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Research on Pricing Strategy of High-speed Railway Based on Modeling: Beijing-Guangzhou High-Speed Railway as an Example

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ABSTRACT
With the development of market economy, the competition of high-speed railway passenger transportation is becoming so fierce that it is urgent to explore new competitive strategies. This paper takes Beijing-Guangzhou High-Speed Railway as the research object and presents the passenger transport product quality evaluation model and passenger transport product pricing model. The models provide a theoretical basis for high-speed railway passenger transport product pricing strategy, in order to obtain higher revenue or higher market share.

Keywords： *High-Speed Railway, Quality evaluation, Pricing optimization*

1. INTRODUCTION

With the development of China's economy, the market of various transport products is expanding, and the competition between air passenger transport and high-speed railway passenger transport is very fierce. It is an important issue to formulate a reasonable pricing strategy for high-speed railway passenger transport in order to improve the competitiveness of high-speed railway.

There are many studies on high-speed railway pricing strategy. J. Q. Luo, H. B. Kuang, Y. Yang, and L. F. Liu [1] based on the perspective of passenger travel, established the evaluation system of high-speed railway and civil aviation competitive factors, which combined with subjective evaluation method and objective evaluation method. Based on the marketing theory, K. Dimanoski, G. Stojic, and S. Veskovic [2] analyzed the passenger satisfaction with railway passenger transport, so as to find out the shortcomings of the existing railway passenger transport service, and put forward the relevant means to improve the service quality. R. J. Qiao, X. N. Zhu, and J. F. Qian [3] evaluated the quality of railway passenger transport products through market surveys, and Make targeted suggestions for improving product quality. A selection model proposed A. Nuzzolo, U. Crisalli and F. Gangemi [4] can be used to simulate the influence of medium and long-distance railway service characteristics changes on users' choice of service. L. H. Kong [5] established the relationship between the market share rate of high-speed railway and the ticket price of high-speed railway. Taking Beijing Changsha passenger transport channel as an example, he determined the optimal ticket price at this time with the goal of maximizing the revenue of high-speed railway. Under the assumption that competitors' pricing remains unchanged, K. Sato and K. Sawaki [6] established a new pricing model based on the maximization of expected revenue, and adjusted the pricing strategy of the railway sector.

Taking Beijing-Guangzhou High-Speed Railway as the research object, this paper constructs models to evaluate the quality and optimize the pricing of high-speed railway and air passenger transport products under different travel distances, so as to form a reasonable pricing strategy.

2. PASSENGER TRANSPORT PRODUCT QUALITY EVALUATION MODEL

2.1. Evaluation principle

There are three principles on which the product quality evaluation model is mainly based on.

- Principles of competition: The evaluation model should reflect the relative advantages and disadvantages of the two products rather than absolute quality.
- Principle of compatibility: The indicators in the pricing model should be able to evaluate the two products.
- Principle of objectivity: The selection of indicators should be linked to market research and reflect the true experience of passengers.

2.2. Evaluation method

There are many common evaluation methods. Based on the above evaluation principles, Analytic Hierarchy Process (AHP) and Gray Comprehensive Evaluation Method are selected to evaluate the quality of passenger transport products. The evaluation steps are as follows:

- Select a number of first level evaluation indicators and second level evaluation indicators under each first level indicator.
- The indicators are divided into five levels, with values of 5,4,3,2,1 (from good to poor).
- Analyze the evaluation indicators, determine the grade, and construct the evaluation sample matrix D.
- Using AHP to determine the weight of each level indicator in the evaluation.
- Get the overall quality evaluation score of the product by using Gray Comprehensive Evaluation Method to calculate.
- Analyze the quality evaluation score and get the evaluation result.

2.3. Selection and quantification of evaluation indicators

This paper uses 6 first-level indicators and 11 second-level indicators to evaluate two passenger transport products, and quantifies the evaluation grade of each second-level indicator, as shown in TABLE I.

TABLE I. EVALUATION GRADE QUANTIFICATION TABLE

First-level indicators	Second-level indicators	5	4	3	2	1
Rapidity	Average travel speed (km/h)	[480,+∞)	[360,480)	[240,360)	[120,240)	[0,120)
Economy	Travel cost per km (one hour-yuan)	[0,1)	[1,2)	[2,4)	[4,6)	[6,+∞)
	Fare-to-income ratio (*10000)	[0,80)	[80,120)	[120,140)	[140,160)	[160,+∞)
	Fare satisfaction	[0.9,1)	[0.8,0.9)	[0.7,0.8)	[0.6,0.7)	[0,0.6)
Comfort	Area per capita(m^2)	[1.2,+∞)	[0.9,1.2)	[0.6,0.9)	[0.3,0.6)	[0,0.3)
	Stationarity satisfaction	[0.9,1)	[0.8,0.9)	[0.7,0.8)	[0.6,0.7)	[0,0.6)
Punctuality	On-time rate	[0.95.1)	[0.9,0.95)	[0.85,0.9)	[0.8,0.85)	[0,0.8)
Convenience	Density deviation	[0,0.2)	[0.2,0.4)	[0.4,0.6)	[0.6,0.8)	[0.8,1)
	Ticket purchase satisfaction	[0.9,1)	[0.8,0.9)	[0.7,0.8)	[0.6,0.7)	[0,0.6)
	In and out station and transfer satisfaction	[0.9,1)	[0.8,0.9)	[0.7,0.8)	[0.6,0.7)	[0,0.6)
Safety	Accident rate (one billion person-km)	[0,0.01)	[0.01,0.02)	[0.02,0.03)	[0.03,0.04)	[0.04,0.05)

The above evaluation indicators involving seats are subject to high-speed railway second-class seats and aviation economy class.

Experts give a quantification of the average travel speed. The quantification of travel cost per km, fare-to-income ratio, area per capita, on-time rate, density deviation and accident rate are referred to this literature [7]. The density deviation is used to measure the consistency between the actual departure time and the expected departure time, and the equation is as follows:

$$R = \frac{1}{n}\sum_{i=1}^{n}\frac{|\alpha_i - \beta_i|}{\alpha_i} \tag{1}$$

α_i is the proportion of passengers' expected departure time in period i, β_i is the proportion of actual departure time in period i.

In order to obtain relevant data, a market survey is required, and the level of satisfaction is quantified in accordance with the level of related questions in the questionnaire survey.

3. PASSENGER TRANSPORT PRODUCT PRICING MODEL

3.1. Transfer passenger flow model

In this paper, logit model is used to study the impact of ticket price changes on the share rate of high-speed railway and aviation, so as to calculate the transfer passenger flow. The equation is as follows:

$$P_i = \frac{e^{-U_i/\bar{U}}}{\sum_{i=1}^{n} e^{-U_i/\bar{U}}} \quad (2)$$

P_i is the probability that the passenger transport product i is selected, U_i is the generalized travel cost of the product i, $\bar{U}$ is the average value of the generalized travel cost of several products, and n is the total number of optional passenger transport products. The generalized travel cost equation is as follows:

$$U_i = (p_i + q_i) + (T_i + H_i + Y_i + M_i) * VOT \quad (3)$$

The equation (3) divides the travel cost into two parts, the first part is the economic cost and the second part is the time cost.

Economic cost includes the price p_i of passenger transport products and the cost q_i of arrival, departure and transfer in the whole travel process.

In time cost, VOT is the value of passenger time, T_i is the travel time of passenger transport product i, H_i is the time required for arrival, departure and transfer, Y_i is the delay time of passenger transport product i; M_i is the passenger fatigue recovery time. The value of passenger time and the passenger fatigue recovery time equations are as follows:

$$VOT = \frac{SA}{T} \quad (4)$$

$$M_i = \frac{J}{1 + a * e^{-b*T_i}} \quad (5)$$

SA is the average monthly wage of the region, T is the average monthly working hours. J is the maximum time to recover fatigue, a and b are parameters. According to literature [8], the maximum recovery time is 15 hours, in high-speed rail, a is 59, b is 0.29; in aviation, a is 79, b is 0.25.

3.2. Induced passenger flow model

In this paper, the induced passenger flow is calculated by gravity model.

$$Q^{AB} = k * \frac{(E_A E_B)^a}{U_{AB}{}^{\beta}} \quad (6)$$

A and B are nodes, E_A and E_B are the passenger flow influencing factors of A and B, which are fixed values here, and U_{AB} is the generalized travel cost between A and B. k, α, and β are all parameters. According to the literature [9], the value of β is 0.709.

3.3. Price-revenue model

Under the condition that the number of high-speed trains per day remains unchanged, the operation cost of high-speed railway is basically unchanged, which can be regarded as a fixed value. Then the price-revenue model is as follows:

$$W = F * p - I \quad (7)$$

W is the total revenue, F is the total passenger flow, p is the ticket price, and I is the total cost.

When the ticket price changes, the generalized travel cost changes from $U_i(U_{AB})$ to $U'_i(U'_{AB})$. And the calculation formulas for passenger flow transfer rate r_n and passenger flow induction rate u_n are as follows:

$$r_n = \frac{P'_i}{P_i} - 1 = \frac{\dfrac{e^{-U'_i/\bar{U'}}}{\sum_{i=1}^{n} e^{-U'_i/\bar{U'}}}}{\dfrac{e^{-U_i/\bar{U}}}{\sum_{i=1}^{n} e^{-U_i/\bar{U}}}} - 1 \quad (8)$$

$$u_n = \frac{Q'_{AB}}{Q_{AB}} - 1 = \frac{U_{AB}}{U'_{AB}} - 1 \quad (9)$$

When the current ticket price and total passenger flow are known, if the ticket price is changed from p to p', the total passenger flow will change from F to F', and the new total revenue W' is:

$$W' = F' * p' - I = (1 + r_n + u_n) F * p' - I \quad (10)$$

At this point, the pricing model has been constructed.

4. CASE ANALYSIS OF BEIJING-GUANGZHOU HIGH-SPEED RAILWAY PRICING STRATEGY MODEL

4.1. Background

The Beijing-Guangzhou High-Speed Railway was put into operation on December 26, 2012, with a total length of 2118 km, undertaking a large number of passenger transport services along the line.

There are many cities along the Beijing-Guangzhou Corridor, and large cities with a permanent population of more than 1 million people include Beijing, Shijiazhuang, Zhengzhou, Wuhan, Changsha, and Guangzhou. This paper selects four passenger transport markets, namely Beijing Zhengzhou, Beijing Wuhan, Beijing Changsha and Beijing Guangzhou, as well as two passenger transport products, high-speed railway second-class and aviation economy class in order to simplify the analysis and facilitate market research. Through product quality evaluation and pricing optimization, the Beijing-Guangzhou High-Speed Railway pricing strategy was formulated.

4.2.Quality evaluation of passenger transport products

This paper takes Beijing-Wuhan as an example to evaluate the quality of two passenger transport products. The author selected Beijingxi Railway Station and Beijing Capital International Airport to conduct an investigation from March 23 to April 6, 2019, including working days, weekends and Qingming holidays. The survey period is 9:00-12:00, 13:00-16:00, 17:00-20:00, which basically includes each travel period. Satisfaction data are obtained through 376 valid questionnaires out of 400 total questionnaires. The density deviation is calculated from the actual departure time and the expected departure time in the questionnaire.

Average travel speed and travel cost per km are obtained from 12306 and Ctrip. Fare-to-income ratio is calculated from the data of ticket price and per capita income in literature [10]. The area per capita is obtained by querying the relevant data of common models. The on-time rate and the accident rate are estimated from the literature [11][12][13].

Finally, the evaluation grade of the second-level indicators of high-speed railway and aviation passenger transport products are obtained, as shown in TABLE II.

TABLE II. SECONDARY-LEVEL EVALUATION GRADE OF PASSENGER TRANSPORT PRODUCTS IN BEIJING-WUHAN CORRIDOR

Second-level indicators	High-speed railway	Grade	Aviation	Grade
Average travel speed (km/h)	250.3	3	570.9	5
Travel cost per km (one hour-yuan)	2.26	3	1.29	4
Fare-to-income ratio (*10000)	72.20%	3	65.80%	2
Fare satisfaction	102.5	4	130.1	3
Area per capita(m^2)	0.99	4	1.03	4
Stationarity satisfaction	95.30%	5	79.20%	3
On-time rate	>95%	5	80.10%	2
Density deviation	72.10%	2	76.10%	2
Ticket purchase satisfaction	83.30%	4	89.10%	4
In and out station and transfer satisfaction	84.20%	4	72.60%	3
Accident rate (one billion person-km)	<1%	5	<1%	5

Through the questionnaire survey, the ranking of the six first-level indicators is obtained, and the preference weight of passengers is calculated by AHP, as shown in TABLE III. After the consistency test, CR=0.083<0.1, which meets the consistency requirements.

TABLE III. INDICATORS WEIGHT OF PASSENGER TRANSPORT PRODUCTS OF BEIJING-WUHAN CORRIDOR

First-level indicators	weight	Second-level indicators	weight
Rapidity	0.214	Average travel speed (km/h)	0.214
Economy	0.241	Travel cost per km (one hour-yuan)	0.080
		Fare-to-income ratio(*10000)	0.080
		Fare satisfaction	0.081
Comfort	0.146	Area per capita(m2)	0.073
		Stationarity satisfaction	0.073
Punctuality	0.181	On-time rate	0.181
Convenience	0.105	Density deviation	0.035
		Ticket purchase satisfaction	0.035
		In and out station and transfer satisfaction	0.035
Safety	0.113	Accident rate (one billion person-km)	0.113

From the weight and grade of each second-level indicator, the evaluation grade of each first-level indicators is obtained, as shown in TABLE IV.

TABLE IV. FIRST-LEVEL INDICATORS EVALUATION GRADE OF PASSENGER TRANSPORT PRODUCTS IN BEIJING-WUHAN CORRIDOR

First-level indicators	High-speed railway	Aviation
Rapidity	3	5
Economy	3.33	3
Comfort	4.5	3.5
Punctuality	5	2

Convenience	3.33	3
Safety	5	5

According to the Gray Comprehensive Evaluation Method, the gray comprehensive evaluation weight matrix of the two passenger transport products is obtained. Then use the grey comprehensive evaluation weight matrix and the weight matrix of each second-level indicator to obtain the evaluation function matrix of first-level indicator. Finally, the quality evaluation results of high-speed railway and aviation are 3.91 and 3.76.

Similarly, the quality evaluation results of two products in all four corridors can be obtained, as shown in TABLE V.

TABLE V. THE QUALITY EVALUATION RESULTS OF TWO PRODUCTS IN ALL FOUR CORRIDORS

	Beijing-Zhengzhou	**Beijing-Wuhan**	**Beijing-Changsha**	**Beijing-Guangzhou**
High-speed railway	4.12	3.91	3.88	3.17
Aviation	2.98	3.76	3.81	4.23

It can be seen that in the short-distance corridor such as Beijing-Zhengzhou, high-speed railway passenger transport products have an absolute advantage. In the Beijing-Wuhan and Beijing-Changsha medium-distance corridors, high-speed railway has a slight advantage. However, air passenger transport products have an absolute advantage in the long-distance such as Beijing-Guangzhou Corridor.

4.3.Passenger transport product pricing optimization

From the product quality evaluation results in the previous paper, it can be seen that the quality gap between the two passenger transport products is too large to form competition in Beijing-Zhengzhou and Beijing-Guangzhou corridors. However, in the Beijing-Wuhan and Beijing-Changsha corridors, there is little difference in the quality of the two passenger transport products, and the competition is very fierce. Therefore, Beijing-Wuhan and Beijing-Changsha passenger transport channels are selected to optimize the pricing of high-speed rail passenger transport products. Taking Beijing-Wuhan as an example, according to the generalized travel cost evaluation, the generalized cost of high-speed railway and aviation are 752.8 and 862.1 respectively.

Among them, the average ticket price and travel time are obtained by consulting the relevant data of the booking website and the time of arrival, departure and transfer is obtained by questionnaire survey. The fatigue recovery time is calculated by (5). According to the literature [10], the passenger time value is estimated to be 26.1. The average delay time of air passenger transport products is taken as 0.25h [11], and the average delay time of high-speed railway passenger transport products is 0 due to the extremely low delay rate.

If the ticket price of high-speed railway is changed to $p^{'}$, the sharing rate equation and the ticket price-revenue equation are as follows:

$$P^{'} = \frac{e^{-\frac{p'+209.8}{(x+209.8+862.1)*0.5}}}{e^{-\frac{p'+209.8}{(x+209.8+862.1)*0.5}} + e^{-\frac{862.1}{(x+209.8+862.1)*0.5}}} \qquad (11)$$

$$W' = (\frac{P^{'}}{0.534} + \frac{748}{x+209.8} - 1) * 7692 p' - I \qquad (12)$$

From (11), we can see the share rate rises as the ticket price decreases. The revenue should be increased as much as possible on the basis of the reduced ticket price. From (12), it can be seen that when the ticket price is 509 yuan, the revenue is the largest; when the ticket price is 475 yuan, the revenue remains unchanged, but the market share is the largest. At present, the ticket price is about 520 yuan. Reducing the ticket price to 475-509 yuan is better for competition. Similarly, in the Beijing-Changsha corridor, when the ticket price is 584 yuan, the revenue is the largest; when the ticket price is 526 yuan, the revenue remains unchanged, but the market share is the largest. The current ticket price is about 649 yuan, so we should consider reducing the ticket price to 526-584 yuan.

From the above two examples, it can be seen that medium-distance corridors as Beijing-Wuhan and Beijing-Changsha, high-speed railway can appropriately reduce the ticket price to obtain higher revenue or greater market share.

5. CONCLUSION

This paper takes the Beijing-Guangzhou High-Speed Railway as the research object, and selects passenger transport products with different distances between Beijing and Guangzhou. Section 2 presents a quality evaluation model to evaluate the quality of passenger transport products. The ticket price-revenue model, where the specific fare adjustment range is given with the highest revenue or the highest market share as the objectives, is constructed in section 3. In section 4, using the above two models, the pricing of high-speed railway passenger transport products facing fierce market competition between Beijing and Guangzhou is given, in order to obtain the maximum revenue or market share.

Through the combination of the two models, a pricing strategy for high-speed railway passenger transport products is formed. The further development of the strategy is in progress and it refers to the limitation of high-speed railway passenger transport capacity on pricing.

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