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The future demand of transportation in China: 2030 scenario based on a hybrid model

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Abstract

Transportation demand in China has experienced rapid development and transformation in recent years, which has led to enormous energy consumption and environmental emissions. The aim of this manuscript is to construct a hybrid model to forecast future transportation demand in China that combines the advantages of existing methodologies. We first review previous studies to summarise the main categories, advantages and disadvantages, and results of various methodologies for forecasting transportation demand. Based on this review, we develop a hybrid model based on the GDP elastic coefficient method, which uses the mode split method and vehicle population method and includes three modules: the vehicle population module, the passenger traffic module and the freight traffic module. Using this model, a forecast of transportation service demand in China in 2030 is derived and compared with other studies. According to the results, vehicle ownership, passenger transportation demand, and freight transportation demand will continue to experience rapid growth. The total traffic volume, the share of aviation in passenger traffic and the share of water in freight traffic are very sensitive to the GDP growth rate.

Keywords: transport; demand; model

1. Introduction

Driven by economic growth, the total transportation demand in China is growing rapidly, and the transportation mode is rapidly becoming more high speed, convenient, and comfortable. From 1978 to 2009, the

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intercity passenger traffic volume per capita in China increased from 190 person-kilometres (pkm) per annum to 1860 pkm per annum, for an average annual growth rate of 7.5%. The freight traffic volume per capita increased from 1030 tonne-kilometres (tkm) per annum to 6038 tkm, for an average annual growth rate of 5.9%. For transportation, the share of the highway in intercity passenger traffic volume increased from 12% to 54%, whereas the share of the railway decreased from 63% to 32%. The railway share in freight traffic volume decreased from 73% to 31%, and the water share increased from 18% to 22% (NBSC, 2010).

In recent years, China's rapidly increasing transportation demands have produced enormous new energy demands, especially for oil. From 2000 to 2009, the oil consumption of the transportation sector increased by an average of 8.4% annually and reached 185 million tonnes in 2009 (DESNBS and DGANEA, 2010). With limited domestic oil supply due to the lack of oil resources in China, increasing amounts of oil are imported to satisfy this demand. In 2009, the oil importing dependency of China surpassed 50%, creating energy security concerns for the entire country. The increasing oil consumption of the transportation sector also produced serious environmental issues, such as increasing conventional emissions and greenhouse gas (GHG) emissions.

Therefore, it is important to explore the future energy demand of China's transportation sector in light of energy security and environmental protection. To forecast the future energy demand of the transportation sector, a "Two-step Method" is commonly used. The first step is estimating transportation service demand, and the second step is estimating energy consumption intensity. Energy demand is then derived by combining the results of the two steps. By comparing previous studies, we found that the forecasting results of China's transportation energy demand varied greatly. The major reason for this variance is the difference in the intermediate results for the transportation service demand.

This paper aims to review the methodology for forecasting transportation service demand and to construct a hybrid model that combines the advantages of existing methodologies and can be used to forecast China's transportation service demand. The main content is organised as follows:

1) Section 2 presents a literature review of previous work;
2) Section 3 presents the methodology and database of the hybrid model;
3) Section 4 presents the results and discussion.

2. Literature Review

There are two broad categories of methodologies for forecasting transportation service demand. One involves vehicle population methods, which are used to forecast highway transportation service demand, and the second involves mode split methods, which are used for forecasting total traffic demand.

2.1. Vehicle population methods

For vehicle population methods, the first step is to forecast vehicle population, and the second step is to forecast average vehicle mileage travelled per annum by vehicle type. The traffic volume of road transportation is then obtained by multiplying the vehicle population and the mileage travelled.

2.1.1 Forecasting vehicle population

To forecast vehicle population, vehicle ownership is determined and then multiplied by the forecasted population. Mogridge (1983) introduced several models to forecast vehicle ownership, including the time series model, the durable consumer goods model, the linear regression model, the data decomposition model, and the survival curve model. His work presented the crucial position of the S-shape curve in forecasting vehicle ownership. Qian (2005) further emphasised the suitability of the S-shape curve in forecasting vehicle ownership through his analysis of the relationship between car ownership and economic growth.

Based on the S-shape curve, two main kinds of vehicle population methods have been used in previous research: 1) the Gompertz model and 2) the GDP elastic coefficient method.

The Gompertz model is widely used in vehicle ownership forecasting. The equation is as follows:

$$v = \gamma e^{\alpha \exp(\beta y)} \quad (1)$$

——v is the vehicle population per capita
——y is the income per capita
——γ is the saturation level
——α and β are negative parameters used to describe the shape of the curve

For example, Wang (2005) used the Gompertz model to assess the nonlinear relationship between car ownership and GDP per capita and to examine the time-series regressions of individual countries and the cross-sectional regressions of representative countries as a whole. This study concluded that the Gompertz model can describe developing patterns of car ownership at the country level worldwide.

However, the Gompertz model has disadvantages: the saturation level is normally derived from international comparison, and it is difficult to prove that the saturation levels of different countries are the same.

The GDP elastic coefficient method is an improvement over conventional S-shape curve methods:

$$\log\frac{VP}{cap} = e \cdot \log\frac{GDP}{cap} + f \quad (2)$$

——VP is the vehicle population
——cap represents per capita
——GDP is the gross domestic production
——e is the elastic coefficient
——f is the intercept

Several studies have adopted this method to forecast vehicle ownership. He et al. (2005) used this method to forecast the Chinese car population. Kobos et al. (2005) utilised historic data on Japan, Korea, and Taiwan to obtain a logistic growth curve to capture growth trends and the saturation level, which is a supplement to the conventional elastic coefficient model.

However, GDP elastic coefficient method has problems similar to the Gompertz model: the results are dependent on the setting of the GDP elastic coefficient, which is commonly derived from international comparison, and it is difficult to prove a fit with the target country.

In addition to methods based on the S-shaped curve, two other kinds of methods are commonly used in forecasting the vehicle population, as follows: 1) sales with the survival rate method and 2) the income structure method

Sales with the survival rate method forecast vehicle population using new vehicle sales and the survival rate of existing vehicles. Ou (2010) forecasted China's vehicle ownership using this method. In that study, the growth rate of new vehicle sales was set according to governmental policies and the economic growth trend, and the vehicle survival rate was calculated based on statistical data. The mobility model developed by IEA (2009) adopted a similar method. This method is independent of international comparison but has other problems, such as the difficulty of determining data on new vehicle sales.

The income structure method emphasises the influence of the civilian income structure on vehicle ownership. CAERC (2011) developed a forecasting model for the passenger vehicle population based on the civilian income structure. They assumed that the ownership of passenger vehicles varies by income level, and economic growth directly changes the structure of civilian income and influences the ownership of passenger vehicles. Although this method avoids using historic data from other counties and considers the importance of income level, it is difficult to forecast the civilian income structure or the relationship between income level and vehicle ownership.

Because these methods all have limitations, the forecasting result for the vehicle population in China varies significantly, as shown in Table 1.

Table 1 The forecasting results of previous studies of vehicle population

Source	Summary of the results
Wang (2005)	In 2020, the vehicle population in China will be 326 million
Kobos et al. (2003)	In 2025, the passenger vehicle population in China will be 64 million in the low-growth scenario, 92 million in the medium-growth scenario, and 125 million in the high-growth scenario
CAERC (2011)	In 2030, the vehicle population in China will be 440 million, of which 400 million will be passenger vehicles
Ou (2010)	In 2030, the vehicle population in China will be 338 million

2.1.2 Forecasting vehicle mileage

The methods for forecasting vehicle mileage include direct methods and indirect methods.

The direct methods utilise travel features to directly forecast the average mileage. For example, the forecast model of IEA (2009) is based on the non-linear relationship between average vehicle mileage travelled, travel cost, and income. CAERC (2011) developed a model based on citizen travel features. They assumed that the average mileage travelled by private passenger vehicles would decrease because of the development of public transportation in China, whereas the distance travelled by public transportation vehicles and other vehicles was relatively fixed. Generally, the use of travel features is rational, but problems arise, such as the uncertainties of some parameters and assumptions of travel features.

The indirect methods utilise related data to indirectly calculate the vehicle mileage. For example, He et al (2005) used an equation of total traffic volume, volume share, average load capacity, and actual load rate for each vehicle type. Because their method must set many parameters, the calculation adopted data from the literature referring to different studies, which may lead to inaccuracy.

2.2. Mode split methods

When the subjects of a study are the total traffic volume and the share of each transportation mode, mode split methods are commonly used. Two types of mode split methods are used in previous studies: aggregation methods and split methods. For the former, the total traffic volume of each mode is forecasted separately. For the latter, the total traffic volume is forecasted and then split into each mode.

One example of aggregation methods is the model developed by Zhang (2007), which is based on travel budget. A representative citizen is assumed to have representative hobbies, features, average time, and average money for travel. He uses a fixed ratio of time and money to maximise intra-city travel and utilises the remaining time and money to maximise intercity travel. However, the disadvantages of the model are the lack of consideration of transportation supply and the uncertainties of travel cost for each mode.

For the split method, the main difficulties are how to obtain the total traffic volume and how to divide the total volume into each mode. Schafer and Victor (2000) derived the regression function of passenger traffic volume with the GDP through his observation of 11 districts worldwide and then determined the share of each mode using regression functions and a balance equation. Zhang (2007) used an econometric equation to derive the total freight traffic volume. His method was later referenced by CCTA (1999), Hu and Jiang (2001), Zhou (2003), and Skeer and Wang (2007).

Due to the use of different methods and the limitation of these methods, the forecasting results based on model split methods also vary significantly, as shown in Table 2.

Table 2 The results of previous studies based on model split methods

Source	Object	The total traffic volume	The shares of different modes
Zhang (2005)	Passenger transportation	In 2032, 5.22 trillion pkm with constant energy price, 4.93 trillion pkm with changeable energy price	In 2032, non-motorised modes 50%. For motorised modes: car 14%, bus 15%, aviation 10%, railways 21%
Schafer and Victor (2000)	Passenger transportation	In 2050, 10.8 trillion pkm in China and Mongolia	In 2050, non-motorised modes 50%. For motorised modes: railway 5%, bus 30%, car 15%
Zhang (2005)	Freight transportation	In 2032, 12 trillion tkm	In 2032, railway 30%, highway 35%, water 25%, aviation 1.5%
Zhou (2003)	Passenger transportation	In 2020, 5.03 trillion pkm	In 2020, railway 32%, highway 56%, water 1%, aviation 11%
	Freight transportation	In 2020, 10 trillion tkm	In 2020, railway 32%, highway 16%, water 50%, aviation 0.2%

3. Methodology and database

Based on the literature review, we attempt to develop a hybrid model to combine the advantages of different methods. Because our purpose is to forecast the total traffic volume and the share of each transportation mode, we use the mode split method as the basic framework and the GDP elastic coefficient method as the basic method for forecasting due to its wide application and good data availability. Furthermore, given the dominance of the road transportation sector in the energy consumption and emissions of the transportation sector, we apply the vehicle population method to improve the technical accuracy of highway transportation forecasting. The hybrid model is composed of 3 modules: 1) the vehicle population module; 2) the passenger traffic module; and 3) the freight traffic module. The vehicle population module is developed to determine the vehicle population, and then it is used as an input for the module of passenger traffic and freight traffic. In the following, we briefly introduce the calculation procedure and equations of the three modules and the relative database.

3.1. Vehicle population module

The calculation procedure of the vehicle population module is illustrated in Figure 1. In this module, the passenger vehicle population, bus population, and truck population are first derived by the GDP elastic coefficient method (Equation (2)). Then, the total annual distance travelled by each type is obtained using the data on average vehicle mileage travelled in the literature (He et al, 2005) and the result of vehicle population forecasting (Equation (3)).

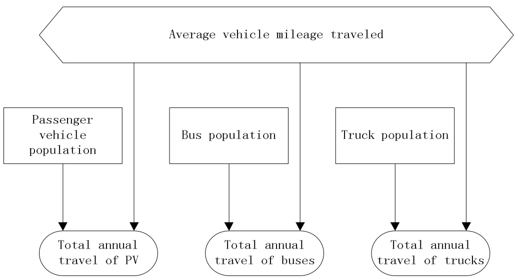

Figure 1 The calculation procedure of the vehicle population module

$$TD = VP \cdot DT \tag{3}$$

——VP is the vehicle population
——TD is the annual total distance travelled
——DT is the average vehicle mileage travelled

3.2. Passenger traffic module

The calculation procedure for this module is illustrated in Figure 2(a). The total traffic volume of intercity passenger transport and the share of railway transport are obtained by the GDP elastic coefficient method (Equations (4) and (5)). The passenger traffic volume of the road sector is derived based on the total annual distance travelled by buses, which is obtained from the vehicle population module. Here, hypothesis A is adopted: the passenger traffic volume of the intercity highway transportation is directly proportional to the total annual distance travelled by intercity buses. Then, by assuming the share of water to be fixed (because it is quite small), the share of aviation is finally obtained as the residual.

$$\log\frac{TV}{cap} = e \cdot \log\frac{GDP}{cap} + f \tag{4}$$

$$S_R = e \cdot \log\frac{GDP}{cap} + f \tag{5}$$

$$TV_{B,j} = \frac{TV_{B,0} TD_{B,j}}{TD_{B,0}} \tag{6}$$

——TV represents the total traffic volume
——S_R represents the share of railways
——TV_B represents the passenger traffic volume of the intercity service road sector
——TD represents the total annual distance travelled by buses
——j represents the observed year, and 0 represents the base year

3.3. Freight traffic module

The procedure for this module is illustrated in Figure 2(b). The total traffic volume of freight transport and the share of railways are obtained by the GDP elastic coefficient method (Equations (4) and (5)) similar to the passenger traffic module. The traffic volume of the road sector is derived from the total annual distance travelled by trucks, which is obtained from the vehicle population module (Equation (7)). Hypothesis B is adopted: the freight traffic volume of the road service sector is directly proportional to the total annual distance travelled by trucks. Then, by assuming a fixed share of aviation (because it is quite small), the traffic volume of water is finally obtained as the residual.

$$TV_{T,j} = \frac{TV_{T,0} TD_{T,j}}{TD_{T,0}} \tag{7}$$

——TV_T is the freight traffic volume of the road service sector, j is the year, and 0 is the base year
——TD represents the total annual distance travelled by trucks

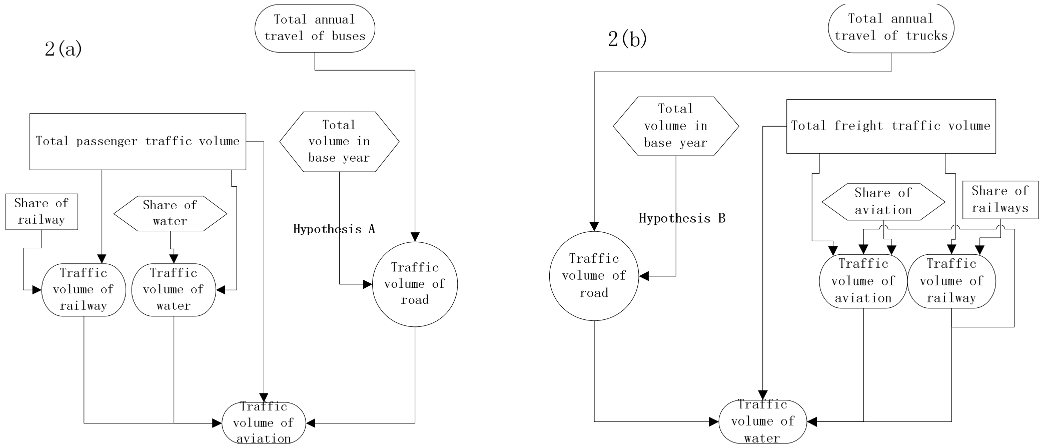

Figure 2(a) The calculation procedure of the passenger traffic module; (b) The procedure of the freight traffic volume module

3.4. Database

We set 2010 as the base year and prior to 2030 as the forecasting period. The annual growth rate of the GDP is set at 7% from 2010 to 2020 and 5% from 2020 to 2030. The annual population growth rate is set as 0.45% before 2030 (CAE, 2011). The GDP elastic coefficients are obtained through international comparison. Because Japan and Korea are neighbours of China, have a population density similar to China, and are newly industrialised countries representing the most recent development patterns in transportation, we use their historical data to derive coefficients for the forecasting. The average vehicle mileage travelled is based on the literature (He et al, 2005)

4. Results and discussions

4.1. Forecasting results

The results show that vehicle population in China will increase from 65 million in 2010 to 294 million in 2030, with an average annual growth rate of 11%. The passenger vehicle population will increase from 48 million to 240 million, and sharing will increase from 70% to 82% of the total by 2030. There will be 13.7 million buses and 39.5 million trucks, constituting 5% and 13% of the total, respectively. These numbers will represent increases of 6.3 million (9%) and 14.47 million (21%), respectively, over the numbers in 2010. Vehicle ownership will reach 200 per thousand people and passenger vehicle ownership will reach 164 per thousand people, equivalent to the levels in Japan in 1978. The total vehicle population forecasted by this model is compared with previous studies in Figure 3. As shown, the results from this paper are slightly conservative because of the conservative context of the GDP growth rate.

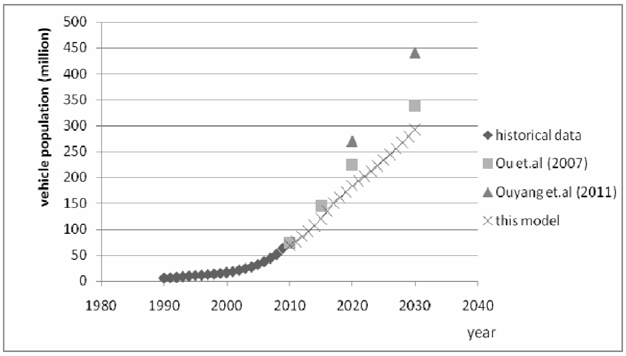

Figure 3 Comparison of the results to historical data and previous research

For intercity passenger transportation, the total traffic volume in 2030 will be 7.59 trillion pkm, 2.8 times the volume in 2010. The share of railways will decrease from 32% to 28%, the share of aircraft will increase from 13.6% to 30%, and the share of highways will decrease from 54% to 42%.

In 2030, freight traffic volume will be 22.7 trillion tkm, 1.9 times the volume in 2010. The share of railways will decrease from 30% to 19%, the share of water transport will increase from 23% to 33%, and the share of highways will slightly increase to 48%.

The results indicate that the current increasing trend in transportation volume and mode transition will continue in the future, driven by economic and population growth. In intercity transportation, more passengers will choose higher-speed and more comfortable transportation, such as cars and aircraft, instead of railways and buses, which are relatively lower-speed and less comfortable. In freight transportation, water will replace railways to a certain degree, partly due to the low cost and high capacity of water transport.

4.2. Sensitivity analysis

Considering the importance and uncertainty of the GDP growth rate for the results, a sensitivity analysis was conducted. Figures 4(a) (on the left side) and 4(b) (on the right side) illustrate the impact of the GDP growth rate on the traffic volume of each mode measured by the percentage change when the annual GDP growth rate changes by -10%, -5%, 5%, and 10% of the current number.

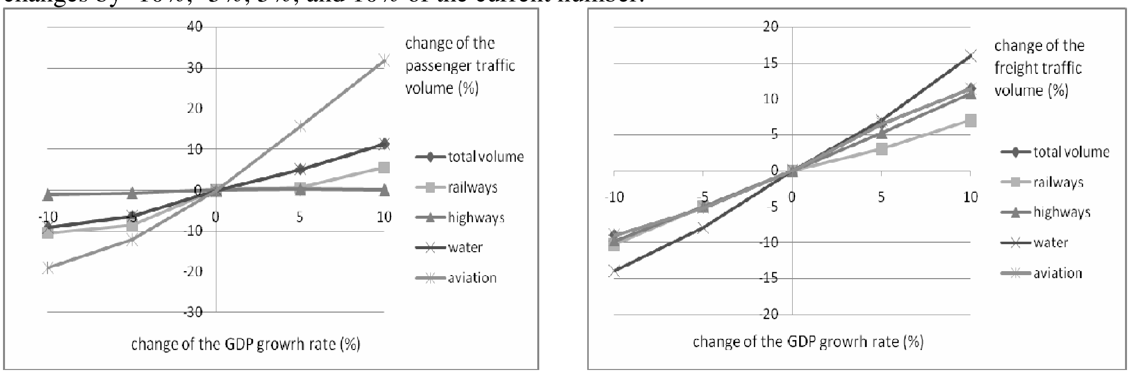

Figure 4(a) Sensitivity of the intercity passenger traffic volume to the GDP growth rate; (b) Sensitivity of the freight traffic volume

Referring to Figure 4(a), the share of aviation is most sensitive to the GDP growth rate in intercity passenger transport. This result is reasonable because high income is a decisive factor when deciding to take an aircraft.

Referring to Figure 4(b), the share of water transport is the most sensitive area of freight transport. This result is also reasonable. Because water transport is the cheapest mode of freight transportation, if the total traffic volume soars, users will turn to water to pay less.

4.3. Uncertainty analysis

Because of the wide application and easy operation of the GDP elastic coefficient method, it was chosen as the basis for this model. However, the results are strongly dependent on the context of the GDP elastic coefficient, which is derived from the international comparison. Therefore, whether the coefficient is suitable for China is questionable. A more advanced method is expected to make the forecast more convincing.

Two important hypotheses are used in the model. One is that the passenger traffic volume of the intercity service road sector is directly proportional to the total annual distance travelled by buses, and the second is that the freight traffic volume of the road service sector is directly proportional to the total annual distance travelled by trucks. These hypotheses may not be consistent with the actual situation. Improvements will be required in future studies; for example, considering the average load capacity may make the hypotheses more realistic.

5. Conclusions

In this work, we review existing methodologies and their applications for forecasting transportation demand. By combining the advantages and disadvantages of various methods, we construct a hybrid model based on the GDP elastic method to forecast future transportation demand in China, including the total traffic volume of intercity passenger transportation and freight transportation and the shares of four transportation modes: highway, railway, aviation and water. The model uses the model split method as the basic framework and adds the vehicle population method to more accurately forecast the demand for road transportation. Using this model, we forecast the 2030 situation of transportation demand in China. The results show that the current increasing trend of total transportation demand and mode transformation is likely to continue. The total transportation demand, the share of aviation in passenger traffic and the share of water in freight traffic are very sensitive to the GDP growth rate.

Due to the uncertainties of future transportation demand in China identified in this study, we suggest that future studies should improve the model. For example, methods in addition to the GDP elastic coefficient should be considered, and the average load capacity of road transportation deserves further examination.

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