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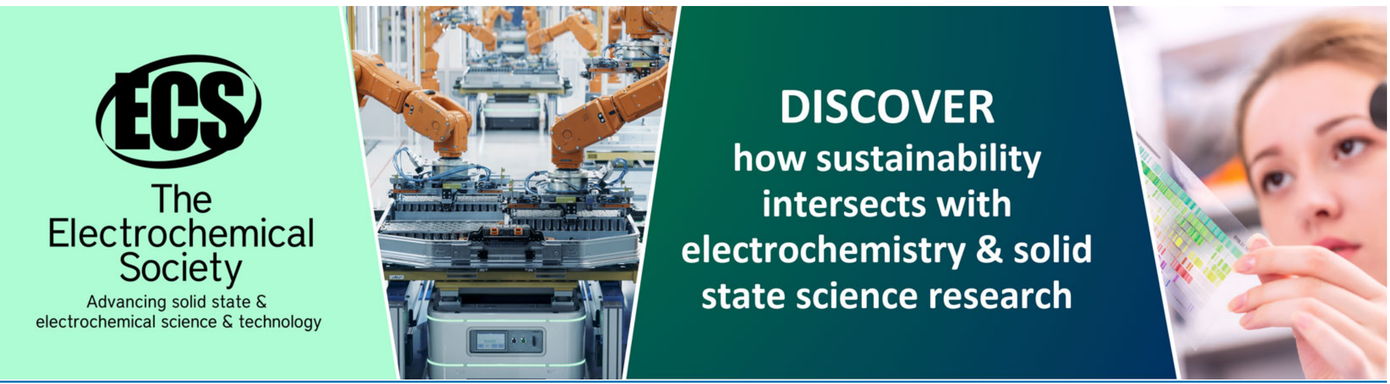

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Analysis of coupling between high-speed railway and common speed railway system in transportation corridor

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Abstract. The high-speed railway and common speed railway subsystems as important components of the railway transportation system, can make railway traffic organization more orderly, when there are a rational division and balance development between them. In order to quantitatively evaluate the coordinate relations between high-speed railway subsystem and common speed railway subsystem, this paper takes the railway transportation corridor from Baoji to Lanzhou as an example. Firstly, using Logit model and grey forecasting model predict the passenger volume, passenger turnover and time value of high-speed railway and common speed railway in the Baoji-Lanzhou corridor. And then, the coupling forecast model of these two subsystems is established. Lastly, the coupling and coupling coordination of these two subsystems using are predicted and analyzed at theatrically level.

1. Introduction

At present, predecessors have done a lot of researches which are related the transport internal system and other systems' coupling relationship. ZAMBELLI[1] and CREPIN.A.S[2] introduced the coupling theory to study the coordination degree between subsystems. Shuai Bin et al[3] divided China regional economy into three types through studying coupling relationship between regional economy and the railway development. Zhu Lei[4] by combining coupling degree and coordination degree, building coupled coordination degree model analyzed the coupling and coordination relationship among various traffic modes of the corridor. Li Xin et al[5] used the coupling function to analyze the relationship between the China railway transport situation and opencast coal mine production, but the paper used analytic hierarchy process in the coupled model for weight calibration, which was influenced by subjective factors greatly, and might reduce the accuracy of assessment. Zhang Yaodong [6] took the urbanization and transport systems as the two main indexes, and built the coupling degree model to study traffic modes in Lanzhou and the coupling mechanism of urban development. Yang Li et al[7] took the Xinjiang as an example and built the coupling degree model of the Xinjiang transportation infrastructure and economic to analyze their coupling mechanism, but the paper did not divide the index weights.

Based on the previous experience, this paper constructed a coupling evaluation model of high speed railway and the common speed railway in Baoji-Lanzhou corridor, and does make a brief forecast and analysis on the coupling degree and coupling coordination of two traffic modes in the next ten years. The result has guide significance for planning the two systems' rail transport corridors development.

2. Coupling evaluation model

According to characteristics of Baoji-Lanzhou transport corridor, firstly, the coupling index systems of

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high-speed railway and common speed railway are established in this paper. As shown in Figure 1.

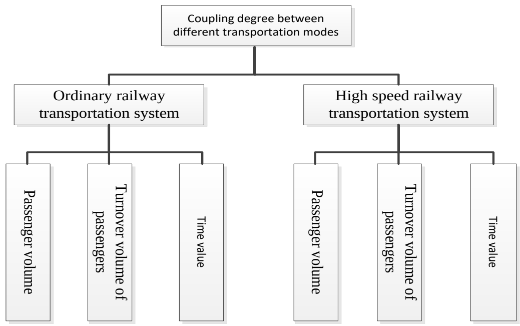

Figure 1. Index system of coupling in different transportation systems

The various indicators in subsystems have different dimensions, because they represent different physical meanings. Based on this, these indicators must be dimensionless before the coupling model is established. The linear power function is used in this paper, as shown in equation (1) .

$$u_i = \begin{cases} \dfrac{X - X_{\min}}{X_{\max} - X_{\min}} \\ \dfrac{X_{\max} - X}{X_{\max} - X_{\min}} \end{cases} \qquad \left(i = 1,2,\ldots\ldots n \right) \tag{1}$$

Where, U_{i} is the effective contribution of x to the system; $X_{\min}$ is the top value of order parameters; $X_{\max}$ is the lower limit of the order parameters.

In a transport corridor, the different transport modes are located in different and interacting subsystems. This paper uses the linear weighting method to calculate order contribution from subsystem to total system. A specific formula is shown as formula (2).

$$U_i = \left(\prod_{i=1}^{n} u_i \right)^{\frac{1}{n}} = \sum_{i=1}^{n} \lambda_i u_i \tag{2}$$

Where U_{i} is the total order parameter; λ_{i} represents the weights of the each order parameter.

This paper builds calculation formulas of coupling degree, as shown in equation (3).

$$C = \left[\frac{n(u_1 u_2 + u_1 u_3 + \ldots\ldots + u_{n-1} u_n)}{\left(u_1 + u_2 + \ldots\ldots + u_n\right)} \right]^{\frac{1}{\mathrm{n}}} \tag{3}$$

Where, the coupling degree of specific criteria is shown in table 1.

Table 1. Coupling grade

Coupling degree	[0,0.3]	(0.3,0.5]	(0.5,0.8]	(0.8,1]
Coupling degree grade	Weak	secondary	preferably	high quality

Entropy weight method could analyze the coordination of indicators in objective and comprehensive way which is not affected by the influence of subjective factors. This paper uses entropy-right method to determine the index weights [8]. The steps of entropy-right method are shown in the following .

The index of j of entropy e_j :

$$e_j = -k\sum_{i=1}^{n} \frac{u_{ij}}{\sum_{i=1}^{n} u_{ij}} In \frac{u_{ij}}{\sum_{i=1}^{n} u_{ij}} \tag{4}$$

The entropy weight of the j index:

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{m} 1 - e_j} \tag{5}$$

This paper builds coupling and coordinating functions among subsystems to fully reflect the coupling strength among subsystems, and the relationships between the efficacy and collaborative effects.

$$D = (C \times T)^{\frac{1}{2}} \tag{6}$$

$$T = k_1u_1 + k_2u_2 + \ldots\ldots + k_nu_n \tag{7}$$

Where, D represents coupling and coordinating degree; T represents the coordinating index among subsystems.

Table 2. Coupling coordination degree

D	[0,0.3]	(0.3,0.5]	(0.5,0.7]	(0.7,1.0]
Degree	Low coordination	Basic coordination	Moderate coordination	Highly coordination

3. Parameter calibration

The time value of common speed railway refers to that the passenger use the extra travel time that the common speed railway mode costs than the high speed railway creating the production value, and it is a negative indicator. On the contrary, high-speed rail will create a positive time value due to the travel time saving. The calculation formula is shown in the formula 8.

$$R_{(t)} = Q_{(t)} \times R \times W_{(O,D)} \times P_{(t)} \tag{8}$$

where, $R_{(t)}$ is the value of travel time; $Q_{(t)}$ is the number of passengers change transport modes; R is the effective utilization coefficient of passenger travel; $W_{O,D}$ is the saved time that passengers change transportation from O to D; $P_{(t)}$ is the unit of time value.

Logit model is a linear equation which considered the major factors as a characteristic varible when people choose travel modes[9]. This paper only studies the relationship between high speed railway and common speed railway in Baoji-Lanzhou corridor. U_i and U_j represent utility functions of high speed railway travel mode and common speed railway travel mode, representively. Therefore, passengers flow share rate in Baoji-Lanzhou corridor can be expressed as:

$$P_{(j)} = expU_j \Big/ \left[expU_i + expU_j\right] \tag{9}$$

The main factors affecting passengers travel modes choice in Baoji-Lanzhou transport corridor are safety, quickness, ticket price and convenience. By referencing relevant information, the safety index of common speed railway and high speed railway are (0.95, 1), respectively. The ticket prices of the main cities in Baoji-Lanzhou corridor are set by the market survey. Quickness and convenience index describe the total travel time and waiting time targets from the starting point to the target point. The calculation formula is as shown in the formula 10 and 11.

$$K_i = T_i / P_{(t)} \tag{10}$$

$$F_{(i)} = T_j / P_{(t)} \tag{11}$$

As a result, the utility function of passengers transport mode choice is shown in the formula (12).

$$U_i = (\theta_1 P_i + \theta_2 K_i + \theta_3 F_i) A_i \tag{12}$$

Where, K_i and F_i refer to the utility value of the quickness and convenience index, respectively; P_i refers to the utility value of the ticket price; A_i refers to the utility value of safety factors; T_i refers to the whole time needed to complete the trip, T_j refers to a time sum of access time and waiting time by transport mode j .

Based on the above analysis, the share rate model are solved by using Trans CAD software, the passengers share rates between high speed railway and common speed railway of major cities in Baoji-Lanzhou corridor in 2012 to 2015, can be obtained , and specific values are provided in table 3.

Table 3. Share ratio of high-speed railway and ordinary railway

Section	2012		2013		2014		2015	
	Ordinary	high-speed	Ordinary	high-speed	Ordinary	high-speed	Ordinary	high-speed
Baoji--Tianshui	0.79	0.21	0.75	0.25	0.73	0.27	0.69	0.31
Baoji--Dingxi	0.75	0.25	0.70	0.30	0.68	0.32	0.65	0.35
Baoji--Lanzhou	0.61	0.39	0.58	0.42	0.57	0.43	0.55	0.45
Tianshui--Dingxi	0.40	0.60	0.42	0.58	0.44	0.56	0.45	0.55
Tianshui--Lanzhou	0.28	0.72	0.30	0.71	0.31	0.69	0.32	0.68
Dingxi--Lanzhou	0.65	0.35	0.68	0.32	0.71	0.29	0.73	0.27

Based on the travel characteristics survey in Baoji-Lanzhou corridor, using Logit model calculates the sharing rate of common speed railway and high-speed railway. The passengers flow of high speed rail can be simulate by the data of the ordinary railway from 2012 to 2015. Grey system theory using the raw data directly added and moving average-weighted sum method to make the resulting sequences show certain regularity, and using typical curve approximate its corresponding curve to predict the systems.

4. Data collection and processing

By collecting the main common speed railway passengers flow of Baoji-Lanzhou corridor from 2012 to 2015, using share rate model can simulate the high-speed rail passengers flow in Baoji-Lanzhou corridor. The specific values are provided in table 4.

Table 4. Passenger of High speed rail from 2012 to 2015

Section	2012		2013		2014		2015	
	Ordinary	high-speed	Ordinary	high-speed	Ordinary	high-speed	Ordinary	high-speed
Baoji--Tianshui	43.68	11.61	42.9	14.3	43.6	16.13	44.1	19.81
Baoji--Dingxi	41.37	13.79	40.1	17.19	40.7	19.18	41.7	22.45
Baoji--Lanzhou	33.68	21.53	33.3	24.11	34.2	25.80	35.2	28.80

Tianshui--Dingxi	22.13	33.20	24.0	33.14	26.3	33.47	28.9	35.32
Tianshui--Lanzhou	15.39	39.57	17.1	40.47	18.5	41.18	20.4	43.35
Dingxi--Lanzhou	35.98	19.37	38.9	18.31	42.4	17.32	46.7	17.27

Based on these four years passengers flow data, grey prediction model is built to predict the common speed railway and high-speed rail passengers flow and Passenger transport turnover of Baoji-Lanzhou corridor in 2017 to 2026, as shown in table 5 and table 6.

Table 5. Passenger forecasts from 2017 to 2026 between Baoji-Lanzhou (ten thousand people)

Years	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
High speed railway passenger flow	195	209	225	241	259	278	298	320	344	369
Ordinary railway passenger flow	238	250	263	276	290	304	320	336	353	370

Table 6. The forecasts of passenger transport volume (ten thousand people/ kilometer)

Years	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Ordinary railway	65196	68081	71094	74240	77525	80956	84538	99279	92185	96265
high-speed railway	61111	66110	71515	77363	83689	90533	97935	105945	114607	123979

Through the yearbook data of Gansu and Shanxi provinces' from 2012 to 2015, it could get the GDP of the main cities' and the number of resident population. From equation 8 and 9, and combing grey prediction model, the travel time value of common speed railway and high speed railway in 2017 to 2026 can be predicted, and Specific values are provided in table 7.

Table 7. The travel time value in the corridor of Baoji-Lanzhou (ten thousand yuan)

Years	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Ordinary railway	26429	30367	34892	40092	46066	52930	60817	69879	80292	92256
High-speed	22128	25370	29086	33347	38232	43832	50253	57615	66054	75730

Dimensionless the index is the main way to resolve the problem that different indicators represent different meanings in coupling system. Using equation (1) quantify the indicators in the railway system. In order to clear the effect degree of each indictor in high speed railway and common speed railway system on the whole railway transport system development, each indictors are given the weights, and they are calculated using the formula (4) and (5), and quantitative results are shown in table 8.

Table 8. The weight of order parameter in transport system

Index	Ordinary railway transportation system			High speed railway transportation system		
	Passenger volume	Turnover volume	Time value	Passenger volume	Turnover volume	Time value
e_j	0.96537	0.96772	0.91377	0.94524	0.94691	0.87825
w_j	0.22613	0.21078	0.56307	0.23850	0.23123	0.53027

In order to clearly understand the stability of Baoji-Lanzhou railway system, based on the formula (3) and (6) in coupling degree model, it can get the coupling degree and the coupling coordination degree between common speed railway and high-speed railway from 2017 to 2026, specific values are provided in table 9.

Table 9. The coupling of high-speed railway and ordinary railway between 2017 to 2026

Years	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Coupling	0.628	0.659	0.681	0.695	0.704	0.707	0.704	0.694	0.677	0.651
Benignity	0.500	0.530	0.558	0.583	0.606	0.626	0.647	0.663	0.676	0.684

This paper makes the coupling and coordination degree line of high speed railway and common speed railway in Baoji-Lanzhou corridor, as shown in Figure 2.

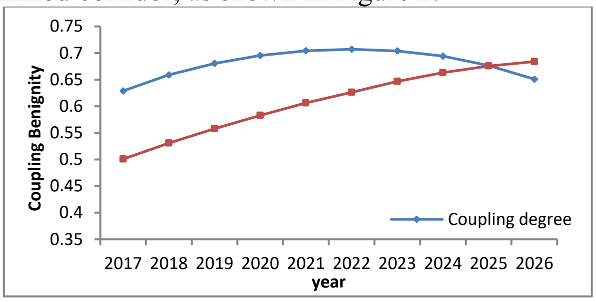

Figure 2. Benignity of coupling between high-speed railway and ordinary railway in the corridor of Baoji-Lanzhou

Combining table 1, table 2 and Figure 2, it can be seen that Baoji-Lanzhou high speed railway had better coupling and medium coupling coordination with common speed railway in the early decade, and the coupling degree has a growing trend from 2017 to 2023, this is because the completion of the high-speed rail will induced some passengers flow so as to increase the passenger traffic volume. However, after the years of 2024, with the region's economic growth, passengers will have a deeply recognition of the time value concept, and the high speed railway passengers flow volume will increase dramatically ,and coupling degree of the high-speed rail and common speed railway appeares to be a certain degree of decline. The overall coordination degree will being a high level, and their interaction effects promote railway system to develop in a more healthy and orderly way.

Based on existing references, this paper sets up the coupled coordination degrees forecast model of Baoji-Lanzhou corridor by combining the logit model and Grey forecasting model. Secondly, based on the existing traffic data, it simulates future ten years data, and it analyzes and predicts coupled coordination relationship between two subsystems within 10 years after the Baoji-Lanzhou high speed railway is finished. As can be seen from above, after the Baoji-Lanzhou high speed railway is completed, it will share passengers transportation tasks with common speed railway.

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