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Research on Traffic Journey Intensity of Residents Based on Gravity Model

Ying Lin[1,a], Chunmei Zhong[1,b] and Yong Liu[1,c,*]

[1]*School of management, Chongqing Jiaotong University, Chongqing 400074, China.*
[a]*linyingdyh@aliyun.com,* [b]*296521013@qq.com,* [c]*yongliucs@cqjtu.edu.cn*
** Corresponding Author: Yong Liu*

Abstract

In order to accurately predict the traffic journey intensity of residents along the highway, according to the mechanisms of production of the traveling, analyze the influences of traffic journey intensity of residents from the three angles including residents' willingness to travel, destination's attraction, traffic resistance, and predict the traveling intensity combined with the unconstrained gravity model. Then introduce the sensitivity of travel cost and analyze the impact of sensitivity of traveling cost on the traffic journey intensity. Finally, with an instance of the radiation areas of Zhaoma highway in Yunnan, calculate the calibration parameters in the unconstrained gravity model combined with the increase method and analyze the sensitivity of traveling cost within the scope of radiation areas. The results show that there is significant exponential relationship between the traffic journey intensity and the sensitivity, and it can provide some theoretical basis for the trip distribution; the gravity model is reliable and viable in some degree, and has a certain guiding significance for planning the road infrastructures.

Keywords: *Traffic engineering; Traffic journey intensity; Gravity model; City attraction; Willingness to travel; The sensitivity of cost*

1. Introduction

With the development of the social economy, the rising of people's living level and the improvement of national transportation network, residents' trip willingness become more and more strongly, and the factors affecting the travel will be more and more complex. Through analyzing the various influences on the residents' trip correctly, predicting the residents' travel intensity reasonably and effectively will be significant and plays an important guidance role on the planning and construction of road traffic infrastructure.

The four-stage predict method is the most widely used one in predicting the travel intensity of residents at present, which is originated in the transportation planning research about Detroit and Chicago in the 1950s [1, 2].The method has become the most extensive theory and method system in the world. Traffic journey generation forecasting is the first stage of the four stages, the forecasting precision directly affects the forecast accuracy of other three stages, and it is also very important in the whole traffic planning. The methods used for trip generation forecasting mainly include the growth rate method, categories generated method and regression analysis [3, 4, 5].The most widely used one is the regression analysis, and it only considers the influence factors which are continuous variable. The veracity of the prediction result greatly depends on the choice of influence factors and the establishment of the regression equation.

To the problem of the low accuracy of traffic journey volume, more and more scholars focus on studying the influence factors on traffic journey from the view of multivariate. Lu and Zou have chosen different impact factors in different cities and established some

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different multiple linear regression models to study the traffic journey intensity of residents. But with the complication of the problem, the simple linear regression model has been difficult to predict the strength of travel accurately [6, 7]. Ding and his partners set up the dual-constrained gravity model considering comprehensively multiple factors such as the regional development of economy, blocked travel time and so on aiming at reanalyzing the problems more deeply. And it has been proved that when the traffic data is relatively abundant, the prediction result of gravity model method is more aligned with the trip generation mechanism, and it is more sensitive to reflect the travel intensity with the change of travel cost and achieve better prediction results [8]. Xu chose indexes and established the function relationship combining the gravity model between interregional traffic and five indicators which are GDP, population, distance, driving time, area of region, and further verify the reliability of the gravity model. But due to the building of roads and rebuilding of the roads, the traffic data is insufficient, and the computation of gravity model becomes the key and difficult point on traffic journey intensity prediction [9]. In this paper, combine the gravity model method and the growth rate method to forecast residents' travel intensity. This way can effectively solve the disadvantages of scarce traffic data.

In order to determine the relationship between the intensity of residents along the highway and the related influencing factors from the perspective of the supply and demand of the economy and transportation, this paper rebuilds the impact factors through analysis of residents in the view of three problems including the trip generation, the destination attraction and the transport resistance, then predict the travel intensity of residents combining the traffic gravity model. This way can comprehensively reflect the travel demand mechanism better considering multiple forces from the thrust of the resident desire to travel, destination attraction and the travel cost.

2. Methodology

In view of the lack of data on road traffic, this paper will combine the gravity model method and the growth rate method to predict the traffic journey intensity of residents, the prediction thinking is as follows: first of all, through analysis of the three forces including the tourists' demand thrust, the destinations' attraction and the travel cost resistance, put forward a new gravity model to predict the strength of the traffic journey. Then according to the change of the traffic parameters and the economic parameters in the study areas, compute the growth rate of the travel intensity, and combined with the growth rate method to predict the of resident traffic journey intensity of the future years. Finally using the data about traffic journey intensity getting by growth rate method of and the related economic data and traffic data to calibrate the unknown parameters of the gravity model, eventually determine the calculation model of the traffic journey intensity from the tourist-guest source to a specific purpose city to provide a certain basis for the service facilities planning along the road. The specific flow is shown in Figure 1.

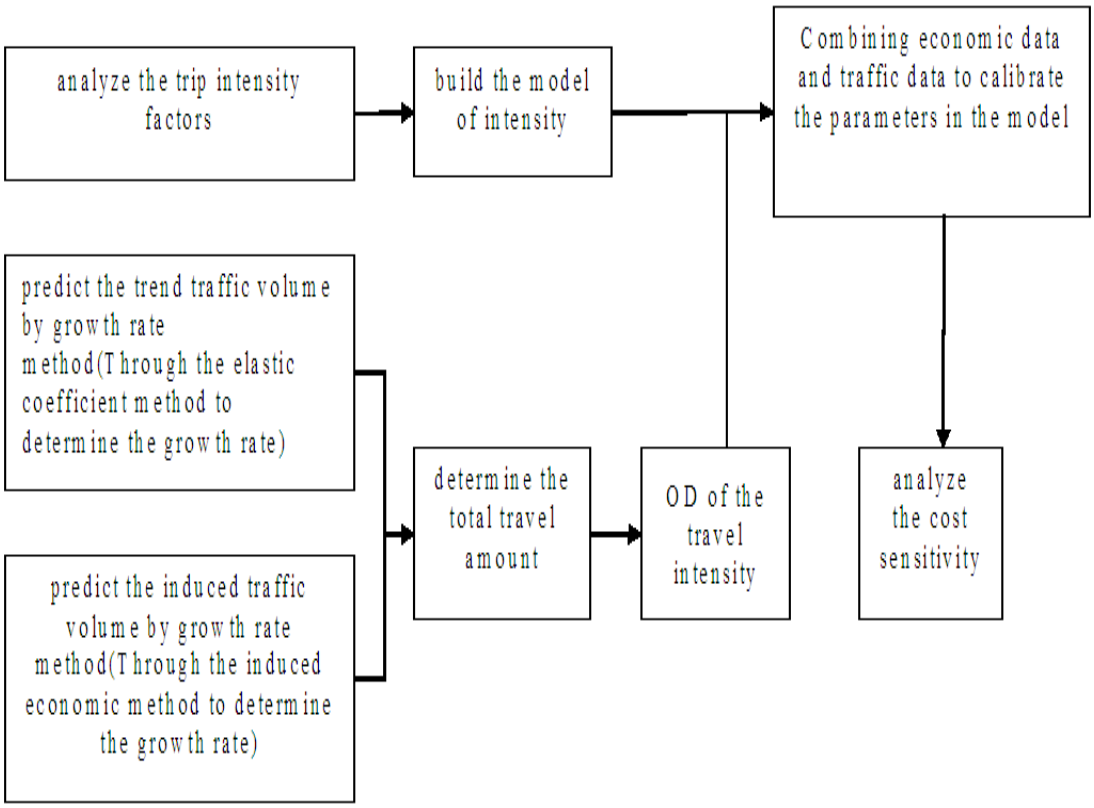


Figure 1. Traffic Journey Intensity Forecasts Ideas

2.1 Analysis of the Influences on the Traffic Journey

The traffic journey intensity is a composite indicator of measuring the travel demands, the travel ability and the service level of urban traffic. And per capita going number is the most direct reaction of the traffic journey intensity of residents. The previous studies have indicated that the residents travel is mainly influences by various factors such as the travel purpose, urban layout, life style, work style, regional economy, road network, traffic facilities, communication development, climate environment and so on. And in general, the travel demand results from the need of social economic activities of the residents.in this paper, based on the disaggregate model, from the perspective of "supply and demand" to explore the influence factors of travel intensity, mainly including the resident willingness to travel, destination city's attraction and travel impedance.

a. Travelers' willingness to travel—that is travel demand thrust. Travelers' desire directly affect the residents' travel intensity, the reason of which is that all the generation of travel behavior is based on the strong and sufficient willingness of residents to travel. The stronger willingness to travel, the greater possibility to travel. Residents' trip willingness is mainly decided by the economic condition. In order to study the strength of a region of travel, with the per capita GDP of local residents to measure the local economy, it is positively related to the intensity of residents. The higher the per capita GDP, the stronger residents willingness to travel, and the more travel will lead to greater intensity. On the contrary, the less willingness to travel, the smaller traffic journey intensity. Thus, this paper approximately thinks that it is exponential relationship between the residents' willingness to travel and per capita GDP in the region, the relationship is shown as Formula 1.

$$A_i = k_1 G_i^{\ a} \quad (1)$$

A_i: thrust of the residents desire to travel;

G_i: starting city's per capita GDP;

a : Exponent of the traffic journey demand thrust;

k_1: adjusting coefficient of the traffic journey demand thrust.

b. the destination attraction degree—that is the pulling force of the destination city. The attraction of the destination is another important factor that affecting residents travel. Only destination is attractive enough, the city can stimulate more tourists to travel.

The destination city's attractive is mainly decided by the city's economic development level and city size. The city's economic development level always measured by the per capita GDP of the destination city. The higher per capita GDP, namely the more advanced the economy, the more foreign population attracted from other areas; on the contrary, the less foreign population attracted from other areas. The scale of the city is usually measured by total number of urban population. The larger city scale, the greater the attraction of the city and the larger number of foreign population will be. These two factors are positively correlated with the residents travel intensity, and have actively promoting effect to the residents. Thus, this paper puts forward a method to compute the pulling force of the destination city, the relationship is shown as formula 2.

$$B_j = k_2 G_j^{\ b} S_j^{\ c} \quad (2)$$

B_j: pull of destination city;

G_i: per capita GDP of destination city;

S_j: population size of destination city;

b c:exponent of the pull;

k_2: adjusting coefficient of the pull.

c. The travel cost—that is the travel resistance. The cost of travel is another important factor affecting residents' travel choice. Residents follow the principle of utility maximization, only getting the greater benefit than the cost of travel, people will choose to travel. In short, the higher the cost of travel, the smaller the probability of travel will be. On the contrary, the greater the probability of travel [10, 11].Residents' travel cost often reflects on the transportation cost, here travel cost is measured by the distance from the generating regions to the destination cities, the farther the distance, the higher the cost of travel. On the other hand, the travel cost is lower. The previous studies on the travel resistance calculation is diversified, this paper chooses the index form as travel impedance function, the specific form is shown as formula 3.

$$f(D_{ij}) = k_3 e^{dD_{ij}} \quad (3)$$

$f(D_{ij})$: travel resistance from city i to city j;

D_{ij}: the distance from city i to city j;

d:exponent of the travel resistance;

k_3: adjusting coefficient of the t Travel resistance.

2.2. Establishment of the Model

The object of study in most of the existing models is the large and medium-sized cities in each traffic areas, but not aimed at analysis of the behavior of the local residents under the background of the open highway service areas. Obviously, the influence degree on residents' travel of the change of the highway network is larger than the change of the road network in large and medium-sized cities. The changes of the economic development in the 2 cases have different degree of impact on residents as well. Therefore, the research on residents travel surrounding service areas is different from previous studies, which needs much deeper analysis. The paper analyzes the influences of traffic journey intensity of residents from the three angles including residents' willingness to travel, destination attraction, traffic resistance, and establish a new model combined with the unconstrained gravity model to predict the traveling intensity. Mathematical expressions of the model is shown as formula (4), and the formula (5) based on the formula (1), (2), (3), (4) is the new model aiming at compute the travel intensity of residents.

$$f_{ij} = k_0 \frac{A_i B_j}{f(D_{ij})} \tag{4}$$

$$f_{ij} = k \frac{G_i^{\ a} G_j^{\ b} S_j^{\ c}}{e^{dD_{ij}}} \tag{5}$$

f_{ij} is stand for the travel intensity from city i to city j; k is the coefficient of gravity, the size is depend on the residents' travel behavior, composition and the developing situation surrounding cities and so on , $k=k_0k_1k_2/k_3$.

2.3. Calibrating Model Parameters

For the newly built or rebuilt road, the traffic data is scarce. This paper chooses the growth-rate method to forecast the amount of travel in the next few years, and then calibrates the gravity model parameter with the predicted data. This approach can not only test the effectiveness and consistency of the two methods, and determine the effect of intensity of various influence factors.

2.3.1. Predicting the Traffic Journey Volume of Future

This measure breaks traffic volume into trend traffic volume, induced traffic volume, and diverted traffic volume [12].Trend traffic volume is formed according to natural growth rules before road reconstruction, induced traffic volume is a part of the induced potential traffic volume formed by the road reconstruction, and the diverted traffic volume is caused by the great changing in road network between different modes of transportation. Transfer traffic volume always predicts with expert consultation method. And the trend and induced traffic volume choose the growth rate method to predict.

Total Traffic Volume = Trend Traffic Volume + Induced Traffic Volume - Transfer Traffic Volume to other road

The growth rate of trend traffic volume is calculated by the elastic coefficient method. According to the analysis of the relevant indicators, usually choose car ownership, passenger transportation and cargo transportation or road traffic volume as transport index, select the gross national product (GNP) as economic indicator, and determine the elastic coefficient of travel by regression analysis.

Due to the fact that the new road will stimulate the changing in the economic potential along the region, the growth rate of induced traffic volume determine by the induced economic model method [13]. Induced economic model is based on the analysis of the

economic potential to get the induced economic coefficient in different regions along the newly built roads before and after the opening to traffic, thus according to the induced economic coefficient to calculate the induced economic growth rate. Economic development potential and accessibility of the economy is correlated positively with the population. The distance between the traffic areas along the road will be shorter, which improves the regional economic accessibility.

2.3.2. Calibrating Model Parameters

The gravity model is transformed to log-linear model by deformation, and this problem is converted into a linear problem strength model directly, then it is effective to use the least square method to estimate the parameters in the model. Use the predicted data for future getting by the growth rate method instead of the historical traffic journey volume, then calculate the unknown parameters in SPSS coupled with the economic index and the transportation index.

3. Analysis of the Sensitivity of Traveling Cost

In addition to the influence of people's income, the residents' willingness to travel is affected by the travel distance. The strength of the residents' willingness to travel is different for different people and different cities. People gaining different income have different sensitivity to the cost of travel. The higher the income, the lower the residents' demand for travel cost and the farther traffic journey distance. On the contrary, the lower the income of the residents' demand, the higher travel cost and the nearer the trip distance [14,15].For example, in high income people, there is a higher proportion which has sufficient willingness to travel than the proportion of low-income people obviously. The reason is that the travel cost is not enough to affect the high income people's choice of travel. The attraction of destinations is more important for the high earners. For this part of people, as long as the city's attraction is enough, no matter how high the cost is, they will choose to travel.

With the increase of people’s income, travel cost in the travel influence factors is less and less important, instead the importance of the travel cost will increase. Introduce a new variable to measure the importance of the cost sensitivity. Cost sensitivity is the sensitive degree of different income residents to travel cost, namely the acceptable cost for different income residents. The higher the cost sensitivity, the smaller the possibility of travel and the smaller travel intensity. The lower the cost sensitivity, the greater the intensity of travel will be. Cost sensitivity and the intensity of travel have negative correlation, and the exponential distribution can describe the relationship well usually using the distance between origin and destination to replace the travel costs.

$$T = \frac{D_{ij}}{I_i} \quad (T > 0) \qquad R(T) = k_4 e^{\lambda T} + m \tag{6}$$

T: the sensitivity of traveling cost;

D_{ij}: the distance between origin i and destination j;

I_i: the annual per capital income of origin i;

R(T):the intensity when the cost sensitivity is T;

k_4、λ、m: the estimated parameters, the size is related to many factors such as the travel behavior, the geographical environment. The value of m can reflect the rigid trips to a certain extent, namely fixed amount of travel. Analysis of cost sensitivity can provide a certain basis to the distribution of traffic flow in four-stage method.

4. Example Analysis

4.1 Traffic Amount Forecast

With a instance of the new highway from Zhaotong to Maliuwan in Yunnan province, the radiation area can be divided into three traffic zones, which are Sichuan, Chongqing and Yunnan. The Travelers by way of Fushui County of Yunnan mainly contain the residents from Sichuan and Chongqing to Yunnan and from Yunnan to Sichuan and Chongqing. In the process of traffic survey, The transport vehicle was divided into three categories which are trucks, buses and cars according to the differences of transport objects and traffic volume. Combined with the related data in the feasibility study report of Zhaoma highway, forecast the trend and induced traffic volume in the radiative zones respectively, and get the predicted traffic volume under the assumptions of not existing the transfer traffic volume.

In the process of forecasting trend traffic volume, car ownership and gross domestic product (GDP) are chosen to determine the elasticity coefficient of vehicle travel in every traffic zones in the future. Due to the national highway 213 and Zhaoma highway all belong to a same channel, the development trend of traffic volume of the national highway 213 for the future is close to zhao ma highway, so this paper combines time series method and elastic coefficient method to determine the growth rate of traffic volume on national highway 213,taking the average value of the result of the two method as the growth rate, and the value can be regarded the growth rate of the traffic volume within the radiation areas of the new highway in the future.

Because of the construction of highway, the interval distance become shortened between the cities along the highway, the economic accessibility is improved around the range, the accessibility of gross domestic product will be enhanced with the increase of the economic accessibility and the population density, and the potential gross domestic product (GDP) will be different. According to the growth potential of GDP before and after the opening to traffic, determine the increase rate of induced travel volume, gain the average traffic growth rate within radiative zones on Zhaoma highways, and the detail is shown as Table 1.Then based on these data and the traffic survey data on national highway 213 someday, predict the trends and induced traffic volume, and the total of this two parts is the total amount of the way(as shown in Table 2.These can be used to calibrate the unknown parameters in the gravity model as some basic data.

Table 1. Traffic Volume Average Growth Rate(%)

Traffic Type	Vehicle Type	2009-2010	2010-2015	2015-2020	2020-2025
Trend Traffic	Passenger Stock (bus and car)	14.68	11	8	5.5725
	Truck	10.1525	8.2675	6.0675	4.76
Induced Traffic	Passenger Stock and Truck	9.544	10.956	8.08	5.95

Table 2. Traffic Summary(pcu/d)

Year	Sichuan to Yunnan	Chongqing to Yunnan	Yunnan to Sichuan	Yunnan to Chongqing
2015	2887	1615	2817	1630
2018	3645	2034	3500	2023
2022	4747	2646	4508	2604
2025	5581	3109	5303	3062

4.2. Calculating Model Parameters

Regard the data in Table 2 as the traffic OD data, and combine with the result of the other methods such time series method about economy developing level(per capita GDP),the convenient degree of transportation(the distance),the population and other relevant data of Yunnan, Sichuan and Chongqing. The model takes advantage of these data as the foundation to evaluate the parameters of model in SPSS software. In order to calculate conveniently, when implementing the trade-off distance, regard the three traffic zones as three points--Kunming, Chongqing, Chengdu, and take the distance of this three points as the travel distance. Model calculation results are as follows:

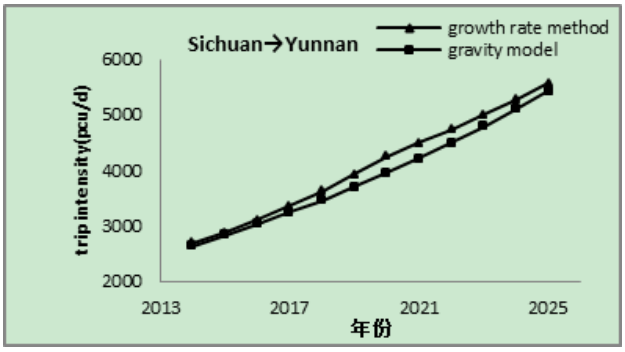
$$f_{Sichuan\to Yunnan} = 0.005 \times \frac{G_{Sichuan}^{0.169} \times G_{Yunnan}^{0.205} \times S_{Yunnan}^{1.616}}{e^{0.005 D_{Chengdu\text{-}Kunming}}} \quad (R^2=0.995)$$

$$f_{Chongqing\to Yunnan} = 0.569 \times \frac{G_{Chongqing}^{0.248} \times G_{Yunnan}^{0.171} \times S_{Yunnan}^{0.422}}{e^{0.00007 D_{Chongqing\text{-}Kunming}}} \quad (R^2=0.995)$$

$$f_{Yunnan\to Sichuan} = 1.421 \times \frac{G_{Yunnan}^{0.256} \times G_{Sichuan}^{0.121} \times S_{Sichuan}^{0.435}}{e^{0.0005 D_{kunming-Chengdu}}} \quad (R^2=0.993)$$

$$f_{Yunnan\to Chongqing} = 0.486 \times \frac{G_{Yunnan}^{0.388} \times G_{Chongqing}^{0.015} \times S_{Chongqing}^{0.45}}{e^{0.00001 D_{Kunming\text{-}Chongqing}}} \quad (R^2=0.999)$$

Selecting per capita GDP of starting point, population of destination city, per capita GDP of destination city and distance from starting point to destination as independent variables, the equation of gravity model was established. Under the condition of 95% the degrees of freedom, the level of significance was less than 0.05,so the model is approved by significant testing. The average error rate of the four groups of data is respectively 4.0382%, 0.0075%, 0.5191%, 0.5519%,and by the size of the R2 value, it can draw the following conclusion: the goodness of fit of the gravity model and the growth rate method is very good, the forecast results of the two ways are consistent and has certain reliability. The four sets of model parameter estimates show that positive correlation exists between three factors including the local residents' per capita GDP, destinations cities' per capita GDP, size of destinations and the intensity of travel, and negative correlation exists between the origin-destination distance and the intensity of travel. The result is consistent with the travel mechanism.



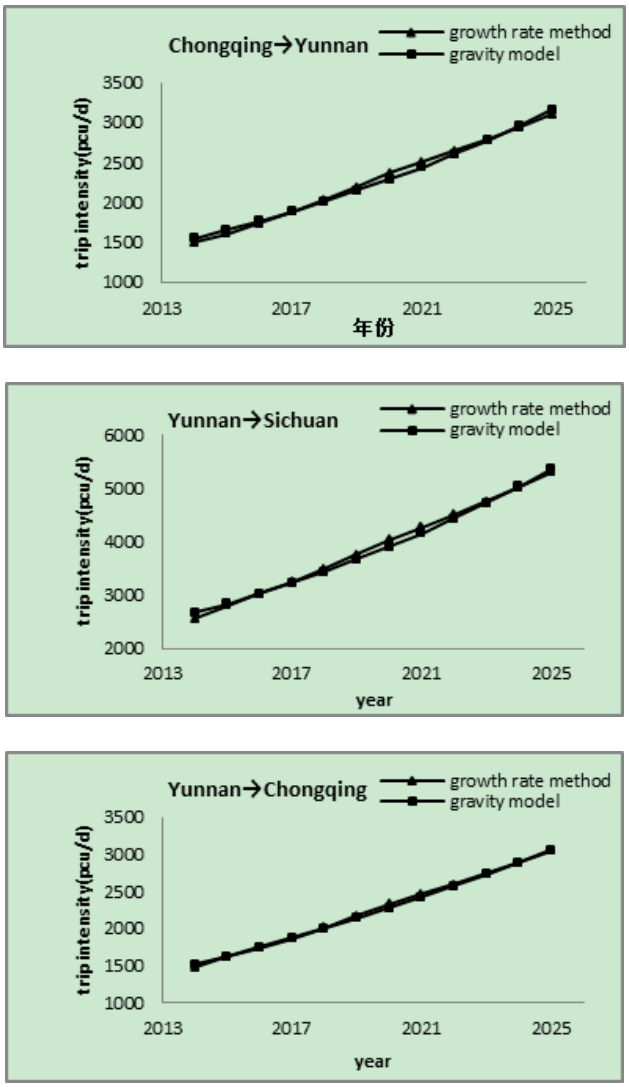


Figure 2. The Predicted Values of Gravitation Model Method and Predicted Values of Increase Method Contrast Diagram

4.3. Analysis of the Cost Sensitivity

Analyze the cost sensitivity from Sichuan to Yunnan, Chongqing to Yunnan, Yunnan to Sichuan. The distribution of travel amount is shown as Figure 3 and the fitting result of exponential relation is shown as Table 3. The analysis results show that the intensity of travel and travel cost sensitivity has significant exponential relation.

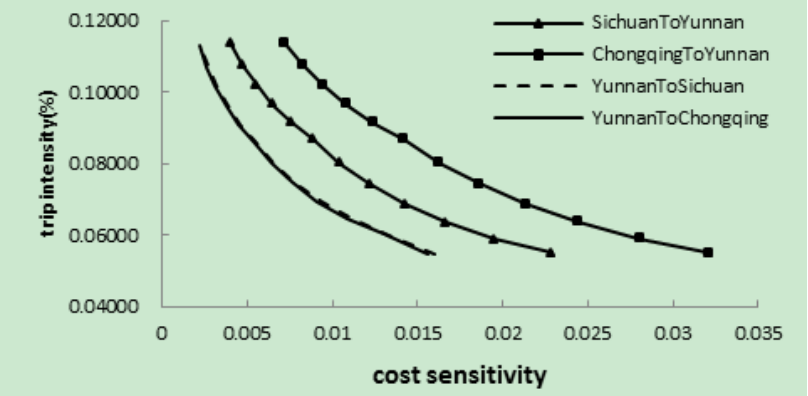


Figure 3. Traffic Journey Intensity Diagram

Table 3. The Relationship between the Sensitivity of Traveling Cost and the Traffic Journey Intensity

	fitting result	Value of R^2
Sichuan To Yunnan	$Y=0.102e^{-105.492T}+0.046$	$R^2=0.999$
Chongqing To Yunnan	$Y=0.116e^{-68.575T}+0.042$	$R^2=0.999$
Yunnan To Sichuan	$Y= 0.09e^{-161.97T}+0.049$	$R^2=0.998$
Yunnan To Chongqing	$Y= 0.09e^{-165.671T}+0.049$	$R^2=0.998$

Note: Y represents the proportion of traffic journey intensity in total intensity and T represents the cost sensitivity.

5. Conclusion

Predicting the travel intensity is one of the focuses and difficulties of transportation planning and engineering. To the situation that the radiation area for expressway is wide and the influence factors of residents' travel are complicated, this paper analyzed the different factors influencing the residents from the perspective of the supply and demand, and established the model of travel intensity combined with these factors. And on this basis, it analyzed the impact of cost susceptibility on residents, which has very strong pertinence and adaptability, and can provide a certain basis for planning the highway and its service facilities.

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Authors

Ying Lin, he is a full professor at the School of Management of Chongqing Jiaotong University currently. In 1983, he received the Bachelor of Engineering in information processing from Xidian University, in 1991 the Master of Engineering in Automatic control form Chongqing University and in 2008 the Doctor of Engineering in computer application from Tianjin University. His research interests include computer application, transportation planning and information management, and Intelligent Transportation System.

Chunmei Zhong, she is a postgraduate student in the department of industrial engineering at school of management, Chongqing Jiaotong University's, where she received the Bachelor degree in information management and information system. Her current research interests include traffic construction integrated system management and Intelligent Transportation System.

Yong Liu, he obtained the Bachelor of Engineering in electronic information science and technology from the Hubei University for Nationalities, in 2007. He received the Master of Engineering in system engineering from Chongqing Jiaotong University, in 2009. Currently, he works as an experimenter in the Management simulation laboratory of Chongqing Jiaotong University. His research interests are in the areas of transportation planning and information management, and Intelligent Transportation System.