A Study on Travel Time Value in Railway Transportation Corridors

HaiJun Li [1 *], HongChang Zhou [2]

[1] *School of Traffic and Transportation*, Lanzhou Jiao-Tong University, Lanzhou 730070, Gansu Province, China.
[*] Corresponding Author Email: lihaijun@mail.lzjtu.cn.

[2] *School of Traffic and Transportation*, Lanzhou Jiao-Tong University, Lanzhou 730070, Gansu Province, China.
Email: 972349233@qq.com

***Abstract* — The value of travel time is an impact indicator when analyzing economic interests of transportation projects. In order to make quantitate study of travel time, the work in this paper first calculated the weighted average of travel time, whose impact is very important, using the weight-sharing rate method. Considering that the Baoji-Lanzhou transportation corridor has not been operated yet, in order to get a more accurate calculation of the value of travel time, based on the current data, we made an in-depth analysis on GDP and the volume of travelers of the year 2017 using Grey prediction model and Matlab. The research and analysis provides value for railway construction department and passenger travel.**

Keywords - value of travel time; weighted average travel time; Grey prediction model

I. INTRODUCTION

During the investment process in railway and road construction, much of the whole computational efficiency is expressed by the form of time savings, and ignoring that its value will lead to improper decision-making, and cause great economic losses [1]. The time value begins to be explored in the early 60's abroad, and our country just begins to study on the basis of foreign research in the early 70's, achieving some results.

A lot of research has been done on the value of travel time, and a lot of valuable results have been obtained. Among them, such as using gravity model analyzes the social value produced by the travel time savings of Beijing-Shanghai high-speed railway [2]. Ingeniously using utility function, and maximum likelihood estimation method studies travel time value in a corridor from Nanjing to Beijing. However, the model has a strong dependence on initial value, and an improperly initial value will lead to a poor reliability result [3]. Using improved logit model analyzes the value of travel time, but it is lack of considering many factors from the different regions and different modes of transport affecting the time value greatly, which should be analysed more comprehensively[4].

In this paper, on the foundation of the existing literature, it uses the gray prediction model making prediction on the city GDP, the resident population and passengers flow of the main stations from Baoji to Lanzhou in 2017. Based on analysing share ratio under a variety of transport modes, using weighted average travel time calculates the average travel saving time after the operation of the Baoji-Lanzhou high-speed railway. Thus it more accurately analyses the travel time value of the main city stations along the corridor of Baoji-Lanzhou.

II. THE TRAVEL TIME VALUE

Time is a kind of irreproducible resources, and human production activities produce value through the consumption of time, so time is a valuable resource. For the travelers, choosing different transportation modes will cost the travelers different time consumption. So considering from the perspective of opportunity cost, the value of travel time is generated by the opportunity cost [5]. The time value refers to the travel time savings that passengers transfer transport mode from a slower running speed one to a faster one. If this saving time used on production activities will create value in a currency form. In china, the related data research shows that the effectiveness produced by time savings from the road is accounted for 30% to 50%, which is a major factor in whether the project is feasible [6]. This shows that it is of great significance to study the value of travel time.

The high speed of the high-speed railway has greatly shortened the time passengers travelling. Only this can create great economic benefits. In general, the passengers travel purpose can be divided into: business, tourism, visiting relatives and friends, shopping, going to school and other purposes. The time consumed in a variety of transportation infrastructure is the cost this travel paying. Especially for business trip, the time consumed in transportation cannot produce value, but by changing the mode of travel, the travel time is shortened, thereby increasing the production time to produce value, namely so-called travel time value. Its formula is shown as the formula (1)

$$R_{(t)} = Q_{(t)} \times R \times W_{O,D} \times P_{(t)} \tag{1}$$

Where $R_{(t)}$ refers to the value of travel time, $Q_{(t)}$ refers to the number of passengers changing the mode of transportation, R refers to the effective utilization coefficient of passenger travel ; $W_{(O,D)}$ refers to the time savings when the passengers change the travel mode from the origin to the destination; $P_{(t)}$ refers to the unit time value.

A. The unit time value

The unit time value refers to the average value produced by a person per hour in an area, which is affected by the gross domestic product and the total number of people in the area. The higher the unit time value, the greater the value of travel time, and the converse is also ture. Its formula is shown in formula (2).

$$P_{(t)} = \frac{G}{T * M} \tag{2}$$

Where G refers to the GDP of the area; T refers to the annual working hours; M refers to the area's resient population.

B. Passengers weighted average travel time

The passengers weighted average travel time is the time measure from any site to another site in the corridor. The passengers average weighted travel time is smaller, indicating that this site and another site are the more closely linked, namely, the accessibility is higher[9]. After the new transport tools are introduced, various transport modes are assigned a weight - sharing rate, which can clearly indicate that passengers travel time is changed after new transport tools are introduced(namely, a comparison of average travel time between before and after new transport tools are introduced. The calculation formula of the passengers weighted average travel time is shown as the formula (3).

$$W_{A,B} = \sum_{j=1}^{n} X_j M_j \tag{3}$$

Where $W_{(A,B)}$ refers to the weighted average travel time between the city A to the city B. X_j refers to the total travel time of the transport mode J , M_j refers to passenger sharing rate of the transport mode J.

C. The number of passengers changing the transport mode

After the high-speed railway operating, the majority travelers will change the original travel modes considering the time saving. So the local passenger market will establish a new balance instead of the original balance. Seen from the formula (1), predicting the number of passengers changing the transport mode after the high-speed railway operating is an important parameter to calculate the travel time value of the corridor. Therefore establishing passenger flow forecasting model is the key of this paper. Considering the special circumstances of the transport system: there are many factors affect the passengers flow transport mode change in the corridor, and they cannot be accurately analyzed, therefore they can not be predicted by an exact mathematical model. When the transportation system is regarded as a grey system, the grey forecasting model has a unique advantage in passenger flow prediction. The model can make a more accurate prediction of the system with less data.

III. GREY PREDICTING MODEL

Grey system theory uses the ways of making a direct summation of the raw data, and moving average weighted summation, to let the generated sequence show a certain regularity, and to use the typical curve to approximate the corresponding curve, and setting the approximation curve as the model predictes the system[7]. The differential equation model of the grey theory is called the GM model. Where GM (1,1) represents the differential equation of the first order single variable.

A. Data preprocessing

The generated sequence is obtained by making a summation of the original sequence, as following shows:

$$X^{(1)} = \left\{ X_i^{(1)} \mid X_i^{(1)} = \sum_{j=1}^{i} X_j^{(0)} \right\} \tag{4}$$

The inverse of the summation generation is called subtraction generation, which can return the summation generation to non generation sequence. This method weakens the randomness and instability of the original sequence. Making the test of the stage ratio and the smooth ratio for $x^{(0)}$, $X^{(1)}$, respectively, when the condition is met, The GM (1,1) model is established for the $X^{(1)}$.

B. Establishing grey forecasting model

Setting $X^{(1)}$ meets the first order differential equation, as shown in the formula (5).

$$\frac{d_{x^{(1)}}}{d_t} + ax^{(1)} = u \tag{5}$$

The formula (6) is obtained by solving the first order differential equation of the formula (5), as following shows.

$$x_{k+1}^{(1)} = \left[x_1^{(1)} - \frac{u}{a}\right]e^{-ak} + \frac{u}{a} \tag{6}$$

By using the least square estimation, we can obtain the coefficients u and a. By bringing the coefficients back into the original equation, the time response equation is obtained. Then by making subtraction, we can get the value of the reduction sequence.

C. the precision test residual

The residual is calculated as following:

$$\varepsilon_k^{(0)} = x_k^{(0)} - \hat{x}_k^{(0)} \tag{7}$$

The ratio of posterior difference

$$C = \frac{s_2}{s_1} \tag{8}$$

Small deviation probability

$$P = \left\{ \left|\varepsilon_k^{(0)} - \bar{\varepsilon}^{(0)}\right| < 0.6475S_1 \right\} \tag{9}$$

If the ratio of posterior difference and small deviation probability of the data in the model are all meeting the accuracy grade demands in table 1, the model can be used to forecast, otherwise, the date calculation must be carried out after residual correction.

TABLE 1. THE MODEL ACCURACY GRADE DIVIDES

Forecasting Accuracy	P	C
Good	>0.95	<0.35
Qualified	>0.80	<0.50
Barely Qualified	>0.70	<0.65
Unqualified	<=0.70	>=0.65

IV. EXAMPLES ANALYSIS

Taking the Baoji-Lanzhou high speed railway as example in this paper, it studies the effect on travel time value in the corridor of Baoji-Lanzhou after the Baoji-Lanzhou high speed railway operating. The Baoji-Lanzhou high speed railway is east from Baoji West to Lanzhou, and its designed speed is 250km/h. after the construction completed, the running time from Baoji to Lanzhou will be shortened to 2.5 hours, and it is expected to operate in 2017.

A. The share ratio

Based on 875 sample data in the corridor of Baoji-Lanzhou, the literature [8] used the logit function and Trans-CAD software to calculate the passenger share ratio of the main city: Baoji, Tianshui, Dingxi and Lanzhou along the Baoji-Lanzhou high speed railway after it operating. Using the same method, based on the existing transportation mode, this paper calculates the share ratio of each major transportation mode of the corridor, the specific values are shown as the table 2.

TABLE 2. THE PASSENGER MARKET SHARE RATIO OF EACH TRANSPORT MODES OF CORRIDOR FROM BAOJI TO LANZHOU WITHOUT HIGH SPEED RAILWAY

Sections	Existing Rail	Super Highway	Highway	Civil Aviation
Baoji--Tianshui	0.66	0.22	0.12	-
Baoji--Dingxi	0.36	0.14	0.50	-
Baoji--Lanzhou	0.27	0.22	0.18	0.33
Tianshui--Dingxi	0.27	0.31	0.42	-
Tianshui--Lanzhou	0.13	0.26	0.61	-
Dingxi--Lanzhou	0.53	0.36	0.11	-

B. The calculation of weighted average travel time

As the Baoji-Lanzhou high speed rail way has not yet been operated, Now supposing that the Baoji-Lanzhou high speed rail way travel at the speed of 250km / h, to speculate the travel time to each station site. The travel time from one station site to other station of other transport modes is obtained from the market survey. By taking the data into the formula (2), the weighted average travel time, which is among the main station sites in the baoji-lanzhou corridor of having high speed railway or not, can be calculated, after making the difference of them, as the formula (10), the passenger average saving time can be obtained as shown in table 3.

$$\Delta W_{O,D} = W_{A,B(no)} - W_{A,B(yes)} \tag{10}$$

TABLE 3. THE WEIGHTED AVERAGE TRAVEL TIME AMONG THE MAJOR STATIONS IN THE CORRIDOR OF BAOJI-LANZHOU

Section	The Weighted Average Travel Time		Average Saving Time (Min)
	Having High Speed Railway (Min)	Without High Speed Railway (Min)	
Baoji--Tianshui	88.82	104.46	15.64
Baoji--Dingxi	246.44	336	89.56
Baoji--Lanzhou	221.23	250.48	29.25
Tianshui--Dingxi	129.95	156.6	27.37
Tianshui--Lanzhou	210.18	247.09	36.91
Dingxi--Lanzhou	78.68	87.88	9.2

C. Predicting the number of passengers changing the traffic mode

According to the market survey, the total passenger traffic flow, among each main station site by various traffic modes in the corridor of Baoji-Lanzhou from the year of 2012 to 2015, can be obtained. In this paper, it establishes the GM (1,1) model by the grey forecasting method. Firstly, setting the passenger flow (843150, 855000, 906850, 995900) from Baoji to Tianshui during the year of 2012 to 2015 as example to predict its passenger flow in the year of 2017. By making the sequence a summation, $X^1 = \{843150, 1698150, 2605000, 3600900\}$, programming by using Matlab, the results are shown as following.

(1)The residual test

$$\hat{U} = \begin{bmatrix} a \\ u \end{bmatrix} = \begin{bmatrix} -0.07712 \\ 751509 \end{bmatrix}$$

After calculating the fitted value $\tilde{X}$, and then making subtraction return the sequence, the model calculated value $\tilde{X}_0^k$ can be obtained. Then analysing the deviation, the result is shown in Table 4.

TABLE 4. THE SIMULATION RESULTS OF PASSENGERS FLOW GREY PREDICTION

Years	Actual Value	Calculated Value	Residual Value	Relative Deviation
2012	843150	843150	0	-
2013	855000	848843	6157	0.72%
2014	906850	916898	-10048	-1.108%
2015	995900	990406	5494	0.552%

Based on the relative data in Table 4, making the fitting curves of the actual passenger flow value and the passenger flow grey prediction value, which is shown as figure 1.

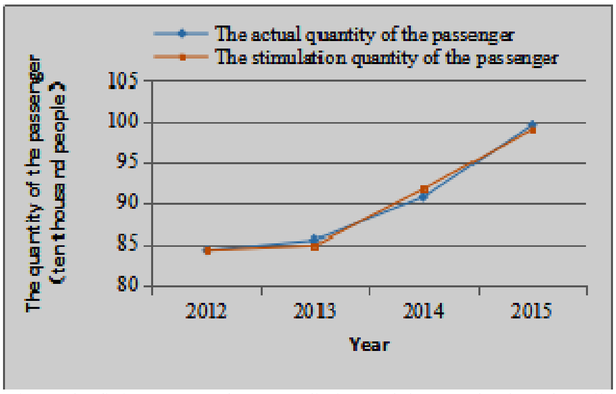

Fig 1. The fitting curves of grey prediction and the actual value of Baoji-Lanzhou.

Combining the figure 1 and the table 4, The fitting effect of grey prediction and the actual value of Baoji-Lanzhou is well, so the credibility by using this method is high.

(1) The post difference test

The mean of original data:

$$\bar{X}^{(0)} = \frac{1}{n}\sum_{K=1}^{n} X_K^{(0)} = 900225$$

The variance of original data:

$$S_1 = \sqrt{\frac{\sum_{K=1}^{n} (X_K^{(0)} - \bar{X}^{(0)})^2}{n-1}} = 69523$$

The mean of residual:

$$\bar{\varepsilon}^{(0)} = \frac{1}{n}\sum_{K=1}^{n} \varepsilon_K^{(0)} = 401$$

The variance of residual:

$$S_2 = \sqrt{\frac{\sum_{K=1}^{n} (\varepsilon_K^{(0)} - \bar{\varepsilon}^{(0)})^2}{n-1}} = 7493 .$$

The posterior difference ratio:

$$c = \frac{S_2}{S_1} = 0.108$$

Small deviation probability: $p = 1$

By checking the table 1, the prediction accuracy is better. Therefore, using this model to predict the passenger flow meets with the model requirement of grey prediction theory. Therefore, using the same method can predict passenger flow among the main station sites in the corridor of Baoji-Lanzhou in the year of 2017. The posterior difference ratio and the small deviation probability are shown in the table 5.

TABLE 5. THE MODEL ACCURACY

Indicator	C	P	Prediction Accuracy
Baoji--Tianshui	0.108	1	Good
Baoji--Dingxi	0.019	1	Good
Baoji--Lanzhou	0.037	1	Good
Tianshui--Dingxi	0.134	1	Good
Tianshui--Lanzhou	0.016	1	Good
Dingxi--Lanzhou	0.113	1	Good

Seen the simulation accuracy from the table 5, the passenger flow prediction of each section meets with the model requirement of grey prediction theory, so the grey model can predict the passenger flowing the year of 2017. The specific prediction results are shown in Table 6.

TABLE 6. THE PASSENGER FLOW PREDICTION IN THE CORRIDOR OF BAOJI-LANZHOU IN THE YEAR OF 2017 (TEN THOUSAND PEOPLE)

D. *sections*	E. *2017*
Baoji--Tianshui	F. *115.56*
Baoji--Dingxi	G. *5.38*
Baoji--Lanzhou	H. *23.01*
Tianshui--Dingxi	I. *47.59*
Tianshui--Lanzhou	J. *21.20*
Dingxi--Lanzhou	K. *222.27*

D. Predicting the per time value in the corridor of Baoji-Lanzhou

In this paper, based on the major cities economic data in the corridor of Baoji-Lanzhou from the year of 2012 to 2015, it establishes the grey prediction model to estimate GDP and resident population of Lanzhou, Dingxi, Tianshui and Baoji by the year of 2017. According to the labor law: working hours per week are 40 hours, in order to be convenient to calculate, the year working time is recorded as 50 weeks, namely, the annual working hours are 2000 hours. Bringing it into formula 3, the unit time value of each great cities, the specific results are shown in table 7.

TABLE 7. THE MAJOR CITIES ECONOMIC DATA IN THE CORRIDOR OF BAOJI-LANZHOU BY THE YEAR OF 2017

Indictors	Lanzhou	Dingxi	Tianshui	Baoji
Population (Ten Thousand People)	371.58	277.75	332.78	377.93
Gdp (Billion Yuan)	2466.97	366.39	648.13	2067.00
Unit Time Value (Yuan)	33.2	6.6	9.7	27.3

E. Travel time value of major cities in the corridor of Baoji-Lanzhou.

In this paper, it ignores the time value produced by other travel purposes, and mainly considers the time value of business trip. Where R represents the passenger travel effective utilization coefficient, and generally it is taken as 50%. According to Formula (1), the travel time value of major cities in the corridor of Baoji-Lanzhou can be obtained, as shown in table 8.

TABLE 8. THE TRAVEL TIME VALUE OF MAJOR CITIES IN THE CORRIDOR OF BAOJI-LANZHOU

Sections	Travel Time Value (Ten Thousand Yuan)
Baoji—Tianshui	411.12
Baoji—Dingxi	26.48
Baoji—Lanzhou	186.10
Tianshui—Dingxi	71.64
Tianshui—Lanzhou	216.44
Dingxi—Lanzhou	565.76
In Total	1477.60

V. CONCLUSIONS

Travel time value is an important index to analyze the economic benefit in transportation project. The travel time value is a kind of opportunity cost, produced by benefits increasing of time savings. By analyzing the travel time value, it has important reference value for formulating ticket price and the choice of passenger travel way.

In this paper, based on the grey prediction model, predicting the traffic flow, GDP and the resident population in the corridor of Baoji-Lanzhou by 2017. Thus the travel time value, in the corridor of Baoji-Lanzhou after operation by 2017, can be calculated. From the above analysis, only time value can generate about 14 million 780 thousand yuan after the operation of Baoji-Lanzhou high-speed railway.

With the study of the travel time value, from the macro aspect, the railway construction decision maker has a preliminary judgment on the feasibility of the railway construction. From the micro aspect, it is better for the travelers to choose travel ways in their favour, to maximize their own interests.

ACKNOWLEDGMENTS

The authors thank the reviewers who gave a through and careful reading to the original manuscript. Their comments are greatly appreciated and have help to improve the quality of this paper. This work is supported in part by the Research Planning Funds of Humanities and social sciences for the Ministry of Education (14YJA790023); Natural Science Foundation of Gansu Province (148RJZA051); Higher Education Research Funds for GansuProvince (2014A051) ; Science and Technology Support Economic Society Development Education Funds of Lanzhou Jiao-tong University(ZC2014005).

REFERENCES

[1] L. D. Zou, B. H. Mao, A. Jin. Research on the model of highways' travel time value in china [J]. Highways & Transportation in Inner Mongolia. 1996, 49 (4): 35-36.

[2] T. J. Hu, X. Y. Zang, J. S. Shen, L. Lei. Analysis on travel time saving value of Beijing -Shanghai high-speed railway [J]. China Railway, 1999 (5): 19-22.

[3] D. Q. Zhang, X. X. Ning. Study on value model of traveling time considering income factor [J]. Journal of systems engineering, 2006, 21 (1).

[4] C. Bu, X. Y. Lin. Study on improvement of logit model for value of travel time [J]. Technology economics. 2009, 28 (3).

[5] C. H. Rong. Western transport economics [M]. Beijing: Economic Science Press. 2002

[6] W. Zhou. Research on several problems on the development management of highway construction [D]. Xi'an: Chang'an University, 2000, 49-50.

[7] J. L. Deng. Grey system theory and its application [M]. Beijing: Science and Technology Press, 1992

[8] H. J. Li. Research on Travel Mode Share and operation Strategy in Baoji-Lanzhou Transportation Corridor [J]. Journal of LanZhou JiaoTong University, 2015, 34 (6) 60-64.

[9] J. Zhou, W. Tu, H. F. Wu. Analysis of the Impact of High-speed Railway on the Regional Economy [J]. Railway engineering cost Management [J].2014(5).

.