Route Optimization of Rail Transit Travel Chain under Bounded Rationality

Changfeng Zhu, Zongfang Wang, Xuejiao Ma, and Xianen Yang

***Abstract*—The route selection of the rail transit travel chain is studied based on the concept of rail transit collaborative optimization. Considering the influence of passenger travel time, passenger flow changes in rail transit, and different types of rail transit on passenger route selection, proposed a theory of path selection behavior analysis based on prospect theory. Based on passenger travel time, the generalized travel cost, the comfort cost, and taking travel path, transfer times, and travelers' travel mode as constraint conditions, an optimization model of rail transit travel chain path was constructed under bounded rationality. An example verifies the rationality of the established model and the designed algorithm. The results show that the larger the general overcrowding extra cost coefficient *w* and the overcrowding additional cost coefficient *s*, the lower the perceived cost of travelers. The smaller the section traveler flow, the larger the departure frequency, and the higher the perceived cost of travelers. In other words, the perceived cost of travelers is inversely proportional to the section traveler flow and the departure frequency.**

***Index Terms*—Rail transit, travel chain, optimal path selection, NSGA-II algorithm**

I. Introduction

In order to better describe the complex travel formed by passengers' displacement in the urban space through different modes of transportation, the mathematical model of passenger travel is constructed with the help of the travel chain. [1] studied the relationship between travelers' travel modes, activities and proposed the concept of the tourism chain and its primary research ideas. Subsequently, the theory was further applied to the field of transportation by scholars.

For the concept of a travel chain, scholars put forward different views. [2] believed that a series of trips linked to each other in space and time constitute a travel chain. [3] thought that travel chain refers to a round-trip trip composed of travel purposes arranged in time order to complete one or more activities. [4] thought that the travel chain should contain much information, such as the travel time, space, way, and activity type. The research results of domestic and foreign scholars mainly focus on the intercity transfer and connection or various transportation modes. There are few studies on passenger travel choice of the whole travel chain, even less on rail transit travel. Among the current research results, the study of travel chains mainly adopts the logit model. [5] the improved mixed logit model was applied to study the relationship between the travel mode selection and activity chain. [6] used a multinomial logit model to analyze personal preference on transportation choice behavior. In the same year, [7] used the logit model to analyze the blocking effect of complex travel chains on the choice of public transport mode. [8] established a stereotype logit model to study the influence of the travel chain complexity on travel mode selection. [9] described the joint selection behavior of the travel chain, travel mode, and departure time based on the cross-nested logit model. [10][11] established different logit models to study the interaction between travelers' choice of travel chain type and mode. The above research focuses on the relationship between the travel chain and travel mode in the travel process.

In addition, other scholars mainly reveal the factors that affect tourism choice behavior by studying tourism chain behavior. [12] established the binary-ordered probability model and the binary poisson regression model to study the travel chain behavior of commuters during commuting. [13] used statistical analysis methods to analyze and study the overall characteristics of the travel chain, the travel mode, and space-time characteristics. [14] built a joint probability model of traveler characteristic variables from the travel chain perspective, aiming at the connection modes at both ends of urban rail transit, and revealed the connection rules of urban rail. [15] put forward the concept of an intercity travel chain and introduces latent psychological variables to build travelers' intercity travel chain model. [16] studied the intercity passenger transfer choice behavior based on travel chain and revealed the impact of individual socio-economic attributes, travel characteristics, and latent psychological variables of passengers on travel mode choice. The travel route selection mainly focuses on network construction and model-solving research. Among them, [17][18] analyzed and researched route selection based on prospect theory. [19][20][21] combined with the logit model, constructed a path selection model.

To sum up, relevant scholars have researched the travel path selection of passenger travel chains, but there are still the following areas for improvement. Firstly, most existing

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scholars mainly study the route optimization of single mode of transportation in cities and need more consideration of the travel chain problem of multiple modes of transportation. In addition, existing studies assume that travelers are entirely rational but fail to consider the route optimization under bounded rationality. Finally, only some scholars study the travel chain of regional rail transit.

Based on this, by analyzing the complexity of rail transit travel problem and the characteristics of travel behavior under the condition of bounded rationality. Considering the influence of rail transit passenger flow and vehicle type on passenger route selection, a travel chain path optimization model was constructed under the condition of bounded rationality.

The structure of this article is as follows. In Section II, we introduced the structure of the rail transit travel chain, the construction of the travel network, and the process of transfer. In Section III, we established a travel optimization model for the travel chain. In Section IV, we designed an algorithm to solve the model established in Section III. Section V is a discussion and analysis, mainly analyzing the impact of some parameter changes on the results. Finally, the conclusion of this paper is in Section VI.

II. Rail Transit Travel Chain Structure

The multi-system rail transit network consists of stations of different systems as network nodes. In this network, different systems form their subnetworks and are connected by transport nodes, multi-system rail transit network can be described as:

$$G = (M, V) \tag{1}$$

Where, G represents the multi-system rail transit network, M represents the collection of multi-system rail transit; V represents the collection of traffic stops.

Rail transit complex network G is composed of an urban rail network, railway network, intercity rail network, suburban rail network, high-speed railway network, and bullet train network, among which the rail transit mode is $M = (U, R, I, S, H, B)$. The schematic diagram of regional rail transit travel is shown in Fig. 1.

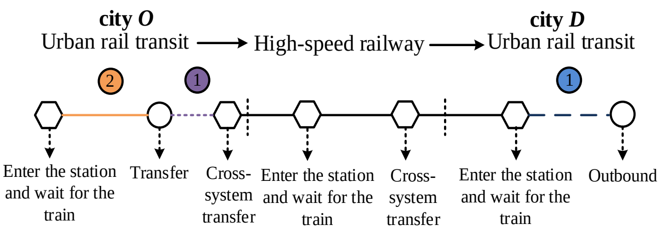

Fig. 1. The travel process of regional rail transit

In order to accurately describe passenger travel needs, a transportation mode including urban rail transit network, intercity rail transit network, universal speed rail transit network and other transportation modes is constructed. As shown in Fig. 2, it is a schematic diagram of the regional rail transit network. In this city O and city D are composed of various rail transit systems and connected by several trans-regional rail transit lines. In order to study the rail transit travel chain and the rail transit network, it is also necessary to study travelers' transfer in the travel process, as shown in Fig. 3, a schematic diagram of rail transit transfer stations.

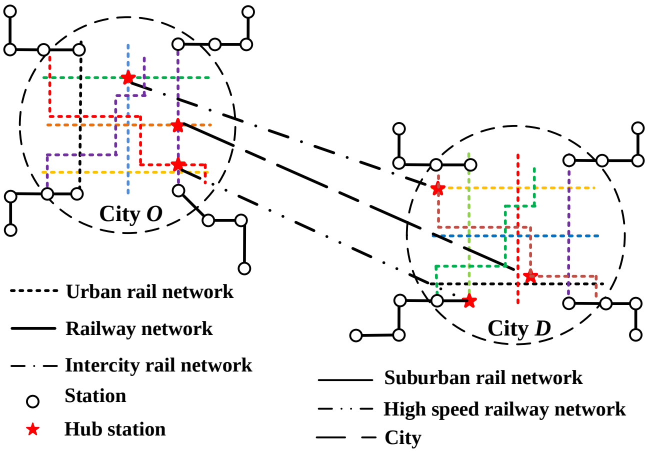

Fig. 2. Schematic diagram of regional rail transit network

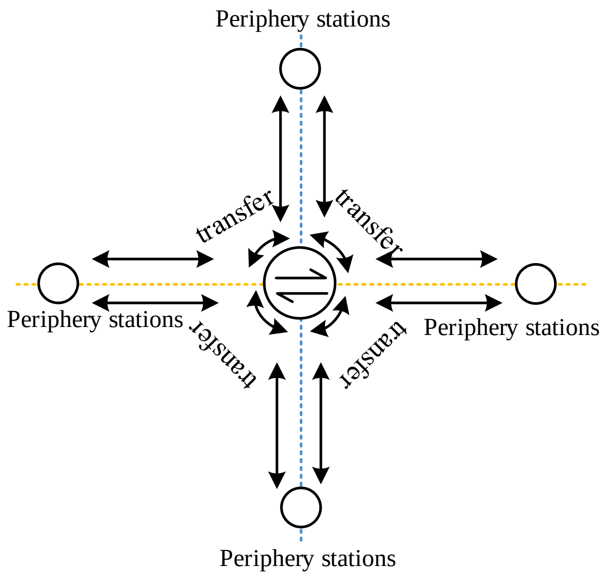

Fig. 3. Transfer diagram of rail transit station

III. Construction of Travel Chain Model

When choosing a route, travelers will comprehensively consider the chosen path based on their needs, mainly focusing on the consumption of travel time, travel money, and personal comfort. The process of selecting rail transit as the mode of travel specifically includes train operation, train parking, and passenger transfer.

A. Construction of Ride Time

The traveling time mainly includes the traveling time of the train from station i to station j and the stopping time of the train at each station. The traveling time model of travelers taking the optional path k in the traveling interval (station i, station j) is:

$$T_{ij}^{k} = t^{k} + \frac{d_{ij}^{k}}{\bar{v}} \tag{2}$$

Where, T_{ij}^{k} represents travelers' travel time (min); t^{k} represents platform stop time between station i and station j (min); d_{ij}^{k} represents the train distance from station i to station j (km); $\bar{v}$ represents the average running time of trains.

B. Construction of Transfer Time

Different passengers inevitably have differences in the transfer process of railway passenger hubs. When they walk to the waiting area at different times, the wait time is usually affected by the transfer times, transfer experience and, purpose.

The transfer time mainly includes the passenger transfer walking time and the passenger transfer waiting time. The transfer walking time is determined by dividing the transfer distance by the walking speed, and the departure interval determines the waiting time.

Taking travelers taking high-speed rail and transferring to rail transit as an example. As shown in Fig. 4, due to passengers being relatively familiar with the travel route, low passenger flow, and high comfort, passengers choose to take the next rail transit. As shown in Fig. 5, due to external factors such as high passenger flow and unfamiliarity with the route, travelers may not take this rail transit train and choose the next train or transfer to other transportation methods.

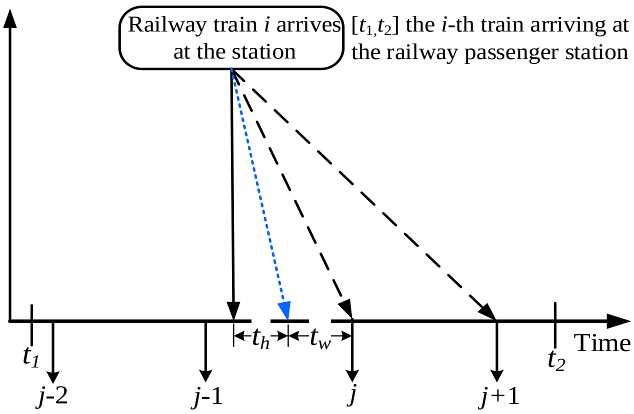

Fig. 4. Explanation of transfer time for travelers

In the first scenario, during the research period $[t_1,t_2]$, there were n rail trains arriving at the station, with j-2 and j-1 trains already departing. Travelers can only take the j-*th* and subsequent rail trains. The time required for travelers to travel from the railway platform to the railway platform is t_h, the waiting time for the rail train after arriving at the railway platform is t_w, and the transfer time for travelers is:

$$T^v = t_h + t_w \tag{3}$$

Where, T^v represents the total transfer time.

The second scenario is shown in Fig.5. Due to the fact that the j-*th* train is already full or the comfort level is too poor, and travelers take the j+1 train. The time it takes for travelers to travel from the railway platform to the track platform is t_h, the waiting time for the track train after arriving at the track platform is $t_w + t_w^{'}$, and the transfer time for travelers is:

$$T^v = t_h + t_w + t_w^{'} \tag{4}$$

Where, $t_w^{'}$ represents the departure interval between two trains.

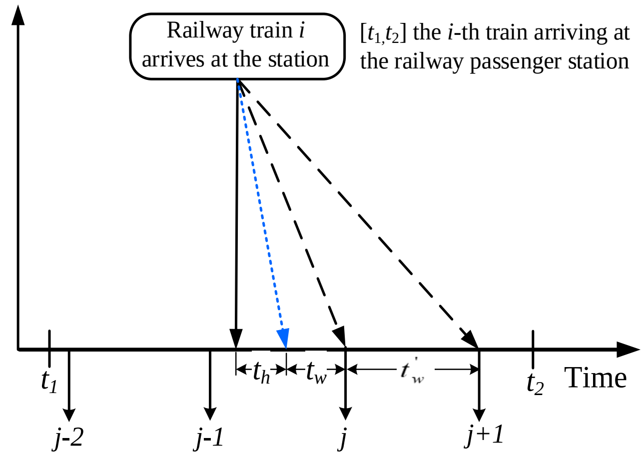

Fig. 5. Explanation of transfer time for travelers

In the first scenario, the waiting time of the traveler is relatively short, thereby shortening the travelers' travel time. Compared with the second scenario shown in Fig. 5, it saves departure time between two trains. The advantage of this situation is that most of the passenger volume of rail transit will not be lost, but a small portion of the traveler volume will inevitably be lost.

C. Value Function

Assume that x_1^0 and x_2^0 are the reference points of early arrival and late arrival respectively, these two reference points divide destination time into three intervals: $(-\infty, x_1^0]$, (x_1^0, x_2^0), $[x_2^0, +\infty)$. If the arrival time is less than x_1^0 or greater than x_2^0, it is considered as early loss or late loss, it's only in the (x_1^0, x_2^0) interval, and can it gain profit. Between (x_1^0, x_2^0), there must be a moment of maximum revenue, which is called the best arrival time, expressed by x. The value function is shown in Fig. 6.

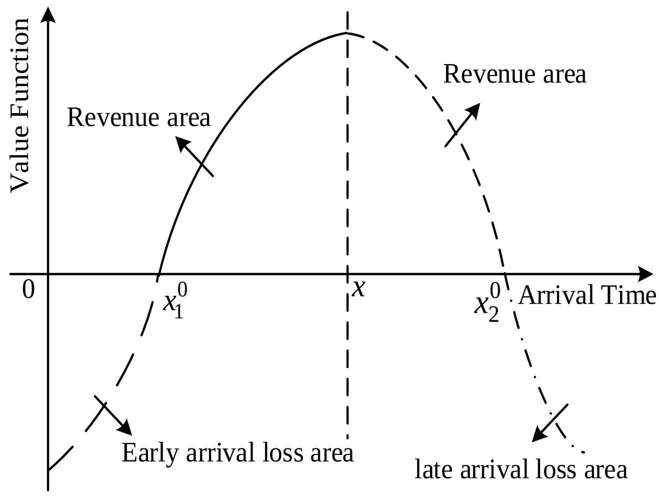

Fig. 6. Value function of two reference points

Travelers tend to arrive early, so the interval distance between x_1^0 and x should be larger than the interval distance between x and x_2^0. Travelers tend to avoid risks in the return interval and pursue risks in the loss interval, so the slope of the loss part of the value function curve is higher than that of the gain part. As can be seen from Fig. 6, x can be divided into left and right parts. The left and right sides are approximately symmetric.

$$v(x_i)=\begin{cases} v_1=-\lambda_1(x_1^0-T_{ij}^k-T^v)^{\eta_1}, & T_{ij}^k+T^v\le x_1^0 \\ v_2=\lambda_2(T_{ij}^k+T^v-x_1^0)^{\eta_2}, & x_1^0<T_{ij}^k+T^v\le x_p \\ v_3=\lambda_3(x_2^0-T_{ij}^k-T^v)^{\eta 3}, & x_p<T_{ij}^k+T^v<x_2^0 \\ v_4=-\lambda_4(T_{ij}^k+T^v-x_2^0)^{\eta_4}, & x_2^0\le T_{ij}^k+T^v \end{cases} \quad (5)$$

Where, v_i represents the value function of the *i-th* interval; λ_i represents the loss avoidance coefficient, and $\lambda_i \ge 1$, $i=1,2,3,4$; η represents risk attitude coefficient, and $0<\eta_i<1$, $i=1,2,3,4$.

D. Weight Function

The weight function is used to simulate the psychological effect on people. Generally, people will attach importance to small probability events and ignore medium and large probability events. In the face of loss, the decision-maker holds the attitude of risk preference, while in the face of income, the decision-maker holds the attitude of risk aversion. According to the research of [22], the probability weight formula is as follows:

$$\varpi(p)=\begin{cases} \varpi^+(p)=\dfrac{p^{\varsigma_1}}{[p^{\varsigma_1}+(1-p)^{\varsigma_1}]^{1/\varsigma_1}} \\ \varpi^-(p)=\dfrac{p^{\varsigma 2}}{[p^{\varsigma 2}+(1-p)^{\varsigma_2}]^{1/\varsigma_2}} \end{cases} \quad (6)$$

Where, $\varpi(p)$ represents the perceived probability of an event occurrence; *p* represents the probability of possible arrival time from station *i* to station *j*, according to the frequency of departure; ς_1 is 0.61 for gains and ς_2 is 0.69 for losses [23].

E. Generalized Travel Cost

The ticket price of the rail transit is determined by its starting and ending stations and ticket system. The ticket price standard of different rail transit systems is also different. Therefore, this paper takes the function of train travel length as the passenger travel cost.

$$C_n^{ij}=f(d_{ij}^k) \quad (7)$$

Where, d_{ij}^k represents the distance between station *i* and station *j*.

Travelers are bounded rational, before taking rail transit, travelers will judge whether to take the train according to the number of people at the station. If there is congestion, the congestion coefficient of passengers will increase, thus increasing the cost of travel.

$$Y_{ij}^n=\begin{cases} 0,\ p_{ij}^n<f_{ij}^n z_{ij}^n \\ \dfrac{p_{ij}^n-f_{ij}^n z_{ij}^n}{f_{ij}^n z_{ij}^n}\cdot w,_{ij}^n z_{ij}^n\le p_{ij}^n<f_{ij}^n c_{ij}^n \\ \dfrac{c_{ij}^n-z_{ij}^n}{z_{ij}^n}\cdot w+\dfrac{p_{ij}^n-f_{ij}^n c_{ij}^n}{f_{ij}^n c_{ij}^n}\cdot s,\ p_{ij}^n\ge f_{ij}^n c_{ij}^n \end{cases} \quad (8)$$

Where, p_{ij}^n represents the section passenger flow between station *i* and station *j*, (person /h); f_{ij}^n represents the departure frequency between station *i* and station *j* (trains/h); z_{ij}^n represents the number of passengers per train from station *i* to station *j* (person/vehicle); c_{ij}^n represents the overcrowding number of each train between station *i* and station *j* (person/vehicle); *w* represents the general crowding extra cost factor; *s* represents the overcrowding extra cost factor; Y_{ij}^n represents the extra cost coefficient between station *i* and station *j* due to congestion. When the number of travelers exceeds the train's capacity, travelers have to wait at the platform for the next train or choose other transportation modes.

The comfort of taking rail transit is positively correlated with the ticket price.

$$C_f^{ij}=Y_{ij}^n\cdot f(d_{ij}^k) \quad (9)$$

To sum up, the objective function of traveler path optimization is as follows:

$$\max \quad f_1=\sum_{i\in E}\sum_{j\in E}\omega_{ij}\cdot v(p_{ij}) \quad (10)$$

$$\min \quad f_2=\sum_{i=1}^{n}C_{ij}^n-\sum_{i=1}^{n}C_f^n \quad (11)$$

In order to ensure the continuity of the transportation process, there is only one complete route for travelers to each destination.

$$\sum_{i\in E}\sum_{j\in E}\sum_{m\in m}x_{ij}^m-\sum_{i\in E}\sum_{j\in E}\sum_{m\in m}x_{ij}^m=1,\forall i=o \quad (12)$$

$$\sum_{i\in E}\sum_{j\in E}\sum_{m\in m}x_{ij}^m-\sum_{i\in E}\sum_{j\in E}\sum_{m\in m}x_{ij}^m=0 \quad (13)$$

$$\sum_{i\in E}\sum_{j\in E}\sum_{m\in m}x_{ij}^m-\sum_{i\in E}\sum_{j\in E}\sum_{m\in m}x_{ij}^m=-1,\forall i=d \quad (14)$$

In order to avoid excessive transfer times in the travel process, the maximum number of transfer times is set.

$$\sum_h\sum_m\sum_i\sum_j r_{ij}^{hm}\le H \quad (15)$$

In order to quickly and accurately locate the travel path and mode, the decision variable is set. When x_{ij}^m =1, it means that the traveler passes station *i*, otherwise, the traveler does not pass. When r_{ij}^{mh} =1, it means that when the traveler passes through node *i* to station *j*, the transportation mode *m* is changed into transportation mode *h*.

$$x_{ij}^m\in\{0,1\},\forall(i,j)\in V \quad (16)$$

$$r_{ij}^{mh}\in\{0,1\},\forall(i,j)\in V \quad (17)$$

IV. Algorithm Design

Due to the problem of route selection, it involves the conversion of various vehicles. In order to ensure the diversity of the population, a non-dominated sorting genetic algorithm-II (NSGA-II) based on an improved elite strategy was proposed to solve the model.

A. Chromosome Coding and Decoding

The chromosomes are set into double chains, with the first chromosome chain representing the station of rail transit and the second chromosome chain representing the way of travel, both of which are encoded by real numbers, the encoding is shown in Fig. 7.

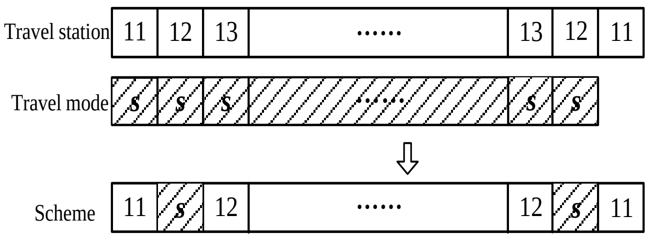

Fig. 7. Coding diagram

B. Crossover Strategy

In order to ensure the diversity of the population, the chromosomes are crossed, the same sites (excluding the starting and ending points) existing in the two chromosomes are traversed and marked, and some chromosomes after the points are crossed and exchanged, as shown in Fig. 8.

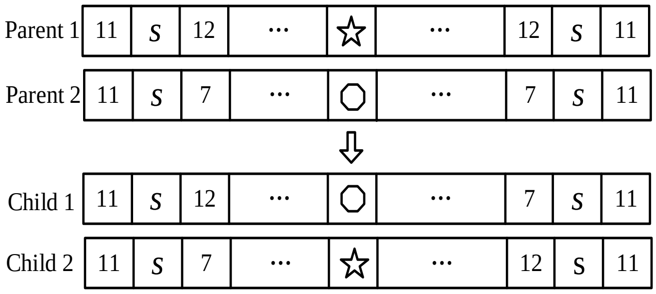

Fig. 8. Chromosomal crossover

C. Elite Strategy

Excellent individuals in the parent generation are retained and directly entered into the child generation, reducing the computational complexity and ensuring that elite individuals are not omitted [24]. The elite policy steps of the NSGA-II algorithm are shown in Fig. 9.

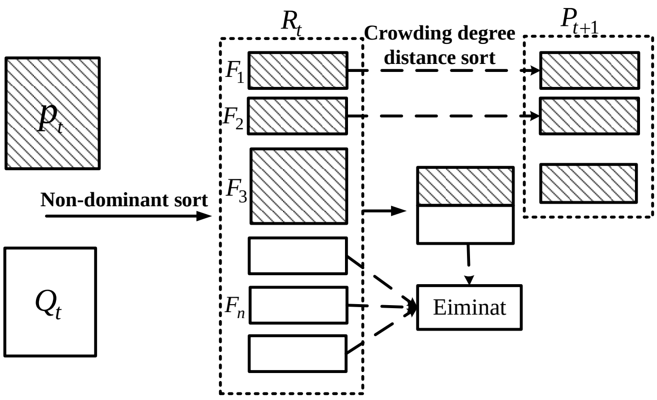

Fig. 9. Elite strategy steps of NSGA-II algorithm

Based on the above analysis, the algorithm steps are as follows:

Step 1: The initial population P_t is randomly generated, and the travel path and mode are selected.

Step 2: Through selection operator, crossover, and other operations, the offspring population Q_t is generated.

Step 3: The initial parent population P_t and the child population Q_t merge into a new population.

Step 4: Forming a non-inferior solution set by using fast non dominated sorting.

Step 5: According to the non-dominant sequence, select chromosomes layer by layer to enter the next generation P_{t+1}, until the chromosome number is the population number.

Step 6: Make $t=t+1$ to determine whether the iteration termination condition is satisfied, if yes, the iteration will end. Otherwise, through the cross-operation, the offspring population Q_{t+1} will be generated and transferred to step 3.

Based on the above analysis, the algorithm flow of NSGA-II is shown in Fig. 10:

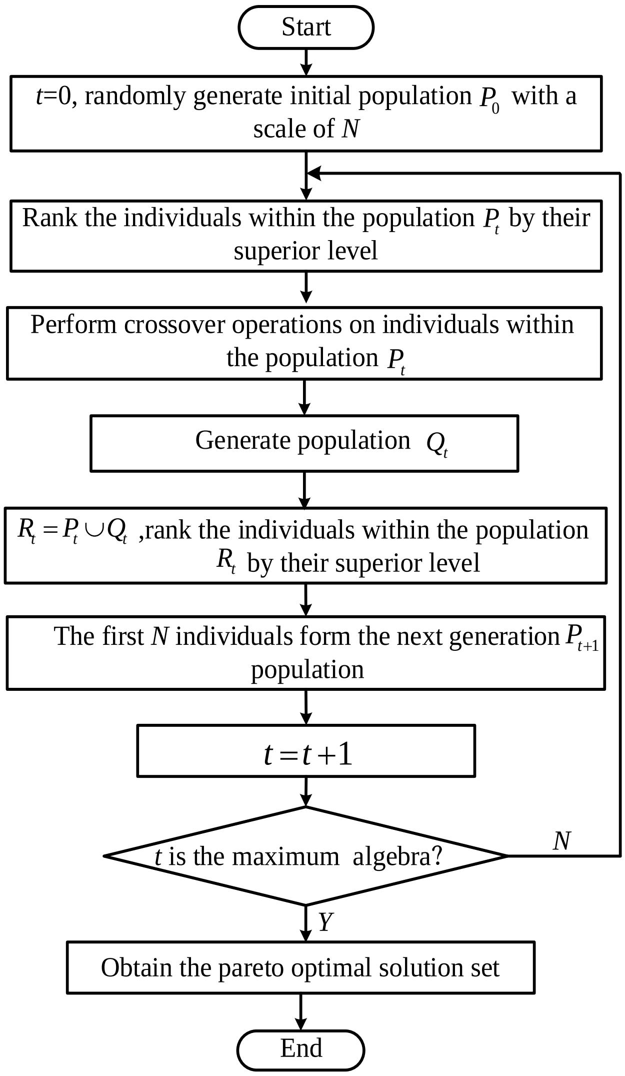

Fig. 10. Algorithm flow chart

V. Example Design and Result Analysis

As an example, this paper takes the path between city *O* and city *D* in a specific urban agglomeration and combines multiple transportation modes in the rail transit network. Passengers take short-distance transportation from the departure station to the hub station of the city and transfer to long-distance transport at the hub station. A combination of multiple rail transit systems provides services for passengers with different travel purposes and service characteristics. This paper takes city *O* and city *D* as examples, and the rail transit network diagrams of the two cities are shown in Fig. 11 and Fig. 12.

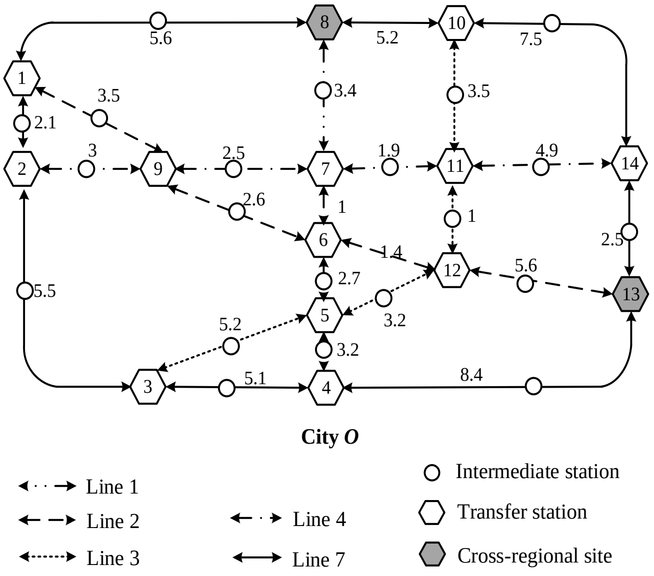

Fig. 11. Schematic diagram of rail transit network in city *O*

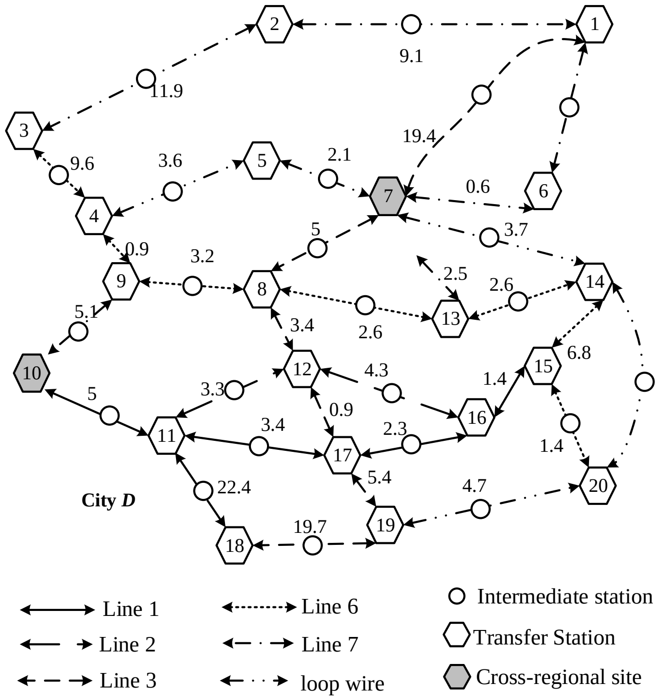

Fig. 12. Schematic diagram of rail transit network in city *D*

The cross-regional stations between the two cities provide transfer for rail transit of different systems, only stations marked as interchange stations are allowed to transfer between the two cities, as shown in Table I, which is the information on the rail transit network of different systems.

TABLE I
RAIL TRANSIT NETWORK INFORMATION OF DIFFERENT SYSTEMS

Rail transit system	Start	End	Ticket price (yuan)	Mileage(km)	Speed(km/h)
Intercity	O_{13}	D_7	128	319	250
High speed railway	O_{13}	D_7	154	309	350
High speed railway	O_{13}	D_{10}	144.5	299	350
Railway	O_{13}	D_7	46.5	315	120
Railway	O_8	D_7	46.5	313	120
Bullet train	O_8	D_7	97	313	200
Bullet train	O_{13}	D_7	96.5	304	200

The operation indicators of each line in the city *O* rail transit network are shown in Table II, and the operation indicators of each line in the city *D* rail transit network are shown in Table III.

TABLE II
OPERATION INDICATORS OF CITY *O* RAIL TRANSIT LINES

Line	Line 1	Line 2	Line 3	Line 4	Line 7
Minimum departure interval/min	2.00	2.75	3.50	3.23	3.50
Number of train formation	6	6	6	6	6
Fixed number of Train (person/train)	1259	1259	1259	1259	1259
Metro vehicle type	type B	type B	type B	type B	type B
Overcrowding (person/train)	1869	1869	1869	1869	1869
Speed(km/h)	40	40	40	40	40

Assume that the earliest departure time of rail transit in city *O* and city *D* is 6:00, the passenger transfer time on foot is 2.5 minutes, the passengers' transfer preparation time is 0.5 minutes, the fare of urban rail transit is 1/3 (yuan/km), Less than 3km is charged at 3km, and more than 3km is charged at 6km. At 7:30 am, a passenger departed from station 11 in city *O* and took the urban rail transit to station 12 in city *D*. After spending 3 hours in city *D*, return to the original route. The path from station 11 in city *O* to station 12 in city *D* is shown in Table IV.

TABLE IV
OPTIMAL PATH SET

Scheme	Path	Transfer system
1	O_{11}-O_7-O_8-D_7-D_8-D_{12}	bullet train
2	O_{11}-O_7-O_8-D_7-D_{13}-D_8-D_{12}	bullet train
3	O_{11}-O_{12}-O_{13}-D_{10}-D_{11}-D_{12}	high speed railway
4	O_{11}-O_{12}-O_{13}-D_7-D_8-D_{12}	bullet train
5	O_{11}-O_{12}-O_{13}-D_7-D_{13}-D_8-D_{12}	bullet train

TABLE III
OPERATION INDICATORS OF CITY *D* RAIL TRANSIT LINES

Line	Line 1	Line 2	Line 3	Line 6	Line 7	Loop wire
Minimum departure interval/min	3.17	3.08	2.50	3.83	6.50	4.50
Number of train formation	6	4/6	6/8	6/8	6	6
Fixed number of trains (person/train)	1440	632/962	962/1292	1440/1920	1860	1960
Metro vehicle type	type B	type B	type B	type B	type A	type A
Overcrowding/(person/train)	2062	882/1342	1342/1802	1547/2062	2322	2580
Speed (km/h）	40	35	35	50	40	40

Since passengers are boundedly rational, considering the value sensitivity coefficient and weight coefficient. It is necessary to carry out a sensitivity analysis on the influence of comprehensive prospect value. Scheme 3 is taken as an example to analyze the travel path, as shown in Fig. 13 and Fig. 14.

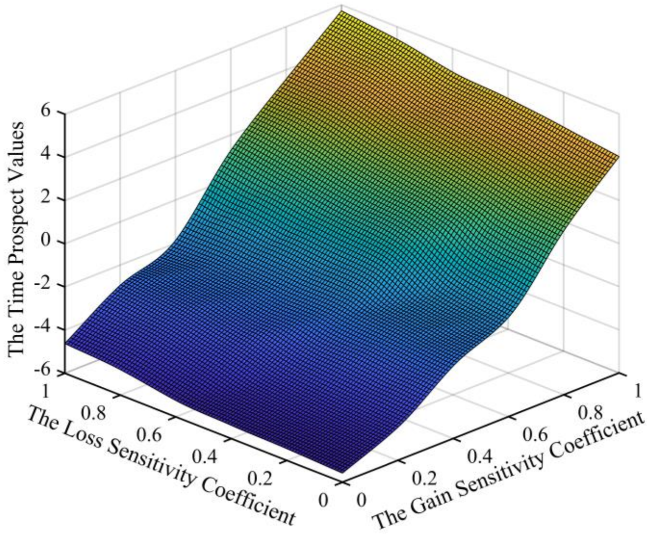

Fig. 13. Influence of value sensitivity coefficient on time prospect values

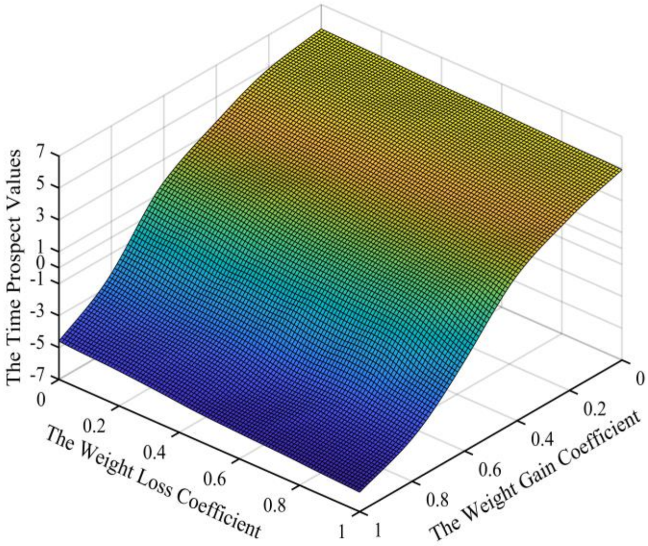

Fig. 14. Influence of weight coefficient on time prospect values

As can be seen from Fig. 13, both the gain sensitivity coefficient and loss sensitivity coefficient affect the time prospect value, and the influence of the gain sensitivity coefficient on the prospect value is much more significant than that of the loss sensitivity coefficient. As seen from Fig. 14, the weight gain coefficient is more sensitive to the influence of the weight loss coefficient on the time prospect values. With the weight gain coefficient increase, the time prospect values show an upward trend.

Assuming that other factors remain unchanged, taking a B-type train with 6 marshals as an example, and the cross-sectional passenger flow at all stations in scheme 3 is 15000 (person/h). The impact of the general congestion additional cost coefficient and the overcrowding additional cost coefficient on the generalized travel cost is shown in Fig. 12.

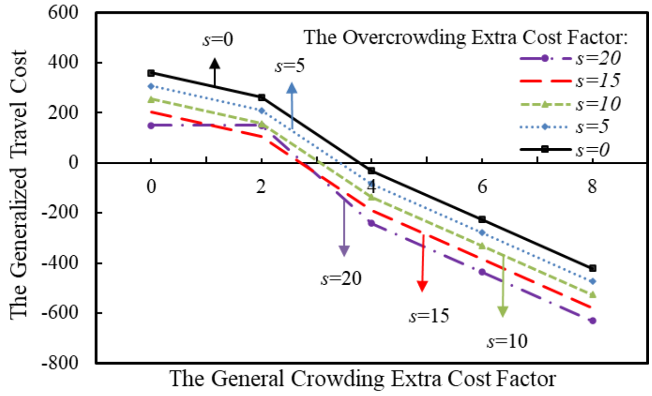

Fig. 15. *w* and *s* influence of generalized travel on cost

As can be seen in Fig. 15, when the general overcrowding extra cost coefficient *w* gradually increases, the generalized travel cost gradually decreases, indicating that when the passenger flow in the section is greater than the number of passengers that can be carried, passengers feel extremely uncomfortable and the perceived cost is negative. The larger the overcrowding extra cost coefficient *s* is, the smaller the perceived cost of travel. From the changes in the curve in Fig. 15, it is found that the additional cost coefficient *s* of overcrowding has a relatively significant impact on travel costs.

Section passenger flow, departure frequency, train size, and train overcrowding all impact the generalized travel cost, among which train size and train overcrowding are mainly related to the train type. Assuming that the departure frequency of the train is 12 trains per hour, the impact of cross-sectional passenger flow changes on generalized travel cost is shown in Fig. 16. Assuming that the cross-sectional passenger flow at each station is 15000 (people/h), the impact of train departure frequency on the generalized travel cost is shown in Fig. 17.

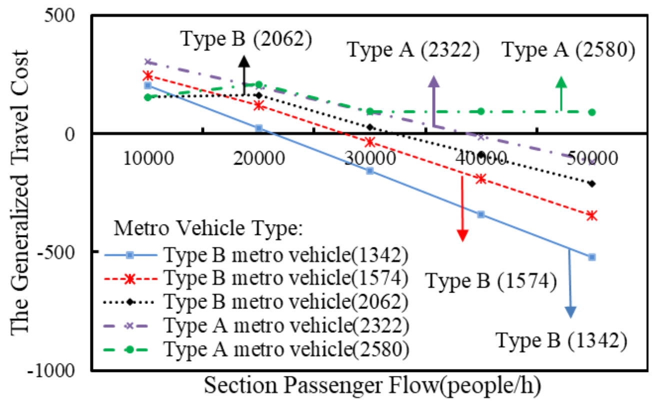

Fig. 16. Influence of passenger flow on generalized travel cost

As can be seen from Fig. 16, it can be seen that as the passenger flow of this section increases, rail transit will become congested, and the perceived cost of passengers will correspondingly decrease. The more passengers there are, the worse the passenger experience. However, the maximum number of passengers a train can carry is the number of overloaded passengers. We should not assume that more passengers are better. Careful consideration should be given to passenger experience, operating costs, and capacity consumption perspectives.

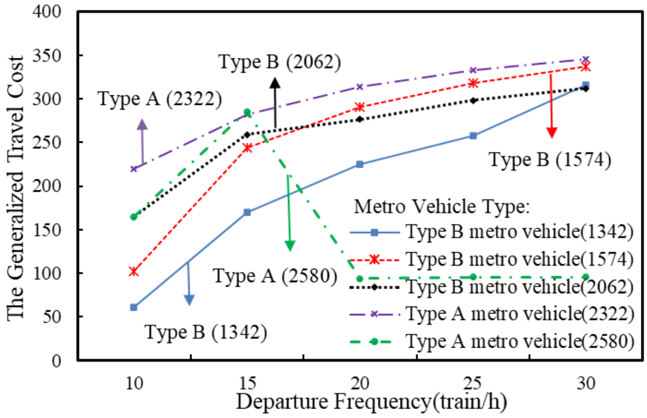

Fig. 17. Influence of departure frequency on generalized travel cost

As can be seen from Fig. 17, the increase in the frequency of departures means that the ability to transport passengers is enhanced, and the perceived cost of passengers is also increased. The dense departures make passengers feel less crowded for the type A metro vehicle with an overcrowding of 2580.

VI. Conclusion

This paper mainly studies the optimization problem of regional rail transit travel chain paths. Because the travel environment is uncertain, an optimization model of the traveler travel chain is established considering the bounded rationality behavior of passengers, and an algorithm for solving the model is designed.

By analyzing the obtained objective function and related parameters, it was found that the effect of the gain sensitivity coefficient on prospect value is much greater than that of the loss sensitivity coefficient. The weight gain coefficient is more sensitive to the effect of the time prospect value than the weight loss coefficient, and the time prospect value increases with the increase of the weight gain coefficient.

The relationship between generalized perceived cost and other parameters is as follows: the larger the general overcrowding extra cost coefficient w and overcrowding extra cost coefficient *s*, the lower the perceived cost of passengers. The smaller the section passenger flow, the greater the departure frequency, and the higher the perceived cost of passengers. That is, the perceived cost of passengers is inversely proportional to the section passenger flow and is directly proportional to the departure frequency.

References

[1] E.L. Pas, “Recent developments in activity-based travel demand modeling,” *Activity-based Travel Forecasting Conference, Arlington: Texas Transportation Institute*, 1997.
[2] Y.J. Chen, and G. Akar, “Using trip chaining and joint travel as mediating variables to explore the relationships among travel behavior, socio-demographics, and urban form,” *Journal of Transport and Land Use*, vol.10, no.1, pp.573-588, 2017.
[3] W.H. Zhang, and Z.C. Juan, “Trip-chain based stochastic dynamic transportation assignment simulation approach,” *Science Technology and Engineering*, vol.11, no.35, pp.8761-8766, 2011.
[4] J.C. Xianyu, “A model for the joint choice of commute mode and trip chaining Pattern,” *Journal of Transportation Systems Engineering and Information Technology*, vol.16, no.5, pp.143-148, 2016.
[5] S. Krygsman, T. Arentze, and H. Timmermans, “Capturing tour mode and activity choice interdependencies: A co-evolutionary logit modelling approach,” *Transportation Research Part A*, vol.41, no.10, pp.913-933, 2007.
[6] C.R. Bhat, “Incorporating Observed and unobserved heterogeneity in urban work travel mode choice Modeling,” *Transportation Science*, vol.34, no.2, pp.228-238, 2000.
[7] D.A. Hensher and A. J. Reyes, “Trip chaining as a barrier to the propensity to use public transport,” *Transportation*, vol.27, no.4, pp.341-361, 2000.
[8] L. Cheng, X.W. Chen, C. Feng, and S. Yang, “Daily Trip chain pattern and its influencing factors of low-income residents,” *Journal of Wuhan University of Technology Transportation Science & Engineering*, vol.39, no.2, pp.273-278, 2015.
[9] L.Y. Yang, and J. Li, “Cross-nested logit model for the joint choice of residential location, travel mode, and departure time,” *Acta Scientiarum Naturalium Universitatis Pekinensis*, vol.53, no.4, pp. 722-730, 2017.
[10] X.K. Wang, Q.L. Rao, C.Y. Tang, and Y.G. Ge, “Commuters’ trip-chain and mode choice relationship,” *Journal of Transportation Systems Engineering and Information Technology*, vol.14, no.2, pp.144-149, 2014.
[11] K. Luan, Z.C. Juan, and F. Zong, “Research on commuter’s choice behavior between travel mode and trip chain,” *Journal of Highway and Transportation Research and Development*, vol.27, no.6, pp.107-111, 2010.
[12] Z.Z. Wu, and Y. Xin, “Joint modeling analysis of trip-chaining behavior on round-trip commute in the context of Xiamen, China,” *Transportation Research Record*, vol.2076, no.1, pp.62-69, 2008.
[13] S.M. Feng, D.J. Jia, and B.Y. Hu, “Analysis of small and medium sized city residents trip chain characteristics,” *Journal of Wuhan University of Technology*, vol.37, no.1, pp.51-55, 2015.
[14] J.Z. Zhou, and D.Y. Zhang, “Behavior model of urban trip chains in multi-mode transportation network,” *Journal of South China University of Technology (Natural Science Edition)*, vol.42, no.2, pp.125-131, 2014.
[15] Y.L. Ye, M.C. Han, and J.J. Chen, “Intercity passenger travel mode choice behavior based on trip chain,” *Journal of Tongji University (Natural Science)*, vol.46, no.9, pp.1234-1240, 2018.
[16] S.H. Ma, Y. Li, and M. Yue, “Study on intercity passenger transfer mode choice based on travel chain,” *Journal of Beijing Jiaotong University*, vol.44, no.6, pp.74-81, 2020.
[17] J.J. Xia, Z.C. Juan, and J.X. Gao, “Travel routing behaviors based on prospect theory,” *Journal of Highway and Transportation Research and Development*, vol.29, no.4, pp.126-131, 2012.
[18] X.J. Li and L.Z. Liu, “Route choice model for commuters based on cumulative prospect theory,” *Journal of Transportation Systems Engineering and Information Technology*, vol.15, no.1, pp.173-178, 2015.
[19] J. Chen, M. Wang, H.P. Li, and L.W. Duan, “Choice behavior of passenger transfer route for urban rail transit network,” *Journal of Transportation Systems Engineering and Information Technology*, vol.17, no.6, pp.235-241, 2017.
[20] E.J. Yao, F.L. Jin, Q.W. Hu, Y.S. Zhang, and Y. Yang, “Analysis of route behavior of urban rail passengers considering transfer thresholds,” *Journal of Southwest Jiaotong University*, vol.52, no.3, pp.639-645, 2017.
[21] J.F. Liu, F.L. Sun, Y. Bai, and J. Xu, “Passenger flow route assignment model and algorithm for urban rail transit network,” *Journal of Transportation Systems Engineering and Information Technology*, vol.9, no.2, pp.81-86, 2009.
[22] K.R. Liu, Q.R. Wang, C.F. Zhu, Z.W. Zhang, and W.J. Sun, “Research on Emergency Personnel Scheduling Considering the Psychological Perception of both Disaster Victims and Emergency Personnel,” *IAENG International Journal of Applied Mathematics*, vol.52, no.3, pp.597-609, 2022.
[23] A. Tversky and D. Kahneman, “Advances in prospect the ory: Cumulative representation of uncertainty,” *Journal of Risk and Uncertainty*, vol.5, no.4, pp.297-323, 1992.
[24] Z.W. Zhang, C.F. Zhu, K.R. Liu, and Q.R. Wang, “Bi-level Optimal Scheduling of Emergency Materials Considering Multimodal Transport,” *Engineering Letters*, vol.30, no.2, pp.494-505, 2022.

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