confluence of the randomly generated intersection point g of the parent $T1 = [t_C^1, t_C^2, t_C^3, \dots, t_C^g, t_C^{g+1}, \dots, t_C^m]$, the individual of the offspring is

$$T2 = [t_C^1, t_C^2, t_C^3, \dots, t_C^g, t_C^{g+1'}, \dots, t_C^{m'}]. \quad (15)$$

Step5. Mutation operation. The mutation process uses uniform mutation; that is, by generating a random number that is uniformly distributed, and selecting a variable in the original individual as a mutation point with a certain probability, the mutation point is subjected to mutation calculation within a specific value range, thereby obtaining new individuals.

Step6. Generate new populations. After the variation of the offspring is completed, the fitness value fit of the progeny is calculated. Then, the parent and the offspring are formed into a new set, set size is $(P_{\text{size}} + P_{\text{size}} \cdot \text{GGAP})$, and P_{size} individuals are selected from the group according to the fitness value from large to small to form a new population.

Step7. Terminate the iteration test. Determine whether the iteration reaches the maximum number of iterations G_{max} , then terminate the iteration and output the optimal chromosome scheme; otherwise return to Step 2.

Using Matlab software to write genetic algorithm program code, after debugging, the program can run successfully.

5. Example Analysis

The long-distance passenger transport west station connected to the high-speed railway passenger west station in a city has 21 departure lines. Among them, three long-distance passenger lines are taken as the research objects, denoted as line 1, line 2, and line 3, respectively, and the operating time is 07: 00–16: 30, and the departure interval is 15 min. 14: 00–16: 00 is selected as the research period, questionnaires are designed, and field surveys are conducted on the sources, travel and waiting times of passengers at long-distance passenger stations, transfer lines, and other issues. On the 12306 official websites, it was found that there was a total of 13 high-speed trains in the West Railway Station during this period. The first train of the high-speed train was denoted as G^1 , and the arrival time was recorded as time 0. The arrival

time of other high-speed rails was cumulatively calculated based on this, and the unit is s.

Table 1 shows the results of the questionnaire survey on the information collection of high-speed railways and the transfer of passenger flow.

Table 2 shows the travel time of the three lines of long-distance passenger transport and the requirements for different total load rates.

5.1. Data Analysis and Parameter Calibration. The passenger flow of long-distance passenger transport west station can be divided into two types: high-speed railway outbound transfer passengers and other sources of passengers according to different sources. After investigation, most of the passenger flow comes from high-speed railway outbound transfer passengers. During the study period, the long-distance passenger west station passengers' arrival situation was investigated and counted. The distribution of the arrival rates of the two types of passengers in different periods is shown in Figure 2.

Taking the high-speed rail outbound transfer passengers as the primary research object, the travel time of this type of passengers follows Weibull distribution. Two hundred samples of travel time samples are randomly selected for analysis. The cumulative distribution of the travel time probability of transfer passengers is shown in Figure 3.

Data fitting to the travel time sample data of high-speed rail outbound transfer passengers is carried out, and the mean $t = 786$ and variance $S^2 = 77928$ of the travel time sample are calculated. The expression of the bias coefficient C_s of the sample distribution is as follows:

$$C_s = \frac{\sum_{i=1}^n (t_i - \bar{t})^3}{(n-3)S^3} = 0.73. \quad (16)$$

From the Chaweibull distribution fitting table: $\alpha = 1.85$, $B(\alpha) = 2.009$, $A(\alpha) = 0.2247$. This is used to calculate the Weibull distribution parameters $\beta = t + S * A(\alpha) = 848.7$ and $\gamma = \beta - S * B(\alpha) = 288.2$. The expression of substitution probability density function is

$$f(t; \alpha, \beta, \gamma) = \frac{1}{560.5} \left(\frac{t - 288.2}{560.5} \right)^{0.85} \exp \left[- \left(\frac{t - 288.2}{560.5} \right)^{1.85} \right]. \quad (17)$$

According to the passenger travel time distribution function, it is assumed that the shortest transfer travel time for passengers is 288 s and the longest is 1502 s. That is, all high-speed rail arrival passengers can reach long-distance passenger transfer stations within 1502 s by default.

5.2. Optimization Results and Analysis. Using Matlab software to write a genetic algorithm program, in the process of solving, the population number is 200, the cross-probability is 0.6, the mutation probability is 0.05, and the genetic algebra is 300. The optimal transfer time in each generation population is calculated as shown in Figure 4.

From the analysis in Figure 4, it can be seen that the total transfer time of the algorithm running before the 50th generation decreases faster; between the 50th and 100th

TABLE 1: Statistics of the arrival time of high-speed railway and the number of passengers transferring to long-distance passenger transport.

Serial number	Arrival time (s)	Transfer demand (person)		
		Line 1	Line 2	Line 3
G ¹	0	13	6	9
G ²	420	8	11	10
G ³	960	24	12	13
G ⁴	1440	11	8	9
G ⁵	1860	9	18	11
G ⁶	2220	13	9	22
G ⁷	2880	10	11	9
G ⁸	3540	8	9	13
G ⁹	3960	10	10	8
G ¹⁰	4620	9	7	10
G ¹¹	5160	10	10	14
G ¹²	5520	12	11	9
G ¹³	6300	11	8	10

TABLE 2: Long-distance bus travel time and total load rate requirements.

Long-distance passenger routes	Full journey time (min)	Full line load requirements for passenger vehicles on different routes	
		Minimum full load rate	Maximum full load rate
Line 1	120	0.6	1
Line 2	90	0.7	1.2
Line 3	108	0.7	1.1

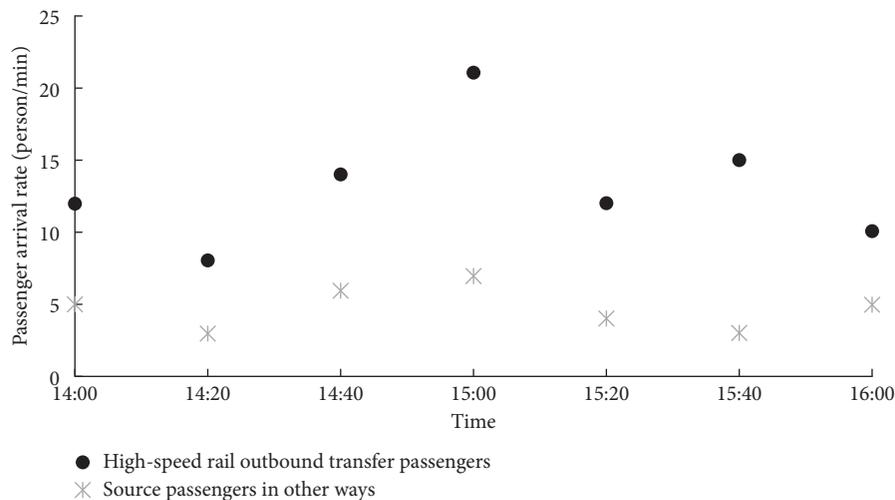


FIGURE 2: Arrival rate of passengers of different source types at the long-distance passenger station.

generations, the whole transfer time is optimized in a small range, and the fluctuation range is not extensive. After the first generation, it remained stable. During the study period, passengers need to spend 43.66 h transfer time when the original 15 min departure interval is adopted. Through genetic algorithm optimization, good optimization of the departure mode during the study period reduced the total transfer time of passengers by 10.53 h and the per capita transfer time by 189.54 s. The optimization effect is more pronounced.

Based on setting the arrival time of the first row of high-speed rails to 0, the results after optimizing the departure

time of long-distance buses are obtained, as shown in Table 3.

The departure time of line 1, line 2, and line 3 is adjusted from the original uniform departure according to the timetable to an uneven exit according to the arrival rate of passenger flow, to reduce the departure interval and reduce the total passenger transfer time.

The matching analysis of the optimized departure schedule of different routes and the arrival passenger flow of high-speed rail transfer passengers is shown in Figure 5.

It can be seen from Figure 5 that the consistency of the number of departures of each line with the passenger's

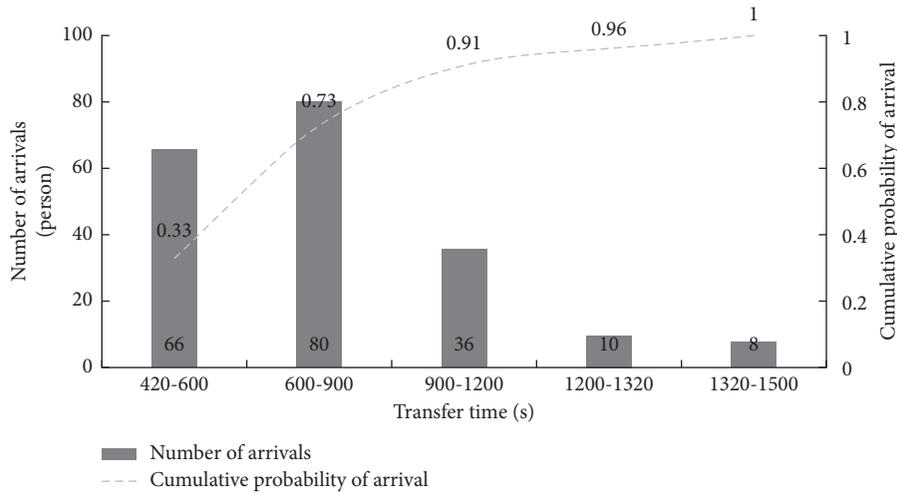


FIGURE 3: Sample analysis of transfer time.

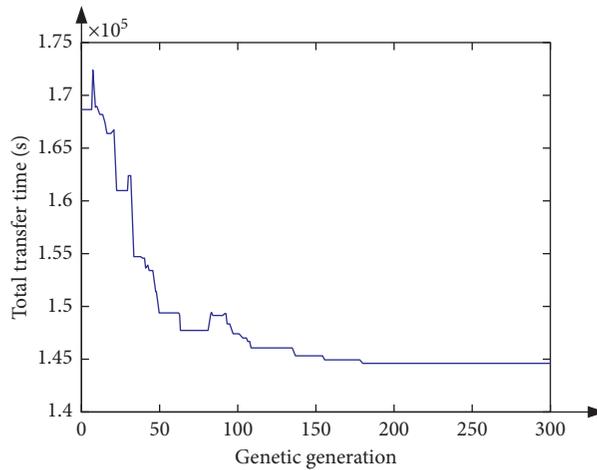


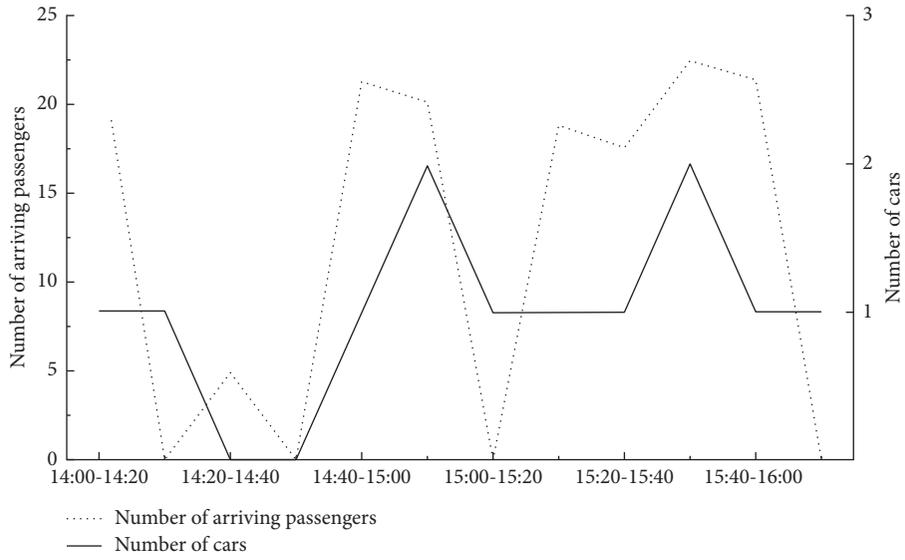
FIGURE 4: Schematic diagram of the genetic evolution of total transfer time.

TABLE 3: Long-distance passenger departure time before and after optimization.

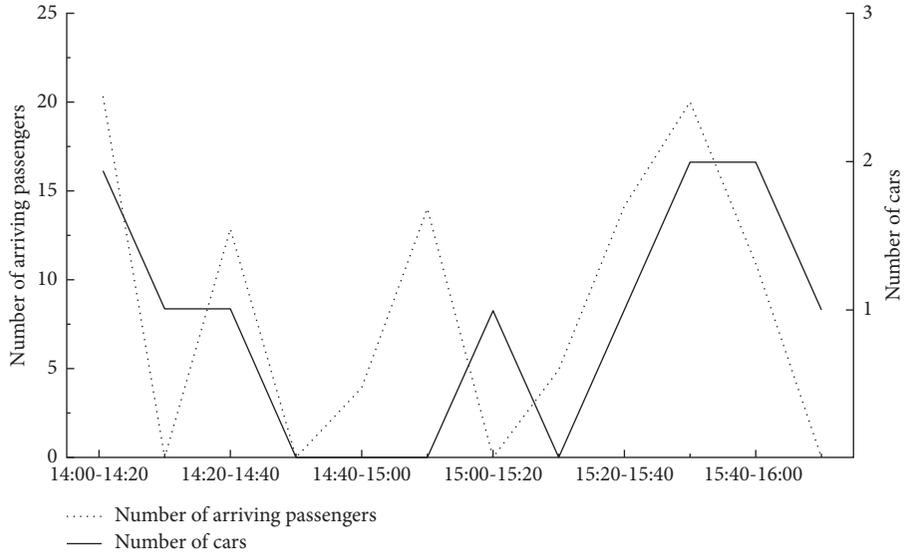
Departure time of line 1		Departure time of line 2		Departure time of line 3	
Before optimization (s)	After optimization (s)	Before optimization (s)	After optimization (s)	Before optimization (s)	After optimization (s)
420	327	540	573	690	768
1320	1462	1440	1506	1590	1673
2220	1986	2340	2187	2490	2245
3120	2570	3240	2779	3390	2846
4020	3794	4140	3437	4290	3576
4920	4228	5040	4335	5190	4268
5820	5490	5940	5204	6090	5193
6720	6586	6840	6380	6990	6279

transfer demand is relatively high. The number of releases in each period has no periodic law. The number of leaves in different periods is quite different, which is more in line with

the arrival rule of high-speed rail stations. To improve the transfer efficiency between the high-speed railways and long-distance passenger transport, a better passenger flow

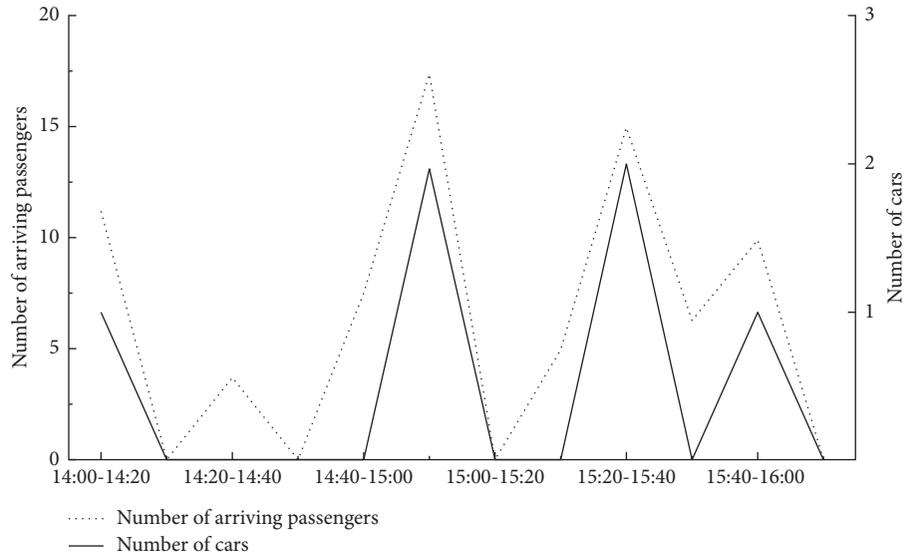


(a)



(b)

FIGURE 5: Continued.



(c)

FIGURE 5: The matching of the optimized departure plan and passenger flow arrival after different routes. (a) Long-distance passenger transport line-matching analysis. (b) Analysis of two matches of long-distance passenger transport lines. (c) Analysis of three matches of long-distance passenger transport lines.

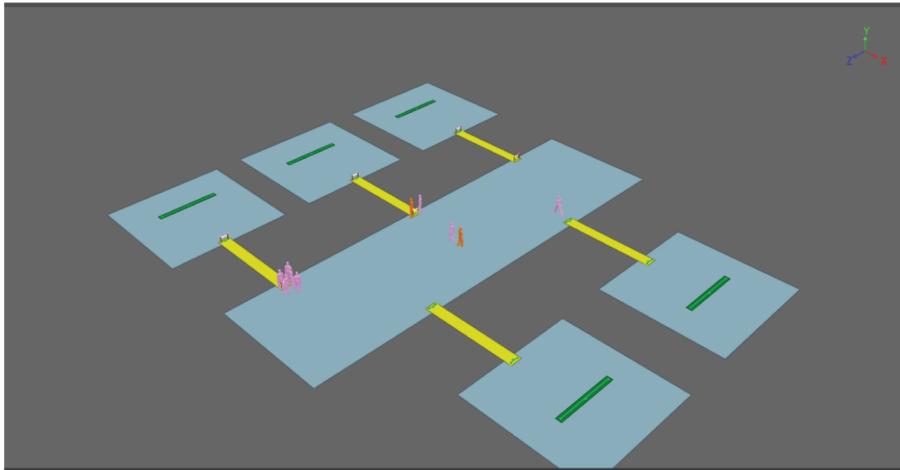


FIGURE 6: Massmotion simulation interface.

data sharing mechanism between the railway transportation department and the city's bus operation management department is needed.

5.3. Massmotion Simulation and Results. At the same time, we also use Massmotion software to simulate the scene. Massmotion is a very flexible advanced pedestrian flow simulation software developed by Oasys. It is widely used in various scenarios from central infrastructure design to cultural event organization. Massmotion does not have an upper limit of processing capacity, and there is no limit on the number of people to process. The total time of this simulation is 2 hours. The passenger source of the passenger station is

also divided into two parts, the west high-speed railway station and other routes, and the passenger riding situation of the three vehicles in the corresponding example is simulated. The model operation simulation of the vehicle departure schedule before and after optimizing the multiobjective coordinated optimization model is compared and analyzed. Finally, the total time is used as the evaluation index to judge before and after the model optimization. The results show that the individual summary time after the optimization of the vehicle schedule is less than before the optimization, indicating that the passenger transfer time is reduced after the optimization of the vehicle schedule. The simulation results and evaluation results are shown in Figures 6 to 9.

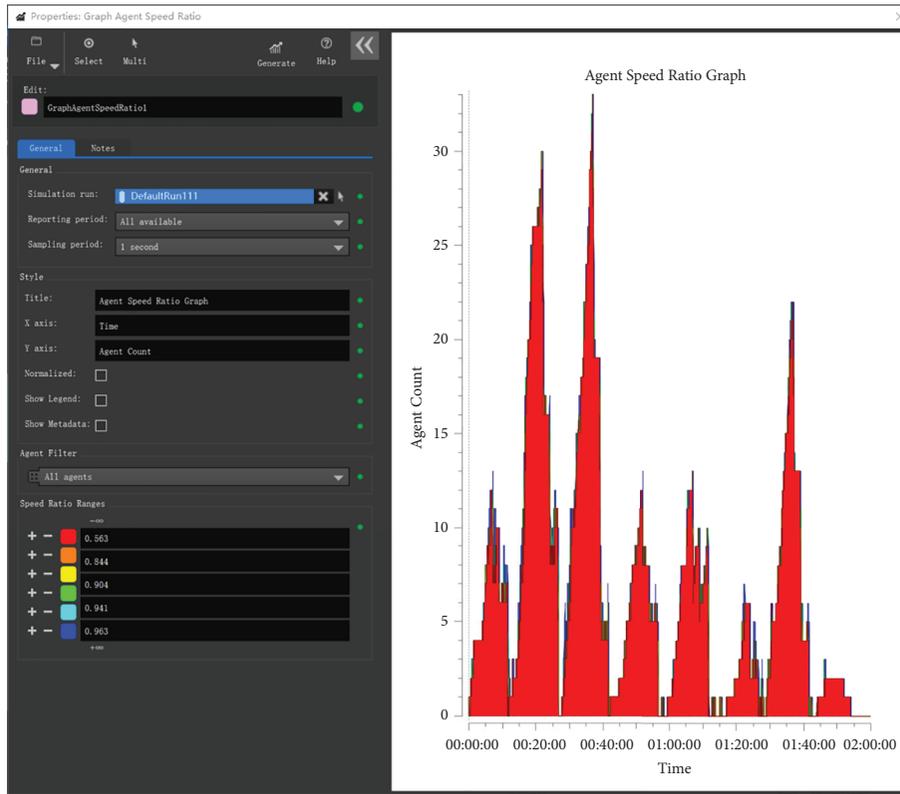


FIGURE 7: Massmotion simulation individual speed ratio chart.

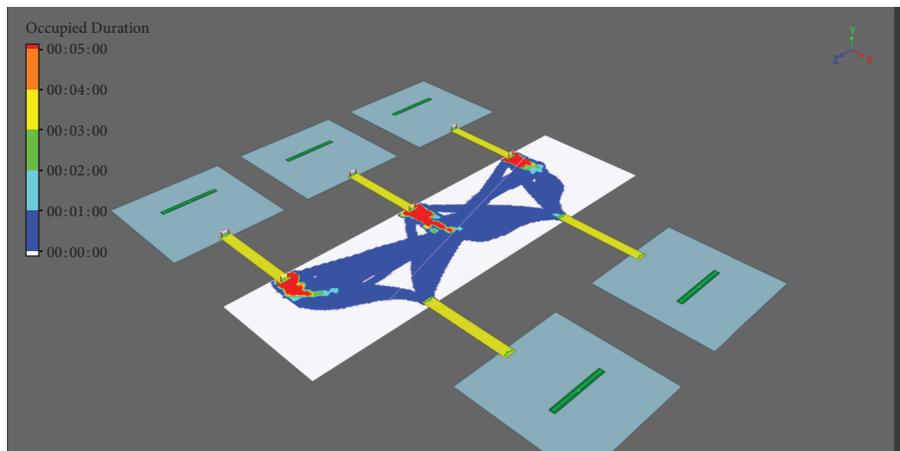


FIGURE 8: The heat map of Massmotion simulation passenger waiting area occupancy time.

Agent ID	Profile	Creator	Entrance	End Object	Start Time	End Time	Duration	Distance	Travelled (m)
1	1200	Profile	Journey1	Portal	Portal4	01:46:42	01:56:47	00:10:05	49.0218
2	1199	Profile	Journey1	Portal	Portal2	01:46:06	01:52:17	00:06:11	37.9677
3	1198	Profile	Journey2	Portal1	Portal2	01:44:59	01:52:16	00:07:17	38.0631
4	1197	Profile	Journey2	Portal1	Portal2	01:43:52	01:52:19	00:08:27	49.9299
5	1196	Profile	Journey1	Portal	Portal2	01:43:08	01:52:17	00:09:09	38.1937
6	1195	Profile	Journey1	Portal	Portal2	01:42:46	01:52:10	00:09:24	36.7989
7	1194	Profile	Journey1	Portal	Portal4	01:42:29	01:43:06	00:00:37	49.552
8	1193	Profile	Journey1	Portal	Portal4	01:42:19	01:43:05	00:00:46	48.8349
9	1192	Profile	Journey1	Portal	Portal2	01:41:49	01:52:11	00:10:22	37.1212
10	1191	Profile	Journey1	Portal	Portal4	01:41:29	01:42:08	00:00:39	49.0024
11	1190	Profile	Journey2	Portal1	Portal3	01:41:25	01:42:07	00:00:42	37.5382
12	1189	Profile	Journey1	Portal	Portal2	01:40:40	01:41:19	00:00:39	36.157
13	1188	Profile	Journey1	Portal	Portal4	01:40:38	01:41:48	00:01:10	54.4
14	1187	Profile	Journey1	Portal	Portal3	01:39:33	01:40:06	00:00:33	38.4013
15	1186	Profile	Journey1	Portal	Portal2	01:38:15	01:38:39	00:00:24	35.9821
16	1185	Profile	Journey1	Portal	Portal2	01:36:06	01:37:18	00:01:13	37.3647
17	1184	Profile	Journey1	Portal	Portal3	01:35:41	01:39:18	00:03:38	40.1826
18	1183	Profile	Journey1	Portal	Portal2	01:35:03	01:37:17	00:02:14	42.1826
19	1182	Profile	Journey1	Portal	Portal3	01:33:54	01:39:15	00:05:21	40.0439
20	1181	Profile	Journey1	Portal	Portal3	01:33:28	01:39:10	00:05:42	38.5137
21	1180	Profile	Journey2	Portal1	Portal4	01:32:48	01:41:42	00:08:54	38.3594
22	1179	Profile	Journey2	Portal1	Portal4	01:32:31	01:41:41	00:09:10	38.5879
23	1178	Profile	Journey1	Portal	Portal2	01:32:24	01:37:15	00:04:51	37.3578
24	1177	Profile	Journey1	Portal	Portal2	01:32:21	01:37:14	00:04:52	37.4878
25	1176	Profile	Journey2	Portal1	Portal4	01:32:00	01:41:50	00:09:50	38.4585
26	1175	Profile	Journey1	Portal	Portal2	01:30:31	01:37:14	00:06:43	37.2454
27	1174	Profile	Journey1	Portal	Portal2	01:30:22	01:37:14	00:06:53	36.6863
28	1173	Profile	Journey1	Portal	Portal4	01:28:32	01:29:05	00:00:33	49.0764
29	1172	Profile	Journey1	Portal	Portal4	01:28:25	01:29:04	00:00:39	48.9027
30	1171	Profile	Journey1	Portal	Portal4	01:27:24	01:28:24	00:01:00	48.6982
31	1170	Profile	Journey1	Portal	Portal3	01:27:24	01:27:50	00:00:26	38.1944
32	1169	Profile	Journey1	Portal	Portal4	01:27:22	01:28:01	00:00:39	48.7619
33	1168	Profile	Journey1	Portal	Portal2	01:26:39	01:27:03	00:00:24	35.8816

(a)

Agent ID	Profile	Creator	Entrance	End Object	Start Time	End Time	Duration	Distance	Travelled (m)
1	1200	Profile	Journey1	Portal	Portal4	01:44:44	01:45:40	00:00:55	48.6841
2	1199	Profile	Journey1	Portal	Portal2	01:44:13	01:50:06	00:05:53	37.7957
3	1198	Profile	Journey2	Portal1	Portal2	01:43:52	01:50:04	00:06:11	50.2198
4	1197	Profile	Journey1	Portal	Portal2	01:43:15	01:50:05	00:06:50	36.916
5	1196	Profile	Journey1	Portal	Portal2	01:41:39	01:50:04	00:08:25	42.3579
6	1195	Profile	Journey2	Portal1	Portal3	01:41:25	01:46:37	00:05:12	39.5661
7	1194	Profile	Journey1	Portal	Portal2	01:41:20	01:50:01	00:08:41	37.7601
8	1193	Profile	Journey1	Portal	Portal4	01:41:05	01:45:00	00:03:55	63.7662
9	1192	Profile	Journey1	Portal	Portal4	01:40:56	01:44:58	00:04:02	50.9227
10	1191	Profile	Journey1	Portal	Portal2	01:40:30	01:49:57	00:09:27	37.0942
11	1190	Profile	Journey1	Portal	Portal4	01:40:13	01:44:59	00:04:46	53.6541
12	1189	Profile	Journey1	Portal	Portal2	01:39:31	01:50:01	00:10:30	36.2984
13	1188	Profile	Journey1	Portal	Portal4	01:39:29	01:44:56	00:05:26	53.9408
14	1187	Profile	Journey1	Portal	Portal3	01:38:32	01:46:36	00:08:04	58.7766
15	1186	Profile	Journey1	Portal	Portal2	01:37:25	01:37:49	00:00:24	35.9821
16	1185	Profile	Journey1	Portal	Portal2	01:35:33	01:36:04	00:00:31	36.0821
17	1184	Profile	Journey1	Portal	Portal3	01:35:11	01:46:42	00:11:31	40.6496
18	1183	Profile	Journey1	Portal	Portal2	01:34:39	01:35:09	00:00:30	35.9376
19	1182	Profile	Journey1	Portal	Portal3	01:33:39	01:46:36	00:12:57	40.2453
20	1181	Profile	Journey1	Portal	Portal3	01:33:16	01:46:30	00:13:13	38.4256
21	1180	Profile	Journey2	Portal1	Portal4	01:32:48	01:44:55	00:12:07	38.8686
22	1179	Profile	Journey2	Portal1	Portal4	01:32:31	01:44:50	00:12:19	38.5268
23	1178	Profile	Journey1	Portal	Portal2	01:32:21	01:33:52	00:01:32	39.1303
24	1177	Profile	Journey1	Portal	Portal2	01:32:18	01:33:51	00:01:33	37.7566
25	1176	Profile	Journey2	Portal1	Portal4	01:32:00	01:44:57	00:12:57	37.971
26	1175	Profile	Journey1	Portal	Portal2	01:30:31	01:33:48	00:03:17	37.3151
27	1174	Profile	Journey1	Portal	Portal2	01:30:22	01:33:56	00:03:34	37.8756
28	1173	Profile	Journey1	Portal	Portal4	01:28:32	01:29:05	00:00:33	49.0764
29	1172	Profile	Journey1	Portal	Portal4	01:28:25	01:29:04	00:00:39	48.9027
30	1171	Profile	Journey1	Portal	Portal4	01:27:24	01:28:24	00:01:00	48.6982
31	1170	Profile	Journey1	Portal	Portal3	01:27:24	01:27:50	00:00:26	38.1944
32	1169	Profile	Journey1	Portal	Portal4	01:27:22	01:28:01	00:00:39	48.7619
33	1168	Profile	Journey1	Portal	Portal2	01:26:39	01:33:48	00:07:09	37.1193

(b)

FIGURE 9: Summary table of Massmotion simulation individual. (a) Summary table of simulated individuals before optimization. (b) Summary table of simulated individuals after optimization.

6. Conclusion

In the study period, the total transfer time of passengers at the original equal interval of 15 minutes was 43.66 hours. Optimized by a genetic algorithm, the unequal interval departure mode was adopted according to the arrival of passengers during the study period. The total transfer time was reduced by 10.53 h, and the transfer time per capita was reduced by 189.54 s, indicating that the optimization effect is noticeable.

The multiobjective coordinated optimization model with unequal interval departure based on the lowest total time cost and the highest transportation capacity matching has specific theoretical and practical value. The optimized results have a particular reference value for passenger transportation companies to formulate vehicle scheduling plans.

Data Availability

The data collection of high-speed train arrival train information and questionnaire survey data on passenger flow transfer used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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