



Research on Optimization of Urban Rail Transit Train Operation Plan under Cross-line Operation Mode

Wang Kai¹, Zou Wenhao², Li Yiheng³, Yang Zhou⁴, Han Yichao⁵

¹Transportation, College of Urban Rail Transit, Shanghai University of Engineering Science, China

Abstract: The segmented operation mode of urban rail transit is prone to cause transfer congestion under high passenger flow, which not only degrades the passenger travel experience but also reduces transfer pressure, optimizes resource allocation, and cuts costs through interconnection and interline operation. This paper selects two intersecting lines forming a Y-shape as the research object, aiming to minimize the system cost consisting of "passenger travel cost" and "enterprise operation cost". Considering constraints such as maximum load factor, minimum tracking interval, and minimum departure frequency, a dual-objective optimization model for interline operation schemes is constructed, and a genetic algorithm is designed to solve the model based on its characteristics. Using passenger flow data from Beijing Subway's Changping Line and Line 8 as samples, the model is solved using MATLAB, and the results are compared with the operation scheme under the traditional single-line operation mode. The analysis shows that after scheme optimization, the total enterprise operation cost decreases by 9.6% compared to the original scheme, and the total passenger travel time reduces by 23%, effectively improving operational efficiency and service retention.

Keywords: genetic algorithm, overline operation, optimization modeling, train operation plan, urban rail transit

1. Introduction

With the rapid advancement of urbanization, the increase in city size and population has made residents' travel needs more diverse and complex, and it is difficult to operate independently on a single line of urban rail transit. The relative independence of lines has caused passengers to transfer multiple times when traveling across lines, which is time-consuming. It is labor-intensive, and the capacity of each line cannot be flexibly allocated, resulting in a waste of resources. Rail transit technology and operation systems are being innovated. For example, Beijing Jiaotong University^[1] introduced large and small road sets and cross-line express jump-stop strategies when exploring the urban rail transit interconnection cross-line operation plan and operation diagram optimization to realize different line networks. intermodal transport; For example, Li Jia of Beijing Jiaotong University^[2] studied the flexible transportation organization that adopts the combined operation of cross-line and fast and slow trains, which can meet the diverse travel needs of passengers, improve the service level and transportation efficiency of passengers, and build an efficient and comfortable urban rail transit system; For example, Li Qingfeng of Guangzhou Metro^[3] proposed that the use of interconnection and cross-line operation reduces the pressure of transfer passenger flow and shortens the travel time of passengers, which is of great significance for improving the service level of passengers. And Zhang Qingbo of Beijing Jiaotong University^[4] pointed out that cross-line operation can effectively alleviate the contradiction between single-line independent operation and passengers' diverse travel needs through flexible and diverse traffic forms, and the contradiction between transportation capacity and passenger flow demand. Cross-line operation can transfer passengers, shorten travel time, improve comfort and attractiveness, balance transport capacity, empty vehicles, cost, and improve efficiency for operators, strengthen regional connections for cities, promote population and industrial flow, and promote regional integration, enhance comprehensive competitiveness and power. Therefore, this paper takes two Y-shaped intersecting lines as the research object, focusing on the optimization of rail transit train operation schemes under cross-line operation. By building a model with the goal of minimizing passenger travel time and enterprise operating costs, combined with genetic algorithms, it is solved and verified by Beijing Metro Changping Line and Line 8 as cases.

2. Problem Description

This paper takes two Y-shaped intersecting lines as the research object, as shown in Fig.2.1. The main line operation section is $[S_1, S_n]$, the branch line operation section is set as $[S_b, S_m]$, S_{n+1} is the first station of the independent branch line, the cross-line operation section is set as $[S_{x1}, S_{x2}]$, the station S_{x1} is the starting station of the cross-line intersection under the cross-line operation, the station S_{x2} is the terminal station of the cross-line intersection, and the station S_b is the turn-back station of the branch line intersection, where $1 < x_1 < b < x_2 < n < m$. $S = \{S_u | 1 \leq u \leq 30\}$ for all stations; The main line intersection is $k = 1$, the branch line



intersection is $k = 2$, and the cross line intersection is $k = 3$; S_1^{turn} is the station with turn-back condition on the main line; S_2^{turn} is a station on a branch line that has turn-back conditions. With the maximum full load rate, turn-back capacity of turn-back stations, minimum tracking interval, etc. as constraints, and the minimization of passenger travel time and enterprise operating costs as the goal, determine the starting and ending positions of cross-line traffic, cross-line traffic trains, main line traffic trains and Departure of branch line traffic trains.

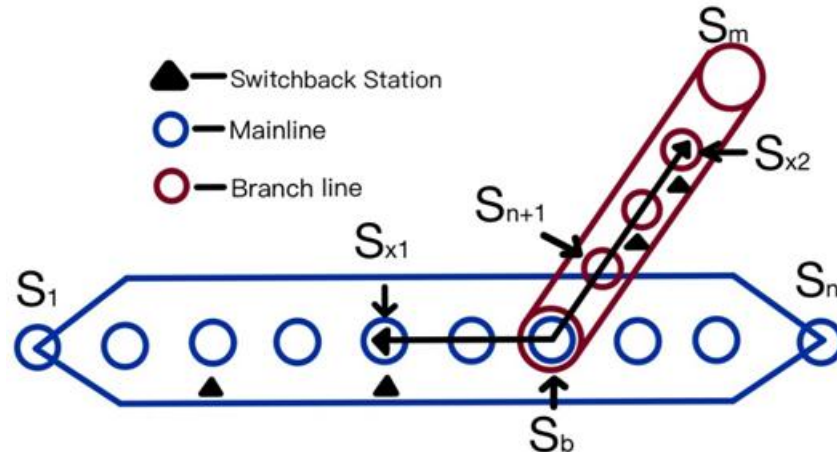


Fig. 2.1: Main line is fully operational, with some branch lines partially operational and operating in a turn-back routing pattern

3. Modeling

3.1 Model Assumptions

Preconditions assumed by the model: 1) The trains implement a unified marshalling plan and a stop plan for station stops; 2) Passengers always choose the ride plan with the least transfer; 3) The number of train personnel and the number of train formations on the main line and branch lines are the same; 4) During the study period, the upward and downward directions are the same, and the train operation status is not affected by the line conditions.

3.2 Objective Function

The two Y-shaped intersecting routes studied in this paper mainly have two subjects, that is, travelers and operators. For travelers, how to shorten the total travel time and reach the destination faster and more efficiently is the main purpose; For operating companies, how to cost and improve passenger operation efficiency is crucial.

3.2.1 Analysis of Passenger Travel Behavior

Because the line in the research object is covered by three routes, the different station locations of passengers affect their choice of travel routes, and this choice behavior also affects the waiting time of passengers. Due to the different station location of passengers, there are also differences in the choice of travel routes, so the Y-shaped line is divided into five passenger flow sections according to the turn-back position of the route. As shown in Fig.3.1:

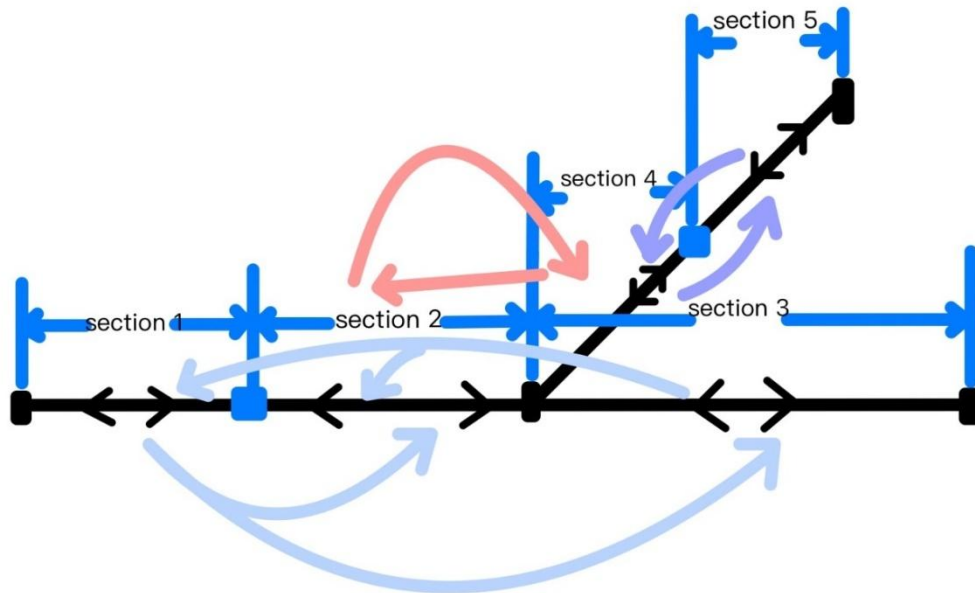


Fig. 3.1: Schematic diagram of two hypothetical lines intersecting in a Y shape

Since the fundamental assumption in this model regarding passengers' travel choice is that they always opt for the trip plan with fewer transfers, when station S_i and station S_j serve as the starting point and the destination of a trip respectively, the following analysis of passengers' travel behavior can be conducted based on different S_i .

When S_i belongs to Passenger Flow Section I, if S_j also belongs to Passenger Flow Section I, passengers can only choose main-line trains; if S_j belongs to Passenger Flow Section II or Passenger Flow Section III, passengers will also choose main-line trains; if S_j belongs to Passenger Flow Section IV, passengers can directly transfer to cross-line trains at station S_{x1} or choose to transfer to branch-line trains or cross-line trains at station S_b ; if S_j belongs to Passenger Flow Section V, passengers will choose to transfer to branch-line trains at station S_b .

When S_i belongs to Passenger Flow Section II, if S_j belongs to Passenger Flow Section I, passengers can only choose main-line trains; if S_j also belongs to Passenger Flow Section II, passengers will choose main-line trains or cross-line trains; if S_j belongs to Passenger Flow Section III, passengers will choose main-line trains; if S_j belongs to Passenger Flow Section IV, passengers will choose cross-line trains; if S_j belongs to Passenger Flow Section V, passengers can choose to directly take cross-line trains and transfer to branch-line trains at station S_{x2} or take main-line trains and transfer to branch-line trains at station S_b .

When S_i belongs to Passenger Flow Section III, if S_j belongs to Passenger Flow Section I, passengers can only choose main-line trains; if S_j belongs to Passenger Flow Section II, passengers will choose main-line trains; if S_j also belongs to Passenger Flow Section III, passengers can only choose main-line trains; if S_j belongs to Passenger Flow Section IV, passengers can choose to transfer to branch-line trains or cross-line trains at station S_b or directly transfer to cross-line trains at station S_{x1} ; if S_j belongs to Passenger Flow Section V, passengers will choose to transfer to branch-line trains at station S_b .

By analogy, the passenger travel behavior when S_i belongs to Passenger Flow Section IV and Section V can be derived.

3.2.2 Establishment of Objective Function

1) Passenger Travel Time

Passenger travel time includes passenger waiting time and passenger transfer time. From the perspective of passengers, it pursues the minimization of travel time and cost. During the study period, the expression of total travel time T_c of all OD passengers is shown as common

$$T_c = T_{ab,w} + T_{ab,tr} \#(3 - 1)$$

Among them, T_c is the total travel time of passengers, in min

$T_{ab,w}$ is the waiting time of OD_{ab} passengers when they travel, in min



$T_{ab,tr}$ is the transfer time of OD_{ab} passengers when they travel, in min

① Passenger waiting time ($T_{ab,w}$)

Passenger waiting time is closely related to the operation of the train on the road to which the passenger starts. According to the analysis of passenger travel behavior, passenger flow can be subdivided into five categories, that is, only passengers can take The passenger flow Q_1 of the main line train, the passenger flow Q_2 that can only take the branch line train, the passenger flow Q_3 that can only take the cross-line train, the passenger flow Q_4 that can choose different transit trains, and the passenger flow Q_5 that needs to be transferred. According to the above analysis, the required diagram is drawn as shown in Fig. 3.1

The corresponding mathematical expression is:

$$Q_1 = C_{11} + C_{12} + C_{13} + C_{23} + C_{33} \# (3 - 2)$$

$$Q_2 = C_{45} + C_{55} \# (3 - 3)$$

$$Q_3 = C_{24} \# (3 - 4)$$

$$Q_4 = C_{22} + C_{44} \# (3 - 5)$$

$$Q_5 = C_{14} + C_{34} + C_{15} + C_{25} + C_{35} \# (3 - 6)$$

Among them, $C_{i,j}$ is the uplink passenger flow volume from passenger flow section i to passenger flow section j , $i \in d$, $j \in d$

If the arrival of passenger flow follows a uniform distribution, and the waiting time for each passenger is equal to $1/2$ of the departure interval of the passenger's route, then the total waiting time for passengers during the time period T is:

$$T_{ab,w} = T \left\{ \frac{Q_1}{2f_1} + \frac{Q_2}{2f_2} + \frac{Q_3}{2f_3} + \left[\frac{C_{22}}{2(f_1 + f_3)} + \frac{C_{44}}{2(f_2 + f_3)} \right] + \left(\frac{C_{14}}{2f_1} + \frac{C_{34}}{2f_1} + \frac{C_{15}}{2f_1} + \frac{C_{25}}{2f_3} + \frac{C_{35}}{2f_1} \right) \right\} \# (3 - 7)$$

Among them, T is the duration of this study, in minutes

f_k represents the departure frequency of trains on different routes, and is a decision variable

$1/f$ represents the departure interval

The average waiting time for passengers is:

$$\frac{T_{ab,w}}{\sum_{a=1}^{30} \sum_{b=1}^{30} OD_{ab}} \# (3 - 8)$$

Among them, OD_{ab} represents the passengers whose travel origin and destination are station S_a and station S_b respectively

② Passenger transfer time ($T_{ab,tr}$)

Based on further analysis of passenger flow, there are five types of passenger flow that will transfer during the uplink. Specifically, when S_i belongs to passenger flow zone I and S_j belongs to passenger flow zone IV, passengers can transfer directly to an interline train at S_{x1} station or choose to transfer to a branch line train or interline train at S_b station. When S_i belongs to passenger flow zone III and S_j belongs to passenger flow zone IV, passengers can choose to transfer to a branch line train or interline train at S_b station or directly transfer to an interline train at S_{x1} station. When S_i belongs to passenger flow zone I and S_j belongs to passenger flow zone V, passengers will choose to transfer to a branch line train at S_b station. When S_i belongs to passenger flow zone II and S_j belongs to passenger flow zone V, passengers can choose to directly take an interline train and transfer to a branch line train at S_{x2} station or take a main line train and transfer to a branch line train at S_b station. When S_i belongs to passenger flow zone III and S_j belongs to passenger flow zone V, passengers will choose to transfer to a branch line train at S_b station. Due to the difficulty in determining the transfer station for passengers, this article determines the transfer point based on comfort. Passenger flow C_{14} chooses to directly transfer to an interline train at S_{x1} station; passenger flow C_{34} will choose to transfer to a branch line train or interline train at S_b station; passenger flow C_{25} chooses to take an interline train to S_{x2} station and then transfer to a branch line train. Therefore, the transfer time for these five types of passenger flow is:

$$C_{14} = \frac{T \cdot C_{14}}{2f_3} \# (3 - 9)$$

Other passenger flow does not transfer:

$$T_{ab,tr} = 0 \# (3 - 14)$$



The total transfer time is:

$$T_{ab,tr} = T_{walk} \cdot Q_5 + \frac{T \cdot C_{14}}{2f_3} + \frac{T \cdot C_{34}}{2(f_2 + f_3)} + \frac{T \cdot C_{15}}{2f_2} + \frac{T \cdot C_{25}}{2f_2} + \frac{T \cdot C_{35}}{2f_2} \#(3-15)$$

Among them, T_{walk} is the walking time for passenger transfer, in min $1/f$ represents the departure interval

The average transfer time is:

$$\frac{T_{ab,tr}}{P} \#(3-16)$$

Among them, P is the number of transfer passengers

2) Enterprise operating costs

This article only considers costs related to trains, mainly including vehicle usage costs, vehicle operating costs, and additional costs for train stops.

The cost of vehicle usage, which includes the expenses related to wear and tear during operation, can be represented by the total number of trains required. Taking into account the need for standby vehicles, the total number of trains required is set at 1.5 times the number of operational vehicles

$$Z_1 = 1.5 \sum_{k=1}^3 \left[\frac{f_k T_k}{60} \right] \#(3-17)$$

Among them, Z_1 is the total number of vehicles required, in column f_k represents the departure frequency of trains on different routes, which is a decision variable\

T_k represents the cycle of route k , measured in minutes

$M_1 Z_1$ represents the vehicle usage cost.

The cost of train operation, which includes the expenses for traction power consumption and labor during the train's operation, is primarily determined by the number of kilometers traveled by the train

$$Z_2 = \sum_{k=1}^3 (f_k \cdot L_k) \#(3-18)$$

Among them, Z_2 is the train running kilometers, unit: km

L_k represents the train running kilometers on route k , unit: km

$M_2 Z_2$ is the train operation cost.

The additional cost of train stops^[5], which refers to the cost of machinery and equipment use supervision and manual service maintenance incurred when the train stops at a platform, depends on the total number of stops made by the train:

$$Z_3 = \sum_{k=1}^3 (f_k \cdot V_k) \#(3-19)$$

Among them, Z_3 is the total number of train stops, unit: times

V_k represents the number of stations in the k th routing

$M_3 Z_3$ represents the cost of train parking.

The total operating cost is:

$$Z_y = M_1 \cdot Z_1 + M_2 \cdot Z_2 + M_3 \cdot Z_3 + M_4 \cdot T_c \#(3-20)$$

Among them, Z_y is the total operating cost of the operating enterprise, unit: CNY

M_1 represents the cost of vehicle wear and tear, measured in units of columns per CNY

M_2 represents the cost per kilometer of train operation, with the unit being CNY per kilometer

M_3 represents the cost per stop for a single train journey, with the unit being CNY per stop

M_4 represents the cost of passenger travel time, calculated in minutes per CNY

3.3 Constraints

3.3.1 Maximum Full Load Rate Constraint

Each section of the line should ensure that its full load rate does not exceed the maximum full load rate limit, with the following constraints:

$$\eta \ll \eta_{max} \#(3-21)$$



Where, η is the rated full load rate of the train

3.3.2 Turn-back Capacity Constraint of Turn-back Station

The departure frequency of each routing train on the line shall not exceed the turn-back capacity of the turn-back station, and the constraint conditions are as follows:

$$f_k \leq \frac{T}{t_{turn}} \#(3-22)$$

Where, t_{turn} is the minimum interval time for train turnaround, with the unit of min

3.3.3 Minimum Tracking Interval Constraint

The departure frequency of trains in each section should meet the minimum tracking interval constraint, which is expressed as follows:

$$f_k \leq \frac{60T}{j_{min}} \#(3-23)$$

Where, j_{min} is the minimum tracking interval, unit: s

3.3.4 Minimum Departure Frequency Constraint

The operating frequency should be higher than the minimum departure frequency and lower than the maximum carrying capacity of the line:

$$f_{max} \geq f_k \geq f_{min} \quad f_k \in N \#(3-24)$$

3.3.5 Constraint On The Number of Vehicles Used

The number of vehicles should not exceed the upper limit of the maximum number of vehicles in use:

$$N = \sum_{k=1}^3 \frac{T_k}{60} f_k \leq N_{max} \#(3-25)$$

3.3.6 Constraints on the Starting and Ending Stations of Cross-line Routing

The starting and ending stations of the cross-line routing are set at stations with turnaround conditions:

$$S_{x1} \in S_1^{turn}, S_{x2} \in S_2^{turn} \#(3-26)$$

4. Model Solution

4.1 Algorithm Introduction

In the optimization of urban rail train cross-line operations, genetic algorithms are efficient tools for solving complex multi-constraint problems. Given the characteristics of "multi-objective and multi-constraint" in cross-line operations (such as balancing passenger and enterprise costs, meeting full load rates, tracking intervals, and other constraints), scheme optimization is achieved by simulating the "selection, crossover, and mutation" mechanisms of biological evolution.

The algorithm in this paper first encodes the train operation plan (line departure frequency, cross-line starting and ending stations) as "chromosomes", with the system's total cost minimization as the fitness function, to select high-quality plans. Then, by crossing and recombining the advantageous features of different plans and introducing the possibility of new plans through mutation, it gradually iterates to approach the optimal solution. Taking the cross-line operation of two lines intersecting in a Y shape as an example, this algorithm can quickly process passenger flow fluctuation data on platforms such as MATLAB, avoiding the limitations of manual calculation, and efficiently outputting operation plans that meet the constraints. It provides reliable solution support for cross-line operations from theoretical models to practical implementation, helping to improve operational efficiency and cost control accuracy.

4.2 Algorithm Design

The algorithm design follows the core logic of genetic algorithms^[6] "encoding-population generation evolutionary operation-termination", and includes six key steps, each closely centered around the actual needs of cross-line operations, as shown in Fig.4.1:

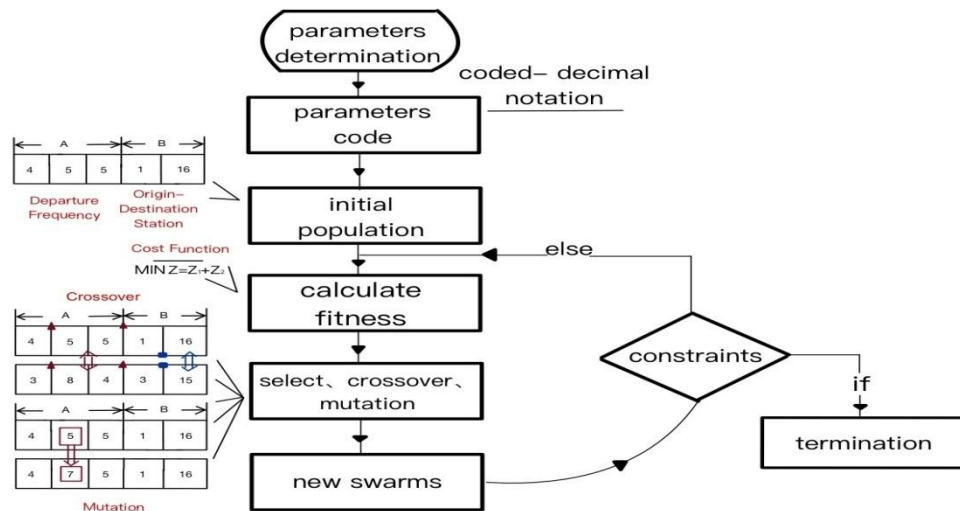


Fig. 4.1: Algorithm flowchart

4.2.1 Encoding

The link algorithm employs a decimal encoding approach, converting the core decision variables of cross-line operations into a computable "chromosome" structure, divided into two parts: A and B. Part A utilizes three sets of decimal codes, corresponding to the train departure frequencies of main line routes, branch line routes, and cross-line routes, respectively. Part B represents the starting and ending station numbers of cross-line trains using decimal codes.

4.2.2 Initial Population Generation

Initially, two core parameters are preset: the initial population size, denoted as n , and the maximum iteration count, denoted as g . During the generation process, two sets of constraints are verified: Firstly, the codes for the starting and ending stations of cross-line routes must correspond to stations with turnaround conditions, ensuring the scheme is feasible in terms of hardware facilities. Secondly, the departure frequency codes for all routes must adhere to the departure frequency constraints, to prevent exceeding line capacity or causing resource waste. Ultimately, n valid initial populations are selected and generated.

4.2.3 Evolutionary Operations Include Selection, Crossover and Mutation

Selection operation evaluates individual fitness, selects high-quality individuals, eliminates inferior individuals, and guides the population to evolve towards a better direction.

The crossover operation adopts a dual-node and single-node crossover strategy, randomly selecting two chromosomes and exchanging some genes based on a set crossover point to generate offspring chromosomes that combine the advantages of the parents.

Mutation operation adjusts the decimal value of a random gene position on the chromosome (such as changing the branch departure frequency code or cross-line station number), and after mutation, it must satisfy the constraints to increase population diversity and avoid the algorithm falling into local optima.

4.2.4 Terminate

The operation terminates when the iteration count reaches the preset maximum iteration count g , and the chromosome with the highest fitness is finally output, corresponding to the optimal cross-line operation train operation plan.

5. Case Analysis

5.1 Line Condition

<1>Line 8 is a north-south rail transit line that runs through the urban area of Beijing, located on the central axis of the city, connecting Qinghe, Nanyuan and six urban districts.

<2>The Changping Line, also known as "Beijing Metro Line 27", is the tenth subway line to be built and operated in Beijing, China. It starts from Xishankou Station in Changping in the north and ends at Jimenqiao Station in the south, passing through Changping District and Haidian District. As shown in Fig.5.1:

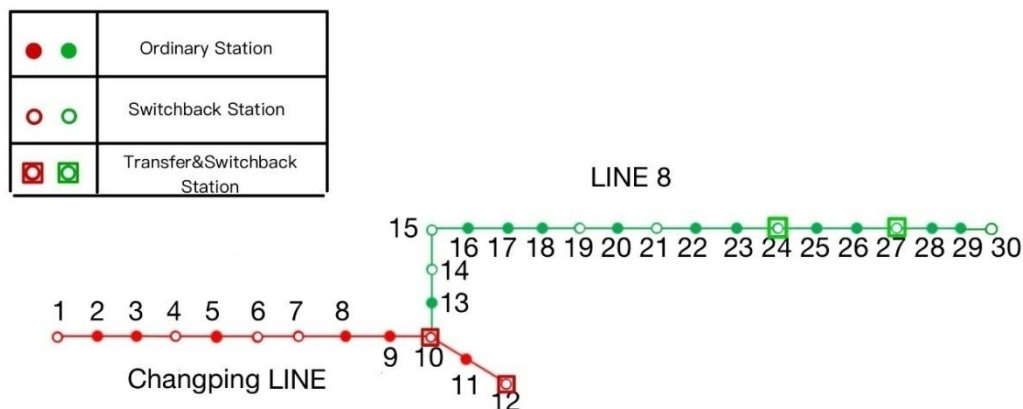


Fig. 5.1: Simplified route map of Beijing Subway Changping Line and Beijing Subway Line 8

5.2 Passenger Flow Analysis

5.2.1 Commuting-oriented Passenger Flow

The tidal phenomenon is significant: the morning peak is mainly from Changping to the central city area (southward via Line 8), and the evening peak is concentrated in the opposite direction; cross-regional commuting has increased, benefiting Changping residents to directly reach the central axis business districts (such as Olympic Park, Wangfujing, etc.), reducing the transfer time by about 15 minutes.

5.2.2 Change in Passenger Flow Structure

The role of Zhuxin Zhuang Station has been upgraded from a transfer node to a cross-line hub, with the design of the same platform transfer improving transfer efficiency. Potential new passenger flow: attracting groups who previously traveled by car or bus, especially commuters from Changping New City to the Haidian Mountain area.

5.2.3 Spatio-temporal Distribution Characteristics

The peak period of working days is concentrated: the cross-line trains have a high load factor from 7:00-9:00 in the morning and from 17:00-19:00 in the evening;

Weekend equilibrium improvement: Line 8 connects tourist attractions (such as Shichahai and Qianmen) and drives leisure travel for residents in Changping.

5.2.4 OD Characteristics

Using the Changping Line as the primary route and Line 8 as the auxiliary route, the cross-line route is established between Changping West Station (CPX) and Nanluoguxiang (NLG). By analyzing the OD passenger flow matrix, the upstream passenger flow on the cross-line route is calculated and illustrated in Fig.5.2:

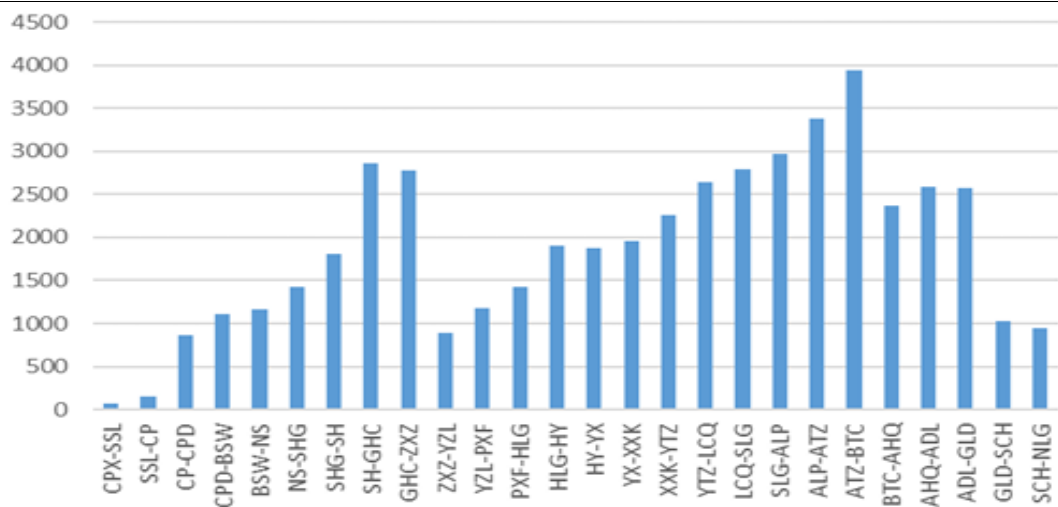


Fig. 5.2: Passenger flow on the uplink section of the cross-line route

Xierqi Station not only experiences a large passenger flow volume and faces significant transfer pressure, but also has a significantly higher number of inbound and outbound passengers compared to other stations. Therefore, it is particularly important to take relevant measures to alleviate passenger flow at Xierqi Station. As shown in Fig.5.3:

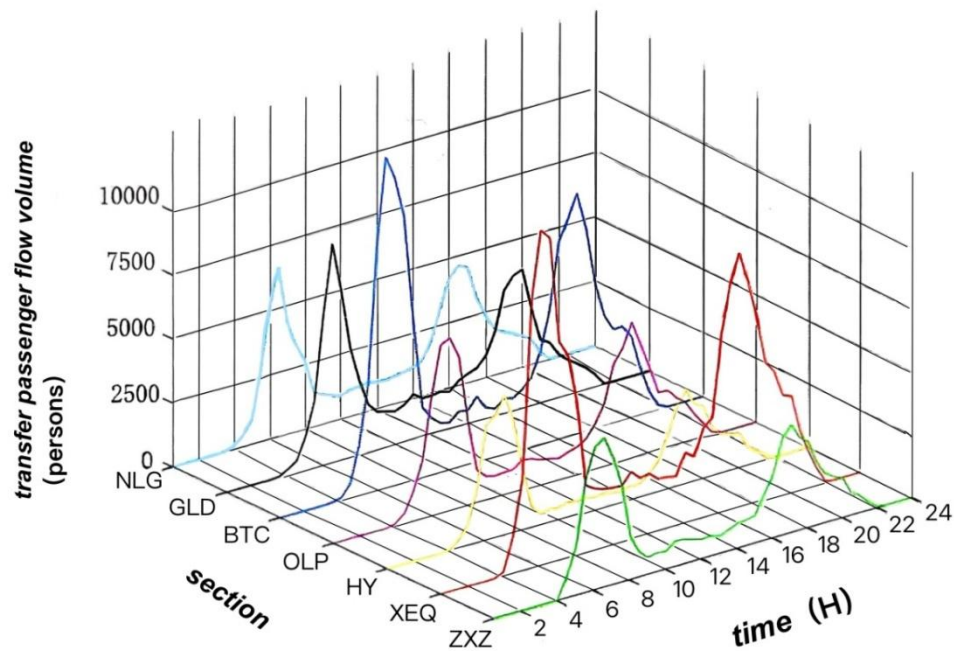


Fig. 5.3: Time-segmented passenger flow volume at each transfer station throughout the day

As can be seen from the figure, the passenger flow volume at each transfer station exhibits a "bimodal pattern" throughout the day, with Xierqi Station and Beitucheng Station experiencing significantly higher passenger flow volume during the morning and evening rush hours compared to other stations.

5.3 Optimization of Train Operation Plan for Two Lines Intersecting in a Y-Shape under Cross-Line Operation Mode

The selected research period (T) for this case analysis is 120 minutes (7:00-9:00), during which the maximum cross-line passenger flow at a section is 4,200 person-times (ZXZ (10)-HY (16) section), and the minimum cross-line passenger flow at a section is 85 person-times (CPX (1)-SSL (2) section).



5.3.1 Model Solution Parameter Setting

Table 5.1: Setting of various parameters for models and algorithms

Parameter Name	Value	Description
Population size (n)	80	Population size corresponds to global search capability
Maximum iteration count (g)	500	The iteration count ensures the algorithm converges to the optimal solution
Crossover probability (pc_1)	0.75	Double-point gene crossover in Part A, high-quality recombination
Crossover probability (pc_2)	0.65	Part B single-point gene crossover probability
Mutation probability (pm)	0.1	Mutation probability, avoid local optimum
Conduct an association verification for "routing - station" to ensure coding compliance		

5.3.2 Model Constraint Parameters and Cost Parameters

Table 4.2: Model constraint parameters and cost parameters

Parameter category	Parameter symbol	Value	Unit
Constraint parameter	Minimum tracking interval (f_{min})	120	seconds
	Minimum departure frequency (f_{min})	3	trains/hour
	Maximum departure frequency (f_{max})	30	trains/hour
	Maximum full load rate (η_{max})	1.2	-
	Train seating capacity (C)	1460	persons/train
	Maximum number of vehicles in operation (N_{max})	75	Columns
	The average minimum interval for train turnaround (T_{turn})	220	Seconds
	Passenger transfer walking time (T_{walk})	4	Minutes
	Cost parameter Passenger time cost (M_4)	0.2	CNY/per minute
	Vehicle loss cost (M_1)	2000	CNY/train
	Train operation cost (M_2)	9.5	CNY/km
	Train stopping cost (M_3)	50	CNY/time

5.4 Result Analysis

This study primarily focuses on the morning peak period. The solution obtained from the genetic algorithm is presented in Table 5.3.

Table 5.3: Genetic algorithm solution result

Main-Branch Line Frequency (f_1)	Branch-Line Frequency(f_2)	Cross-Line Frequency(f_3)	Cross-Line Route Origin Station($S_{\square 1}$)	Cross-Line Route Destination Station ($S_{\square 2}$)
15 trains/h	10 trains/h	8 trains/h	CPX(1)	NLG(29)

Table 5.4: Relevant parameters of passenger travel time and enterprise operating costs under cross-line operation and single-line operation modes

Route Optimization Scheme	Fleet Size (trains)	Fleet Usage Cost (CNY)	Train Running Cost (CNY)	Train Stopping Cost (CNY)	Number of Stops	Total Routing Mileage (km)
Cross-line Optimized Scheme	21	42000	30856	94100	1882	3248
Single-line Original Scheme	34	68000	28443	88050	1761	2994
Route Optimization Scheme	Selected Route		Frequency (trains/h)	Enterprise Cost (CNY)	Total Passenger Travel Time (min)	
Optimized Scheme (Model Constraints)	7-12		8	174041.8	30679	
	1-29		8			
	10-29		8			
Original Scheme	1-12		15	192467.4	39872	
	10-29		10			



Through model analysis, summarize the costs of various aspects of the original single-line operation plan and the new cross-line operation plan.

Among them, the original single-line operation plan has more trains in operation, but fewer stops and operating miles. Under the influence of different train departure frequencies, although the train operation cost and stop cost are lower, the total passenger travel time is too long due to the excessive use of trains and the inability to quickly transfer passengers under single-line operation. The implementation of cross-line operation inevitably increases the number of stops and operating miles, but the uniform departure frequency reduces the number of trains in operation to a certain extent. The cross-line plan also significantly reduces the total passenger travel time, directly affecting passenger time costs and significantly reducing enterprise operating costs.

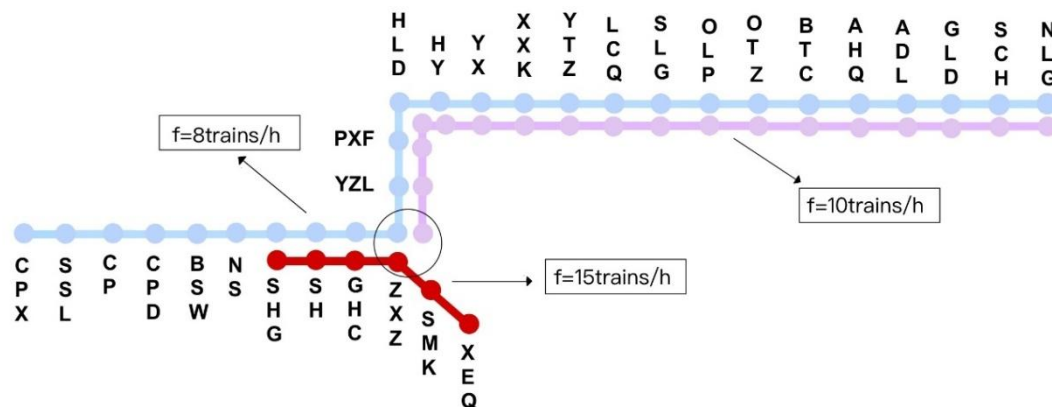


Fig. 5.4: Schematic diagram of cross-line operation between Changping Line and Line 8

The algorithm results show that after the optimization of the scheme, the total operating cost of the enterprise has decreased by 9.6% compared to the original scheme, and the total travel time of passengers has decreased by 23%, greatly improving the operation efficiency of the line.

6. Conclusion

This article provides a detailed analysis of the cross-line operation model, with a focus on introducing and studying the cross-line operation plan for two Y-shaped intersecting lines, and uses images to provide a more vivid presentation.

This article addresses the problems and difficulties of cross-line operation mode, establishes an optimization model for the operation plan of cross-line operation trains based on two lines intersecting in a Y shape, and establishes an objective function based on passenger travel costs and enterprise costs. Then, the genetic algorithm is used to solve the model. Finally, using passenger flow data from Beijing Subway Changping Line and Line 8 as samples, the genetic algorithm is used to solve the established model using MATLAB. The conclusion is that when the starting and ending points of cross-line operation are stations 1-29 in Fig.5.4, the total passenger travel time and total enterprise cost are reduced to varying degrees compared to the original plan. This verifies the effectiveness of the model and algorithm.

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