Research on High-speed Railway Fare Optimization based on Change of Passenger Flow

Jie Zhang, [a], Xiangfei Yang [b], Gu Du [c]
School of Lanzhou Jiaotong University, Lanzhou 730070, China
[a]1772151230@qq.com, [b]525586420@qq.com, [c]522419665@qq.com

Abstract. In recent years, high-speed railway has gradually become an indispensable choice for people to travel. This paper studies high-speed railway fares to increase the benefits of high-speed rail and achieve long-term sustainable development of the railway sector. According to the characteristics of demand, the passenger flow is divided into different periods, with each passenger flow interval as the price adjustment time, and the train income as the objective function to determine the fare of each passenger transport product at each price adjustment time. Taking Baoji-Lanzhou High Speed Railway as an example, the study shows that the train attendance rate is increased by 16.2% and the revenue is increased by 5.8% compared with the original price strategy.

Keywords: fare optimization; passenger flow; Baoji-Lanzhou high-speed railway.

1. Introduction

High-speed railway has become a new trend of railway transportation in modern society. 2020 is the year of China's high-speed railway construction. At that time, the “eight vertical and eight horizontal” high-speed railway network will become a reality. However, under the shell of rapid development, huge debt has become a major problem for China's railways. By the end of 2018, the assets of China Railway Corporation totaled 7.87 million yuan, total liabilities were 5.15 trillion yuan, and the asset-liability ratio was up to 65.44%. Since 2016, the high-speed railway fares have been independently formulated by the China Railway Corporation. There must be a perfect pricing mechanism for custom fares.

1.1 Status of Research on High-speed Railway in China

With the in-depth study of the high-speed railway fare reform, domestic and foreign scholars have now studied in different degrees in the formulation and optimization of high-speed railway fares. X.sun [1] proposed a binomial logit model, and improved the travel frequency of passengers by adjusting the preferential strategy of high-speed rail fare. Tsunoda.y [2] shows that the best government regulation depended on the benefits to consumers of each mode of transportation and the different welfare levels. Jiang da[3] pointed out that when making short-distance high-speed railway fares, it is necessary to pay close attention to the dynamic changes of highways and airlines and make targeted high-speed railway fares. Fan Haiying[4]constructed a Ramsey expansion model based on the high-speed railway revenue management pricing, and combined with examples to show that the method can achieve the maximum profit of railway enterprises and the optimal consumer surplus.

1.2 Analysis of the Current Situation and Existing Problems of China's High-Speed Railway Fares

China's high-speed railway fare scheme refers to the pricing method of universal speed railway and is calculated by the basic fare rate and mileage, as shown in formula (1).

$$P_0=R_0*L_0*D_0+R_1*L_1*D_1+R_2*L_2*D_2+...+R_n*L_n \tag{1}$$

Where, P_0 is the basic fare, R is the fare rate of each section, the specific value is shown in the table below, L is the fare range of each section, D is the discount coefficient under the descending recursion.

Table 1. Basic fare rate of China's high-speed railway

Speed grade	First-class seat	Second-class seat
D-series high-speed train	0.37026 yuan/km	0.30855 yuan/km
G-series high-speed train	0.775 yuan/km	0.485 yuan/km

It is not difficult to see that the price setting method of high-speed railway in China is single. The passenger transportation demand generally changes during the whole year, and the railway transportation enterprises have not adjusted the ticket price according to the change of passenger flow, resulting the transportation resources in the off-season are partially wasted.

2. Analysis of High-speed Railway Demand Characteristics

2.1 Transport Demand Elasticity

The demand elasticity analysis of transportation plays a vital role in studying the supply and demand of high-speed railway fares. Here we discuss the elasticity of demand for transportation in order to provide an accurate and reliable basis for the operational decision-making of high-speed railway freight rates. The degree of reaction to changes in the price of a commodity is expressed as:

$$e = -\frac{\Delta Q}{\Delta P} * \frac{P}{Q} \tag{2}$$

Table 2. Relationship between demand elasticity and supply elasticity and price

Price inco me elastici ty	e>1	e=1	e<1	e=0	e=∞
Price redu ction	incre ase	con stan t	decr ease	Same proportion a nd decrease in pric e	At a given price, the revenue can increase indefinitely, so the manufacturer will not cu t the price.
Price incre ase	decr ease	con stan t	incr ease	Increase in the sa me proportion and price	The return will be reduced to zero

The relationship between demand elasticity and supply elasticity and price is shown in the table 2. Different scholars have done a lot of research on the coefficient of demand elasticity and come to some reliable conclusions: according to the current high-speed rail freight, the demand elasticity of high-speed railway is greater than 1, and travelers are more sensitive to the freight of high-speed railway. The higher the freight rate of high-speed railway, the greater the demand elasticity value.

2.2 Analysis of Passenger Flow Demand

2.2.1 Seasonal Changes

The fig.1 shows that the distribution of passenger flow is season change, July and August during the summer, traffic reach the peak of a year, in late January to February as the peak travel period, but the traffic is less than during the summer, in November of each year in April, for passenger transport in the off-season, volatility is relatively flat during the other months.

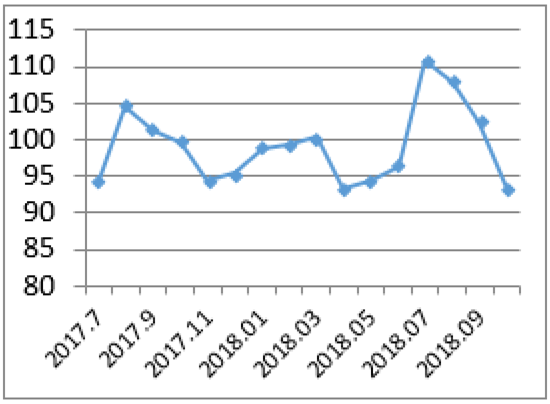

Fig. 1 the total number of passengers sent by lanzhou west station of baolan high-speed railway in 2017-2018

2.2.2 Weekly Distribution

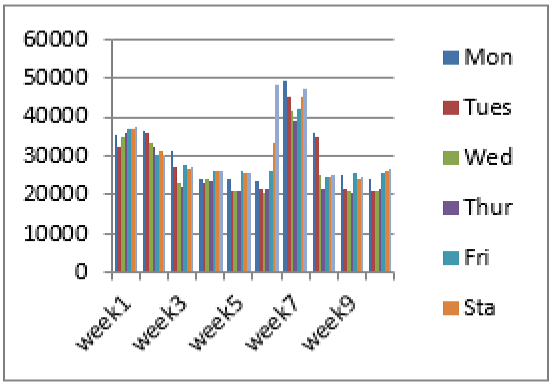

Fig.2 part of weekly passenger flow distribution of lanzhou west railway station in 2017

The paper selects the distribution of weekly passenger traffic in Lanzhou West Station, as shown in Fig.2. The change of passenger flow in one week is mainly due to people's decision to go to work, which leads to the same change in passenger flow every week. According to the weekly passenger flow distribution map, the passenger flow fluctuated steadily during the working day from Monday to Thursday, and increased sharply and reached the peak from Friday to Sunday.

2.2.3 Changes in Holidays

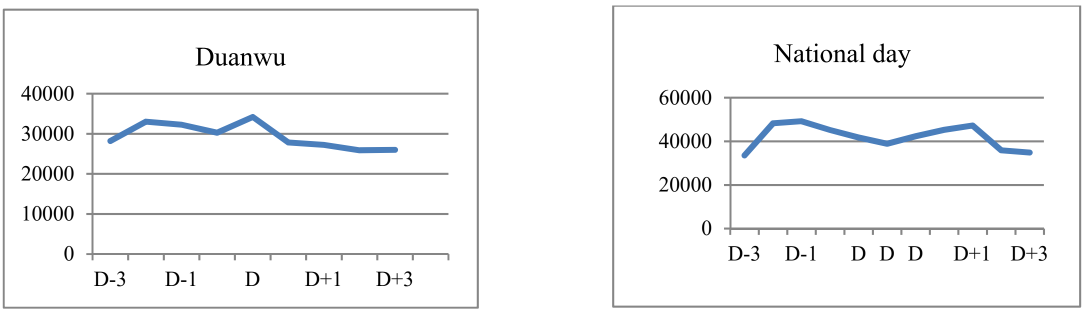

Fig.3 holiday passenger flow distribution of bolan high-speed railway

Holidays in our country mainly include the qingming festival, May Day, dragon boat, represented by the three days of vacation, as well as the National Day golden week and the Spring Festival, it can be seen from Fig.3, The change of holiday passenger flow is mainly reflected in the sudden increase and decrease of daily passenger flow.

According to the above analysis, China's passenger flow distribution is regular changes.Experience in the development of fare levels in different countries and relevant studies have shown that the higher the fare level is, the better the higher the fare level is[5]. Therefore, this paper comprehensively considers the distribution law of passenger flow and the actual situation of the region, and divides the ticket price into Spring Festival travel, summer travel, weekends and holidays, weekdays (Monday to Thursday except the first grade), and the low peak period of passenger flow.

3. Model Construction and Case Analysis

The passenger product is represented by j=1...n. The resource is represented by i=1...m. According to the definition of passenger products and resources, passenger products are composed of several resources. The occupation relationship between passenger products and resources can be represented by 0-1 variables. For example, if passenger product j occupies resource i, then a_{ij}=1, otherwise a_{ij}= 0, with A=[a_{ij}]indicates the resource-passenger product occupancy relationship matrix,use the train to indicate the resource i.At the time of price adjustment, the ticketing period of passenger product j is divided into Q_j grades, and the rank is represented by Q=1..Q_j.Use l_j^Q to represent the length of time period under the Qth passenger flow grade of passenger product j.According to the relevant regulations, the maximum up and down floating ratio of fares does not exceed 10%. Z is the number of times the train is operated during the price adjustment period, and C_i is the train capacity of a single train.

$$\max R(\lambda)=\sum_{j=1}^{n}\sum_{Q=1}^{Q_j}\lambda_j^Q P_j^Q\left(\lambda_j^Q\right)l_j^Q \tag{3}$$

s. t.

$$\sum_{j=1}^{n}\sum_{Q=1}^{Q_j}a_{ij}\lambda_j^Q l_j^Q \le ZC_{i,}\theta_i \tag{4}$$

$$P_{下限} \le P_j^Q(\lambda) \le P_{上限},\ \ \theta_{Q,j} \tag{5}$$

In this model, a function of expressing price with the requirement as the independent variable in the economics--Log-linear requirement function is introduced, and the expression is as follows:

$$P(\lambda)=\left(\varepsilon_0^{-1}\ln\left(\frac{\lambda_0}{\lambda}\right)+1\right)P_0 \tag{6}$$

Where, P is the product price, λ_0 is the demand density under the base price, ε_0 is the absolute value of the price elasticity of the demand under the base price, which is the demand elasticity of the transportation mentioned above, and P_0 is the standard fare.

This article takes the D8971 train operated by the Lanzhou Passenger Transport Section in the Baoji-Lanzhou High Speed Railway as an example to verify the validity of the fare method used. The paper selects the data from Tianshui South to the western part of Lanzhou. The matrix of the occupation relationship between resources and passenger products is as follows:

$$A=\begin{bmatrix}1 & 1 & 0\\ 0 & 1 & 1\end{bmatrix} \tag{7}$$

The D8971 train has a capacity of 702, C_i = 702, i = 1, 2. According to the requirements of this example after referring to the research on the price elasticity of demand in different documents, the values of the price elasticity of demand in the first stage and the second stage are set to 1.2 and 1.1 respectively.

Table 3 shows the comparison between the obtained results and the original fare.P_1 and P_2 represent the adjusted peak and low peak prices respectively.The regular day price is the existing standard price, λ_1 and λ_2 are the relevant demand density for new prices during high and low peak periods.

It can be seen from the analysis and calculation that the pricing strategy increases the fare of the train during the peak period and lowers the fare during the low peak period. It can also be seen that during the peak period, the demand density of each interval has increased, but the demand density in the low peak period has decreased compared with the current demand density, but the overall passenger flow has increased by 4,482 people. The rate has increased by 16.2%, which proves that the price strategy not only regulates market demand well, but also stimulates potential demand.

Table 3. calculation results

product	Base fare (yuan)	Grade price (yuan)		Demand density (person/hour)				Cycle (days)	
	P_0	P_1	P_2	λ_0^1	λ_0^2	λ^1	λ^1	L_1	L_2
Tianshui South-Qin'an	12	13	11.5	1.10	0.909	1.10	0.87	172	193
Qin'an-Lanzhou West	71	82	65	2.01	1.90	2.43	1.73	172	193
Tianshui South - Lanzhou West	83	104	72	4.06	3.64	5.54	3.10	172	193
Proportion of revenue growth					5.8%				
Attendance rate increase ratio					16.2%				
Passenger traffic(person)					4482				

4. Summary

Based on the analysis of the passenger flow data of baolan high-speed railway, this paper takes the single transport product of high-speed railway as the research object and train revenue as the objective function to establish the fare optimization model based on the change of passenger flow. Fare according to the passenger flow will be developed into three different levels of fare, in the peak period of passenger flow to increase the fare appropriately, in the low peak period of less passenger flow to reduce the fare appropriately, the regular day is still the implementation of the existing standard fare. The results show that the fare level strategy can not only effectively adjust the market demand, but also play a significant role in improving the overall train revenue.

References

[1]. X. Sun, E. Yao, X. Feng. Impacts of high-speed rail fare discount strategies on travel frequency of the passengers in China.Advances in Transportation Studies.Vol.10(2015)No.2,p.115-124.

[2]. Tsunoda Y. Transportation policy for high-speed rail competing with airlines. Transportation Research Part A: Policy&Practice.Vol.116(2018), p.350-360.

[3]. Da Jiang. Research on the method of formulating high-speed railway fares based on different modes of transportation. (Master of Engineering, Southwest Jiaotong University, China,2014). p.8-10.

[4]. Haiying Fan. Study on the Pricing Method of China's High-speed Rail Revenue Management. Price Theory and Practice, Vol.12(2015) No.10, p.161-163.

[5]. Jie Liu, Shiwei He. Analysis and enlightenment of foreign high-speed rail fare system. Comprehensive Transportation,Vol.8(2010)No.3,p.81-84.