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Research on Comprehensive Optimization of Train Marshalling and Parking Scheme of Intercity Railway Based on Operation Cost

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Abstract

In view of the waste of transport capacity caused by a single train formation mode due to the uneven temporal and spatial distribution of passenger flow in the early stage of intercity railway opening, starting from the train operation cost, the operation schemes of large and small marshalling trains with various stop modes are studied. Taking the minimization of train operation cost as the objective function, taking the number of running trains and parking scheme of large and small marshalling trains as decision variables, and comprehensively considering the constraints such as train section full load rate and OD service frequency, the operation scheme model of large and small marshalling trains is constructed. The genetic algorithm is used to solve the problem, and the operation scheme of large and small marshalling trains in the whole day is obtained. Taking Guangqing intercity railway and Guangzhou east ring intercity railway as an example, compared with the current train operation scheme, the large and small marshalling train operation scheme with multi stop mode can reduce the train operation cost by 59%, and the average daily section load ratio can be increased from 0.2888 to 0.8665, which shows that the large and small marshalling train operation scheme with multi stop mode can effectively reduce the train operation cost and improve the section full load rate.

Keywords

Intercity Railway, Passenger Flow Characteristics, Stop Plan, Operating Costs, Large and Small Marshalling Train

1. Introduction

Intercity railways are dedicated rail passenger lines that serve adjacent cities or urban agglomerations. At present, the overall "attendance rate" of China's intercity railways is not high, especially in the early stage of the opening of the line, resulting in losses in most operating enterprises. The main reasons can be concluded in two aspects, one is that most intercity railways are still in the passenger flow cultivation period, and the cultivation time is long; Second, due to the mismatch between the existing operating mode of intercity railways and the current situation of passenger flow, it is mainly reflected in the train operation plan. Through the survey, it was found that the current intercity railway operation plan mainly has the characteristics of a single train stop mode, a single train group mode, and a large departure interval (Jiang, 2015; Sun & Lu, 2017; Yang, 2011, Tian, 2020).

Literature (Huang, 2015, 2018) mentioned that due to the relatively single train speed level of intercity railways, the research on intercity railway operation scheme focuses on train departure intervals, the number of marshallings and the stop scheme of trains at intermediate stations along the way. Represented by the literature (Chang et al., 2000), it uses passenger flow data as the input of the system, with the goal of minimizing the operating costs of enterprises and minimizing the travel time of passengers, and optimizing the train stop plan, frequency and group size. In the literature (He, 2014; Claessens et al., 2007; Goossensaab, 2006; Xu & Zou, 2005), from the perspective of transport enterprises, the transportation scheme is optimized under the constraint of meeting basic transportation needs to minimize transportation costs.

Although the above literature considers the optimization of the train running scheme in the multi-group mode, the objective function is mostly the minimum total cost, and the optimization of the train full load rate is less considered. Therefore, starting from the train operating cost, we will explore the comprehensive optimization scheme of train marshalling and train stop to save train operating costs and improve the full load rate of trains while meeting the existing passenger flow needs.

2. Optimization Model of Large and Small Group Train Operation Scheme in Multi-Stop Mode

2.1. Problem Description

Whether in urban rail transit or intercity railway, compared with the line running a single group of trains, the use of large and small groups of trains can make the transportation capacity and passenger flow of the time and space distribution more matched, can alleviate the waste of transportation capacity, the low frequency of service at some stations, passenger waiting, transfer and long travel time in transit, etc., based on this, starting from the train operating costs, in the case of fully investigating the OD passenger flow data of intercity railway lines and related operating parameters, study the study of meeting a certain train frequency without crossing the train. Under the constraints of OD service frequency and other constraints, the optimization of train operating costs and full load rates on intercity railway lines using "large and small grouping, multiple stopping modes" is compared to using "single grouping, stopping modes".

2.2. Parameter Definition of the Model

Taking the operating cost of the train as the optimization goal, and taking the number of trains and stops of the trains in the large and small groups as the decision variables, the optimization model of the operation scheme of the large and small groups of trains in the multi-stop mode is constructed. The parameters involved in the model and their meanings are shown in Table 1.

Table 1. The meaning of parameters in the model.

PARAMETERS	MEANING	REMARK
C_l	The cost per kilometer of vehicle operation	
C_s	The cost of each stop for a vehicle	
f_k	he number of trains in the k type	Decision variables
$f_{\max}$	The maximum number of open rows in an operating period	
$f_{1\min}$	The minimum number of trains opened in large groups	
$f_{2\min}$	The minimum number of trains opened in small groups	
g_k	The number of vehicles grouped	$g_1 = 8, g_2 = 4$
L	Intercity rail line mileage	
$\eta_{\max}$	The upper limit of the cross-sectional full load rate	
$\eta_{\min}$	Lower bound of the average cross-sectional full load rate	
L_1	Total mileage of the small interchange route	
$L_1 + L_2$	Total mileage of the large interchange route	
$a_{k,u}^r$	0,1 variable indicating whether the rth train of the group type k stops at station u,	$a_{k,u}^r = \begin{cases} 1, & \text{stop} \\ 0, & \text{no} \end{cases}$
C	Vehicle capacity	
η_d	The cross-sectional full load rate of the dth interval	
$\eta_{\max}$	The upper limit of the cross-sectional full load rate	
$\eta_{\min}$	The lower limit of the cross-sectional full load rate	
Q_{ij}	Total OD passenger traffic from i station to j station	
q^i	A train attracts passenger traffic at i station	
q_d	Cross-sectional traffic in the d zone	
$r_{i,j}$	The number of trains that stop at stations i and j	
U	A collection of stations along the line	$U = \{u \mid u = 1, 2, \cdots, U\}$
W	A meeting place at a station along the small interchange	
B	A collection of stations in the Large Interchange after the elimination of stations that duplicate the Small Interchange	
Z	The objective function of the model	
ε_r	0,1 variable,1 indicates large intersection	

2.3. Objective Function of the Model

Starting from the actual operation of intercity railways, based on the actual passenger flow OD requirements, it is found that the running cost of trains caused by a single large group of trains and a single stop mode is too high, and the large and small group train operation scheme using the multi-stop mode can reduce the operating costs of the train, so the objective function of the model is to minimize the operating costs of the train. From the perspective of train operation, the train operating cost mainly includes the train operation cost and the train stop cost, of which the operation cost includes the energy consumption cost of the train such as electricity, the line use cost, and the train operation cost is related to the vehicle travelling kilometers and the operating cost of the vehicle per kilometer; the cost of train stops refers to the costs incurred by the train during the stop at the station, which is related to the number of train stops and the cost of each stop. The objective function is as follows:

$$\min Z=\sum_{k=1}^{2} f_k\cdot g_k\cdot L_1\cdot C_l+\left(\sum_{r=1}^{f_1} g_1\cdot\varepsilon_r+\sum_{r=f_1+1}^{f_1+f_2} g_2\cdot\varepsilon_r\right)\cdot L_2\cdot C_l$$

$$+\sum_{k=1}^{2}\sum_{r=1}^{f_k}\sum_{w=1}^{W} a_{k,w}^{r}\cdot g_k\cdot C_s+\left(\sum_{r=1}^{f_1}\sum_{b=W+1}^{U} a_{1,b}^{r}\cdot g_1\cdot\varepsilon_r+\sum_{r=f_1+1}^{f_1+f_2}\sum_{b=W+1}^{U} a_{2,b}^{r}\cdot g_2\cdot\varepsilon_r\right)\cdot C_s$$

2.4. Constraints of the Model

The constraints of the model mainly include the number of trains, train full load rate, OD service frequency, stop constraint, integer value constraint of variables, and 0, 1 variable constraint.

1) The upper and lower limits of the number of open rows and columns

Considering the operating costs of the enterprise and the operation safety of the train, and meeting the number of trains in the large and small group trains during peak hours, it is necessary to set upper and lower limits on the number of trains opened in any period:

$$\sum_{k=1}^{2} f_k\le f_{\max},\ f_1\ge f_{1\min},\ f_2\ge f_{2\min}$$

2) Full load rate constraint

According to the OD passenger flow demand, the cross-sectional passenger flow can be obtained, and then the cross-sectional full load rate can be obtained. Considering the train capacity, it is necessary to constrain the upper limit of the cross-sectional full load rate and the lower limit of the average cross-sectional full load rate:

$$\eta_d=\frac{\sum_{i=1}^{d}\sum_{j=d+1}^{N} q_{ij}}{\sum_{k=1}^{2} f_k\cdot g_k\cdot C}\le\eta_{\max},\ \bar{\eta}_d\ge\eta_{\min}$$

3) OD service frequency constraints

In order to meet the travel needs of passengers, the number of OD service trains cannot be less than the minimum:

$$\sum_{k=1}^{2}\sum_{r=1}^{f_k} a_{k,i}^{r} \cdot a_{k,j}^{r} \geq \frac{Q_{ij}}{\min\left(q^{i}, q^{j}\right)}$$

4) Stop constraints

The train operation interchange is divided into two types: large interchange and small interchange, and the stop mode is divided into three types: large station stop, station stop and station choice stop. According to the stop needs of different stations of different interchanges, the specific stops of the trains are restricted as follows: small interchange trains can choose 3 kinds of stops, first and last stops and intermediate 1 stop; Dajiao road trains can choose 3 schemes: station stop, big station stop and intermediate choice of 2 stops; The specific constraints are as follows:

$$\sum_{w=1}^{W} a_{k,w}^{r} \cdot \left(1-\varepsilon_r\right) = 2 \text{ or } 3 \text{ or } W, k=1,2; r=1,2,\cdots,f_1+f_2$$

$$\left(a_{k,1}^{r} + a_{k,W}^{r}\right) \cdot \left(1-\varepsilon_r\right) = 2, k=1,2; r=1,2,\cdots,f_1+f_2$$

$$\sum_{u=1}^{U} a_{k,u}^{r} \cdot \varepsilon_r = 3 \text{ or } 5 \text{ or } U, k=1,2; r=1,2,\cdots,f_1+f_2$$

$$\left(a_{k,1}^{r} + a_{k,W}^{r} + a_{k,U}^{r}\right) \cdot \varepsilon_r = 3, k=1,2; r=1,2,\cdots,f_1+f_2$$

5) Integer variable value constraints

$$f_k \in Z^{+}$$

6) 0, 1 variable value constraint

$$a_{1,u}^{r} = 0,1;\ \ a_{2,u}^{r} = 0,1$$

2.5. Model Solving Algorithm

Genetic algorithms are used to solve the model. Genetic algorithm search range is large, high degree of traversal, with good global convergence, can search for satisfactory solutions in a short period of time, is the most commonly used algorithm in the optimization of intercity railway operation scheme, so the genetic algorithm is used to solve the above problems. Using binary coding, the 0-1 variable is used to indicate the group type of the train and whether there is a stop at each station, that is, the group type of each train and the stop sequence code constitute a chromosome.

3. Study Case Analysis

3.1. "Guangqing + Guangzhou East Ring" Intercity Railway Overview

Guangqing Intercity and Guangzhou East Ring Intercity are fully operated and managed by Guangdong Intercity Railway Operation Co., Ltd., a wholly-owned subsidiary of Guangzhou Metro Group, and the two intercity lines intersect at Huadu Station, and the overall operation is in the mode of "Guangqing + Guangzhou East Ring Road", connecting Guangzhou City and Qingyuan City, with a total length of about 60.8 km and 9 stations, as shown in **Figure 1**. According to the actual line conditions and passenger flow, 8 groups of large and small interchanges are adopted, and there are two types of stop modes: large station stop (Qingcheng - Huadu - Baiyun Airport North) and station stop. In order to facilitate subsequent calculations, the Guangqing Intercity and Guangzhou East Ring Intercity stations are numbered sequentially from Qingcheng to Baiyun Airport in the north direction of 1 - 9.

3.2. Passenger Flow Analysis

1) OD analysis of passenger flow

The passenger flow data of the line during the evening rush hour (17:00-19:00) on Tuesday, January 19, 2021 was selected as the passenger flow OD parameter of the model, and the passenger flow OD distribution was shown in **Table 2**.

It can be seen from the table that the passenger flow OD between the three first-class stations of 1, 6 and 9 is significantly higher than that between other stations, and the OD between some secondary nodes is 0, and there is no passenger flow round-trip.

2) Distribution characteristics of passenger flow day time

Select the passenger flow data of the line for one day, and calculate the passenger flow of the whole line according to each hour as a time period, and the distribution of passenger flow daily time period is shown in **Figure 2**.

Table 2. OD distribution of passenger flow during the evening peak hour (17:00-19:00).

0D	1	2	3	4	5	6	7	8	9	Total
1	0	14	18	18	8	86	30	32	68	274
2		0	0	14	0	18	8	0	18	58
3			0	0	2	16	4	0	12	34
4				0	6	50	8	6	24	94
5					0	34	4	0	12	50
6						0	118	76	148	342
7								8	42	50
8								0	13	26
9									0	0
Total	0	14	18	32	16	204	172	122	350	928

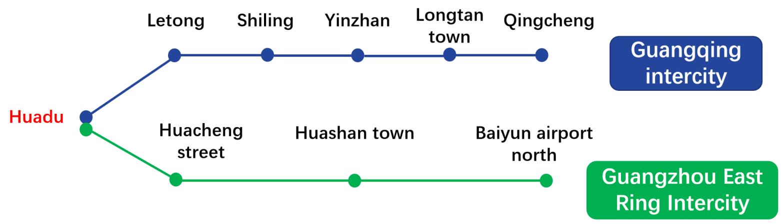

Figure 1. Intercity route map of Guangqing intercity and Guangzhou East Ring Road.

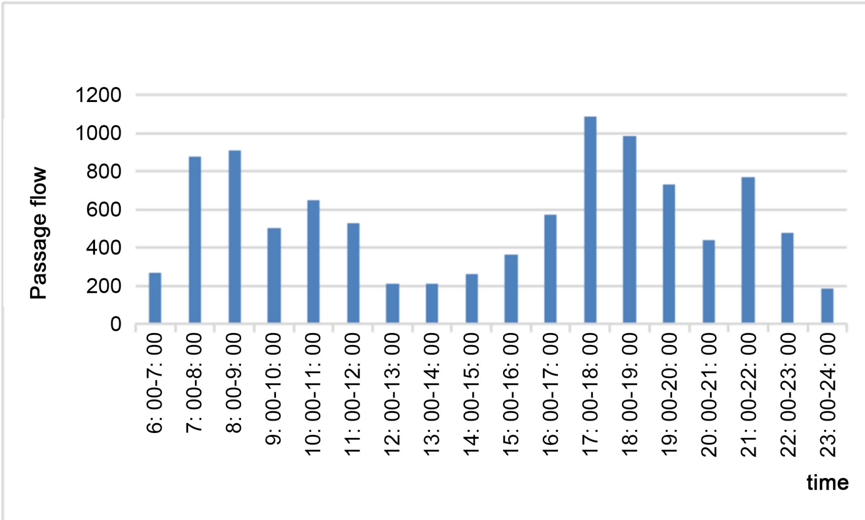

Figure 2. Distribution of passenger flow throughout the day and time period.

As can be seen from the above figure, the passenger flow of the intercity railway line fluctuates significantly at different times of the day, and the overall appearance is "two peaks and three valleys", 7:00-11:00 is the morning peak hour, 17:00-19:00 is the evening peak hour, and 17:00-18:00 reaches the peak of the full-day passenger flow. 6:00-7:00 in the morning, 12:00-15:00 in the afternoon, and after 23:00 in the evening, it is the trough of passenger flow. There is a rise and fall during the morning rush hour, 9:00-10:00 is a small trough of passenger flow, and 10:00-12:00 pick-up. After 21:00 in the evening, there is a small peak.

3) Spatial distribution characteristics of passenger flow

Based on the full-day OD passenger flow data, the passenger flow of each section of the whole day is calculated, as shown in Figure 3. As can be seen from the figure, the 5-6, 6-7 section has the largest passenger flow, and the peak pattern appears.

In summary, we can see that the passenger flow of the Guangqing intercity railway and Guangzhou East Ring Intercity Railways has the characteristics of uneven distribution in time and space, the distribution of passenger flows at different times of the day is uneven, and the passenger flow is concentrated in the morning and evening peak hours; The distribution of passenger flow OD is uneven, with passengers from the beginning to the end accounting for the vast majority, and the passenger flow at the intermediate station is relatively small.

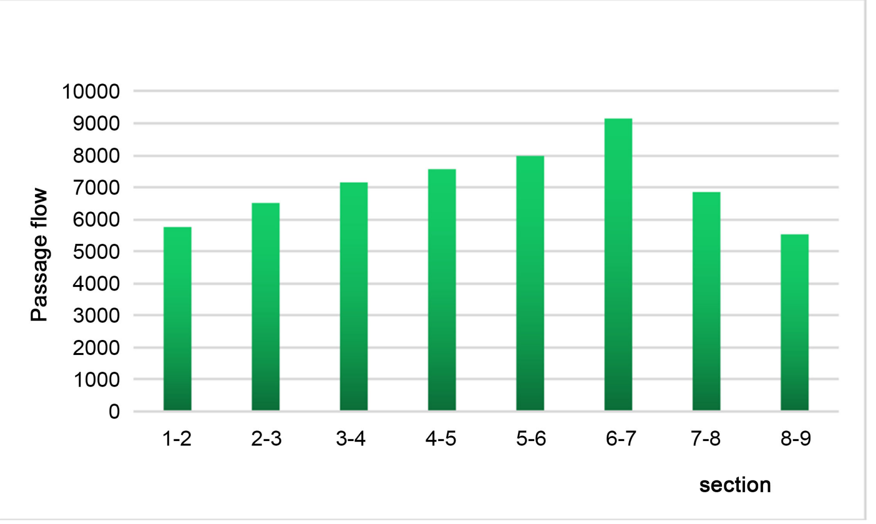

Figure 3. Passenger flow distribution between full-day stations.

3.3. Model Parameter Settings

According to the line situation, the Intercity Railway Design Code, the relevant provisions of the intercity railway operation and management and related literature (Liu, 2020; Miao et al., 2017; Bi et al., 2006), the model parameters are valued, as shown in Table 3.

3.4. Model Calculation Results

1) Algorithm convergence

According to the constructed model and algorithm program, the large and small group train operation scheme of the Guangqing intercity and Guangzhou East Ring Intercity multi-stop modes is generated, and the iterative convergence of the genetic algorithm of the model is shown in the following figure.

From Figure 4, it can be seen that the genetic algorithm has good convergence, can effectively solve the multi-stop mode of large and small intersections, large and small group train operation scheme model, the solution efficiency is high, the number of iterations and other parameters are set reasonably, and the local optimal has been reached.

2) Model optimization results

In the proposed train operation plan of the large and small group under the multi-stop mode, 2 trains with 4 cars and 1 train with 8 cars are opened during peak periods, as shown in Table 4, compared with the current train operation plan, the optimization rate of train operating costs reaches 59%, and the optimization of the full load rate of the section reaches 200%, as shown in Table 5.

The optimization of the model's stopover scheme is reflected in the optimization of the Guangqing Intercity and Guangzhou East Ring Intercity only station stops and direct trains from Qingcheng to Huadu (as shown in Table 6); After optimization, there are stations in the stop-and-go plan, which includes station stop-stop and stop-stop (Huadu-Huacheng Street-Baiyun Airport North and Huadu-Huashan Town-Baiyun Airport North Train), which can better meet the actual needs of passenger flow.

Table 3. Passenger flow distribution between full-day stations.

PARAMETERS	MEANING	VALUE	UNIT
C_l	The operating cost of the vehicle per kilometer	10	yuan per train·kilometer
C_s	The cost per stop of the vehicle	100	yuan per train·times
C	Quota for each vehicle	66	person
L	The full length of the line	59.6	kilometer
η_{max}	The upper limit of the cross-sectional full load rate	100%	1
η_{min}	Lower bound of the average cross-sectional full load rate	20%	1
f_{max}	The maximum number of open rows in an operating period	8	train
$f_{1\min}$	The minimum number of trains opened in large groups	1	train
$f_{2\min}$	The minimum number of trains opened in the small group	1	train
q^1	The passenger traffic attracted by single trains at first class stations	200	People/train
q^2	The passenger traffic attracted by single trains at secondary stations	75	People/train

Table 4. Multi-stop mode of large and small group trains running plan.

Train	Station									Grouping
	1	2	3	4	5	6	7	8	9	
1	0	0	0	0	0	1	0	1	1	4
2	1	1	1	1	1	1	1	1	1	8
3	0	0	0	0	0	1	1	0	1	4

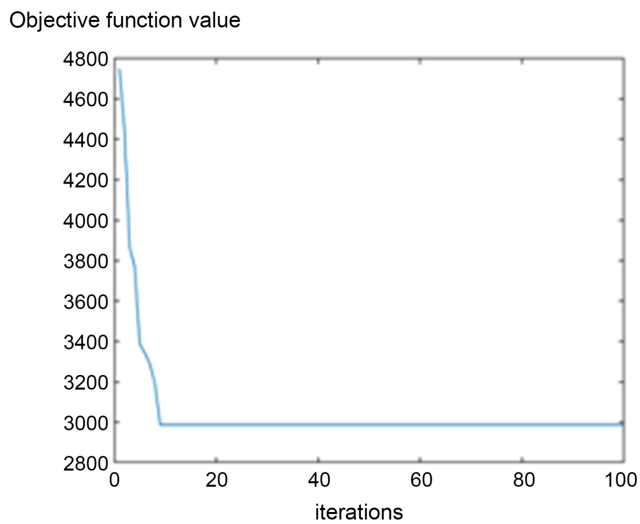

Figure 4. Genetic algorithm convergence.

Table 5. Optimization results of the train operation scheme of the small and small groups.

	Present	After optimization	Optimization amount	Optimization rate
Train operating costs	6270	2560	3710	59%
Cross-sectional full load rate	0.2888	0.8665	0.5777	200%

Table 6. Current train travel schemes.

Train	Station									Grouping
	1	2	3	4	5	6	7	8	9	
1	1	0	0	0	0	1	0	0	0	8
2	1	1	1	1	1	1	1	1	1	8
3	1	0	0	0	0	1	0	0	0	8
4	1	1	1	1	1	1	1	1	1	8
5	1	0	0	0	0	1	0	0	0	8
6	1	1	1	1	1	1	1	1	1	8

4. Conclusion

It is of great significance to study the optimization of intercity railway train marshalling and stopping scheme from the perspective of operating costs to improve the operation status of enterprises. The optimization model of the large and small group train operation scheme in the multi-stop mode can better adapt to the passenger flow needs in the early stage of intercity railway opening, reduce the operating cost of the train, and improve the full load rate of the section. In the future, with the development of supporting facilities and equipment along the intercity railway line and the gradual formation of the intercity railway network, the passenger flow demand and passenger flow travel characteristics of the intercity railway will also change, so the follow-up research will further optimize the train marshalling scheme, stop plan, departure interval, etc. on the basis of considering the interchange connection between the intercity railway or the intercity railway and the high-speed rail, and improve the matching degree of the train's capacity and passenger flow demand on the basis of reducing the operating cost of the train.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

Bi, Y. X., Liu, J. H., & Jiang, Z. B. (2006). Analysis on the Impact of Mixed Operation of Different Groups of Trains on Urban Rapid Rail Transit Lines. *Urban Rail Transit Research, 9,* 54-57.

Chang, Y. H., Yeh, C. H., & Shen, C. C. (2000). A Multiobjective Model for Passenger Train Services Planning: Application to Taiwan Region High-Speed Rail Line. *Transportation Research Part B: Methodological, 34,* 91-106. https://doi.org/10.1016/S0191-2615(99)00013-2

Claessens, M. T., Dijk, N. M. V., & Zwaneveld, P. J. (2007). Cost Optimal Allocation of Rail Passenger Lines. *European Journal of Operational Research, 110,* 474-489. https://doi.org/10.1016/S0377-2217(97)00271-3

Goossensaab, J. W. (2006). On Solving Multi-Type Railway Line Planning Problems. *European Journal of Operational Research, 168,* 403-424. https://doi.org/10.1016/j.ejor.2004.04.036

He, B. S. (2014). *Research on the Theory and Method of Coordinated Optimization of High-Speed Railway Train Operation Scheme and Train Operation Diagram.* PhD Dissertation, Beijing: Beijing Jiaotong University.

Huang, Z. P. (2015). Research on Intercity Train Operation Scheme Based on Passenger Travel Choice Behavior. *Journal of Wuhan University of Technology (Traffic Science and Engineering Edition), No. 6,* 1135-1136.

Huang, Z. P. (2018). Intercity Train Operation Scheme Based on Travel Time Satisfaction. *Journal of Lanzhou Jiaotong University, 37,* 22-25.

Jiang, M. M. (2015). *Research on Optimization of Intercity Railway Train Stopover Scheme.* MA Thesis, Beijing: Beijing Jiaotong University.

Liu, S. (2020). *Study on the Effect of Multi-Group Train Operation Scheme of Intercity Railway.* MA Thesis, Beijing: Beijing Jiaotong University.

Miao, W. L., Ni, S. Q., Pang, T., & Wang, W. X. (2017). Research on Optimization of Intercity Train Frequency Based on Time Period Division. *Railway Transportation and Economy, 39,* 7-8.

Sun, R. J., & Lu, Y. (2017). Research on Intercity Railway Commuter Travel Based on Passenger Travel Characteristics of Beijing-Tianjin. *Smart City, No. 6,* 63-64.

Tian, Y. L. (2020). Optimization of Standardized Train Operation Scheme of Changzhutan Intercity Railway. *Smart City, No. 20,* 11-13.

Xu, R. H., & Zou, X. L. (2005). Research on Optimization Method of Passenger Dedicated Line Train Operation Scheme. *Journal of Tongji University (Natural Science Edition), 33,* 1608-1611.

Yang, X. Y. (2011). *Characteristics of Passenger Travel Behavior of Chengmianle Intercity Railway.* MA Thesis, Beijing: Beijing Jiaotong University.