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RESEARCH PAPER

Intercity Rail Transport Pricing Strategy Based on Efficacy Coefficient Method

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Abstract: By utilizing the efficacy coefficient method, this study proposes a multi-criteria modeling approach for the reasonable pricing decision of intercity rail passenger transport. The proposed model aims at minimizing the average travel time and energy consumption per passenger-trip for an intercity rail passenger transport system. It is empirically confirmed that the variation of the ticket price imposes significant influence upon the transport ratios of different travel modes. It is proved that the average travel time per passenger-trip and the system energy consumption declines with the reduced fare. As for the operation of rail passenger transport system mentioned in the case study, if its fare is adjusted to 55.8 yuan/passenger-trip, the average travel time and energy consumption per passenger-trip decrease by 7.8% and 2.1%, respectively. This study is able to assist the sensible decision-making of ticket price, which can also effectively promote the operation efficiency and sustainability of an intercity rail transport system.

Key Words: integrated transportation; passenger transport shares optimizing; efficacy coefficient method; intercity transportation

1 Introduction

The fast growing economy in China greatly boosted the formation and development of the regional economic circle within the past decades. Under this circumstance, the intercity transport demand also witnessed a considerable increase. Therefore, the competition in different transport modes became much more intense. Among them, highway and intercity rail transport have been two modes with strong competitive power for medium and short-distance travel in the economic circles. Ticket pricing is an effective way to optimize the passenger transport structure. Thus, how to determine the fare of intercity rail transport becomes an important issue to develop a high-efficient transportation system which saves energy and is environmentally-friendly.

Academics both domestic and abroad have conducted ample research in passenger traffic structure optimization. Andres *et al.*[1,2] predicted the passenger traffic structure with the Logit model. This model ignores the competitiveness of each transportation mode in time-space, therefore the influence of network traffic is not take into account. In the strategic research of traffic management, Patrick *et al.*[3–5] took fares as important measures of traffic control. Lu *et al.*[6] proposed an optimization model developed for the urban traffic structure with the issues of energy efficiency and sustainable development. But their model did not consider the influence of intercity trips. Currently, intercity rail transit pricing only considers investment withdrawal and the attendance of public transportation.

The Efficacy Coefficient Method has been widely applied to financial risk and efficiency evaluations, but has been rarely used in the passenger transport structure. In that context, this paper aims at minimizing travel time and energy consumption while maximizing operating revenues. On this basis, we simplified the multi-criteria model into a bi-level model, and solved it by heuristic algorithms. With the efficacy coefficient method we can get the optimal solution that minimizes the defined constraint objective functions. The results of this study can be helpful in setting ticket prices for intercity rail passenger transport systems.

The latter parts of this paper are organized as follows: travel characteristics of the economic circle and assumptions of this paper are discussed in Section 2. Next, Section 3 proposes the multi-objective model and normalizes it by the efficacy

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coefficient method. And then, path choice and mode split is accounted for in fixed demand stochastic user equilibrium, which is considered the lower layer in the bi-level programming model. Section 4 cites an example of some economic circle in China. Finally, Section 5 gives conclusions and recommendations for pricing intercity rail transport operator in China, and also provides future research issues.

2 Travel characteristic analysis and assumptions

2.1 Travel characteristic analysis

An urban economic circle consists of closely-related cities with the distance among them being less than 500 km. Intercity rail transport, intercity buses, and cars are the three most commonly used transportation modes for interurban travel. An urban economic circle is a complicated network with multi-path and multi-mode, and can be denoted as $G=(N, L)$. N denotes the set of nodes, L denotes the set of links; $tr(train)$ denotes the urban rail transit of the intercity, and a, b denote cars and intercity buses, separately. Therefore, the network of intercity rail transport, cars and intercity buses can be defined as $G_{tr}=(N_{tr}, L_{tr})$, $G_a=(N_a, L_a)$, and $G_b=(N_b, L_b)$ separately. K_{rs}^{st} and K_{rs}^{tr} denote the path of the highway and intercity rail transport network. Q_{rs} denotes the traffic demand of rs as the transportation origin destination.

2.2 Assumptions

(1) Each means of conveyance is simplified into three routes, L_{rs}^{tr} denotes a restrict line for intercity rail transit. L_{rs}^{a} and L_{rs}^{b} denote the road path, and L_{rs}^{a} is parallel to L_{rs}^{tr}.

(2) The total travel time in the regional economic circle does not change.

3 Modeling

3.1 Multi-target modeling

It is well known that profit is a major concern for the operating department, with ticket prices being directly related to operating incomes. Furthermore, maintaining a balance of payments can be one condition of sustainable development. Suppose that construction costs are not including in the model.

$$\max \ l^r \cdot q_r(u_r) p_r - q_r(u_r) W \tag{1}$$

$$W = e^r \cdot q_n\left(u_n\right) \cdot l^r + C \tag{2}$$

where $q_r(u_r)$ represents the quantity of passengers which vary with the intercity rail transit fare; l^r denotes the length of the intercity rail transit (km); p_r represents the fare rate per kilometer of intercity rail transit (yuan). In Eq. (2), W represents the average operation costs per passenger-trip (yuan/p.km), where e^r denotes the energy costs per passenger-trip of intercity rail transport (yuan/p·km), and C represents other operation costs other than energy costs per passenger-trip (yuan).

Meanwhile, different traffic structures will lead to different energy costs and system travel time, thus the total costs of energy and travel time are also considered in the model, and are shown in Eqs. (3) and (4).

$$\min \ \sum_n \left[q_n\left(u_n\right)/c\right] \cdot e^n \tag{3}$$

$$\min \ \sum_n q_n\left(u_n\right) \cdot t_t^n + \sum_n q_n\left(u_n\right) \cdot t_c^n \tag{4}$$

Equation (3) aims at minimizing the energy consumption, which is measured by the product of the traffic frequency and specific energy consumption. c is a single-pass delivery capacity of different conveyance means, and e^n is the specific energy consumption of different conveyance means. Intercity rail transit operates according to the schedule, while intercity buses and cars operate according to the quantity of passengers.

Equation (4) targets the minimum system travel time, which is calculated by the summation of all passengers. t_t^n denotes the in-car time of the nth conveyance means, and t_c^{n} represents the transfer time of means.

3.2 Evaluation function

The efficiency coefficient method[9] is used to solve the three objective functions mentioned above to find the optimal values, respectively. We then can get global optimum solution by taking the cubic root of each optimal value. The formulations are showed in Eqs. (5) to (9). $P_{\max}$ denotes the maximum operational profits and is set to a value of *1*, meanwhile, $P_{\min}$ represents the operational incomes that can only balance the payments, it is set to a value of 0. Without considering other factors, the efficiency coefficient of operational profits can be obtained as follows:

$$d_1 = \frac{1}{p_{\max} - p_{\min}}(p - p_{\min}) \tag{5}$$

In Eq. (5), P denotes the actual operational costs. The efficiency coefficient of operational profits is calculated by dividing the difference between the actual profits and minimum profits by the subtraction of the maximum and minimum profits. Based on the research of Carlsson-Kanyama[10], the energy consumption of transportation is at most 1.1×10^4 MJ per person every year to achieve the sustainable development of transportation. But considering the fact of China, we increased the upper limit of the international standards by 60%, then make the upper limit 1.8×10^4 MJ , and had the corresponding efficiency has a value of 1. The efficiency coefficient of energy consumption is shown in Eq. (6):

$$d_2 = \frac{1}{\overline{E}_{\min} - \overline{E}_{\max}}(\overline{E} - \overline{E}_{\max}) \tag{6}$$

In Eq. (6), $\overline{E}$ denotes the total energy consumption, and is calculated by dividing the difference between the actual energy consumption and utmost consumption by the subtraction of the minimum and maximum consumptions.

Thirdly, T is defined as the system travel time in the economic circle, which can be calculated by Eqs. (10) and (11). $T_{\max}$ and $T_{\min}$ represent the maximum and minimum time