Journal of Transportation Technologies, **2012, 2, 267-276**
http://dx.doi.org/10.4236/jtts.2012.23029 Published Online July 2012 (http://www.SciRP.org/journal/jtts)

Modeling Motorization Development in China

Junlei Wang[1,2], Xiaoduan Sun[1,2], Yulong He[1,2], Shuzhan Hou[1,2]
[1]Transportation Research Center, Beijing University of Technology, Beijing, China
[2]University of Louisiana, Lafayette, USA
Email: junleicn@sina.com, xsun@louisiana.edu

Received April 16, 2012; revised May 14, 2012; accepted May 29, 2012

ABSTRACT

Entering the 21st century, China's economic development has reached new heights and the country has ascended to the world's second largest economy. The 20 year unrelenting development in China also stimulates income growth. The increased disposable income enables an ordinary Chinese family vehicle ownership which was unthinkable two decades ago. The most populous country has started a love affair with automobile just like in the United States. Annual automobile sales in China rose from 2.1 million in 2000 to 18.1 million in 2010 with a yearly growth rate of 24.3%, which spurs the vehicle ownership increase from 18.1 million in 2000 to 78.8 million in 2010, a growth rate of 15.9% The unprecedented motorization development in China is making a huge impact on all aspects of society, including negative consequences that cannot be ignored. Traffic congestion, air pollution, and dependency on imported oil are huge emerging problems threatening Chinese sustainable development. Although these problems occurred and still exist in many other developed and developing countries, they are more acute in China today. By collecting and analyzing the massive data from various sources, this paper explores the relationship between economic development and level of mobility by studying the historical developments from several developed counties and discusses the key issues in Chinese motorizetion development. The objective of the study is to predict the future level of motorization and its potential impacts.

Keywords: Motor and Society; Motorization; Gompertz Growth Function; Vehicle Ownership; Per Capita GDP; GDP Elasticity; Forecast

1. Introduction

Entering the 21st century, China's economic development has reached new heights and the country has ascended to the world's second largest economy. Based on published statistics, GDP growth in China has remained above 8% from 2000 to 2010, which is from 1203.0 billion US Dollars (current value) in 2000 to 5848.8 billion US Dollars (current value) in 2010 based on the China Statistic Bureau [1,2] as shown in **Figure 1**. At the same time, per capita GDP increased from 949.2 US Dollars (current value) in 2000 to 4382.0 US Dollars (current value) 10 years later. China has reached the category of middle-low income countries from low-income countries.

Since the 1990s, China has accelerated transportation development. After more than 20 years of construction, the national roadway infrastructure has emerged as one of the largest highway transportation systems in the world. By the end of 2010, total roadway mileage reached 4.0 million kilometers and national highway density is 41.75 kilometers/100 square kilometers. Freeway mileage has reached 74.1 thousand kilometers in 2010, as shown in **Figure 2**. Total road mileage and total freeway mileage rank second in the world following the United States.

The unrelenting 20 year development in China also stimulates income growth. The increased disposable income enables an ordinary Chinese family vehicle ownership which was unthinkable two decades ago. The most populous country has started a love affair with automobile just like in the United States. In recent years, the growth momentum in automobile sales seems unstoppable. Annual automobile sales rose from 2.1 million vehicles in 2000 to 18.1 million vehicles in 2010 with a yearly growth rate of 24.3%, which spurs the vehicle ownership increase from 18.1 million in 2000 to 78.8 million in 2010 with a growth rate of 15.9%, as shown in **Figure 3**. The number of vehicles per 1000 people rose from 12.7 in 2000 to 60 in 2010 resulting in an annual growth rate of 16.6%. Only passenger cars and comercial vehicles are considered as vehicles in all statistics cited by this paper. Motorcycles and three-wheeled vehicles are not counted.

After China became number one in the world in annual automobile production and sales in 2009, another milestone was reached when more than 18 million vehicles were sold in 2010, a 32.3% increase from the last year's

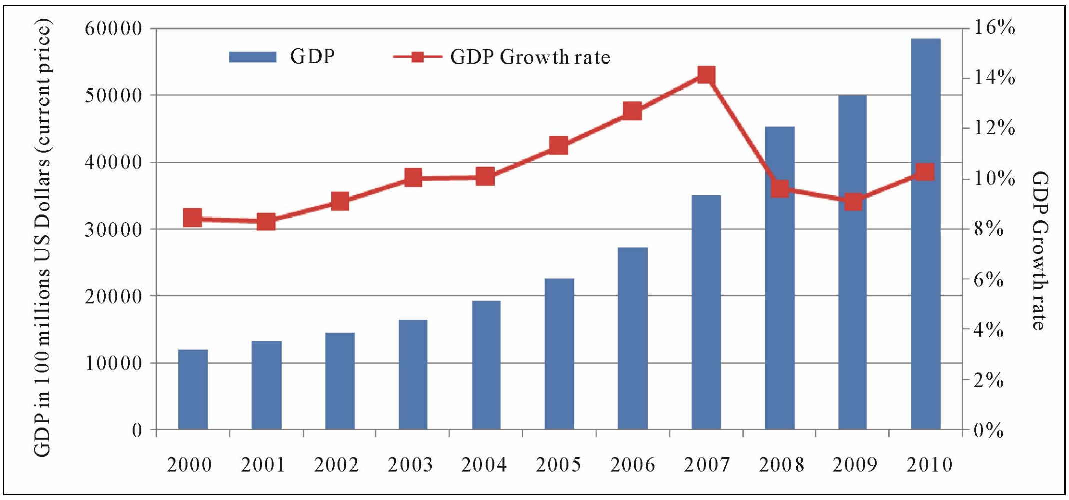

Figure 1. Annual GDP and GDP growth rate in China.

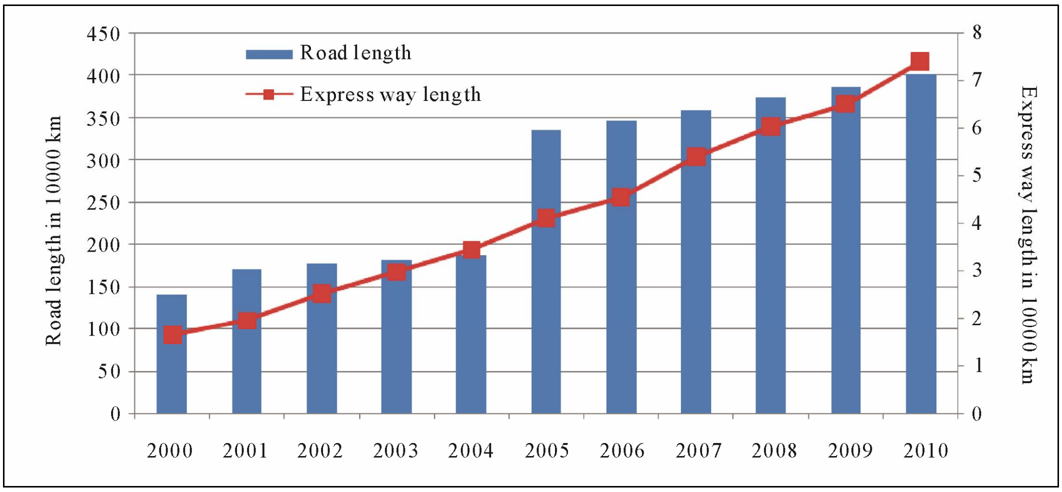

Figure 2. Length of roadway and expressway in China by year based on China statistic bureau [1] and ministry of transport of the people's republic of China [3].

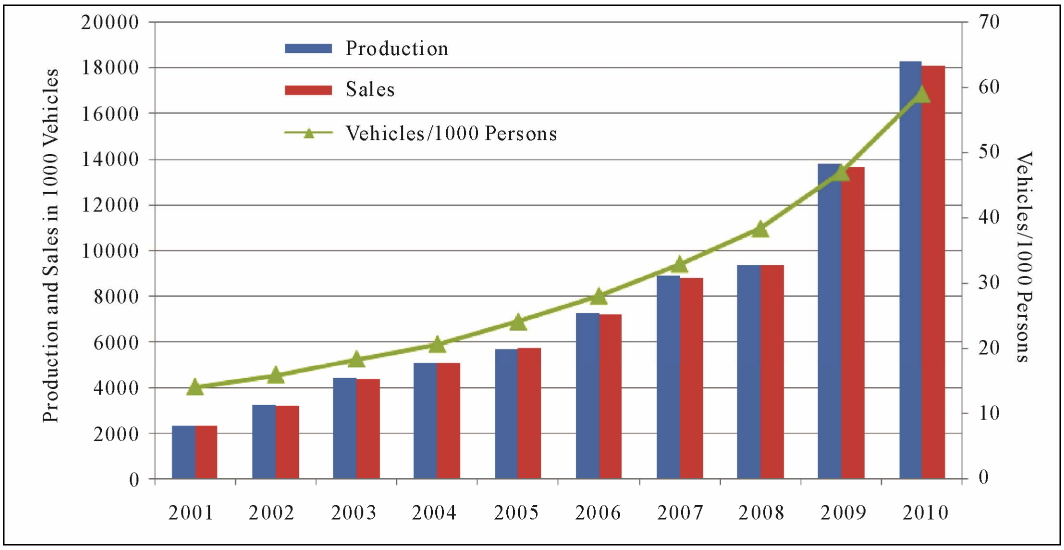

Figure 3. Automobile production and sales of China by year based on China automotive technology and research center [4].

record. Considering the vehicle ownership rate (number of vehicles per 1000 people) is still 10 to 20 times lower than the rates of Japan and United States, as shown in **Table 1**, this demonstrates a great potential for future motorization development in China.

2. Economic Development and Level of Mobility

Several studies were conducted on the motorization development in China in the past, which can be summarized in three groups based on the methodology. The first group uses the linear regression to model the motorizetion process in China [5], which has very limited applications since the relationship between influential variables and level of motorization is basically not linear. The second group models the situation by system dynamic model, which is only suitable for short-term mobility development prediction such as the GM automobile market prediction model and State Information Center of China automobile market prediction model [6]. The third group utilizes Gompertz model [7-9] for the long-term prediction as in this study. Previous studies in this group used the data before 2009, which did not account for the spike in vehicle ownership in 2010. For instance, the maximum vehicle ownership in 2020 predicted by previous studies is 0.15 billion. But it is certain now that this number will be reached in 2015.

Automobiles are considered durable goods and the consumption of the good is closely related to the level of per capita income. Based on studies from Dargay, Qi, Wang, the World Bank, and International Road Federation [4,7-10], the development experience of many developed countries shows that a higher level of per capita income always stimulates a higher vehicle ownership rate, as shown in **Figure 4**.

According to **Figure 4**, the positive increasing trend between per capital income and level of motorization is not simply a linear form but rather an S-shaped curve. The demand for automobiles can be seen in four stages; in stage 1, vehicle ownership increases slowly as income increases; vehicle ownership increases fastest in stage 2

Table 1. Vehicles per 1000 population from selected countries.

Year	Japan	USA	Germany	France	Brazil	China	World
2005	592	683	597	596	124	24	137
2006	594	829	530	598	128	28	140
2007	593	833	533	598	136	33	143
2008	591	822	536	598	143	38	145
2009	578	817	544	601	154	47	144

Source: World motor vehicle statistics-2011 [10].

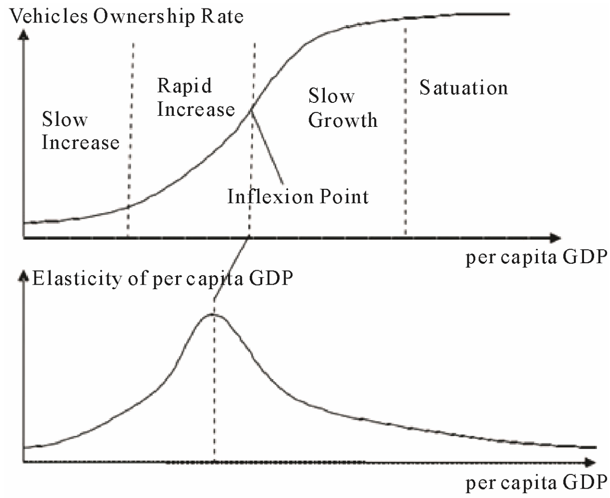

Figure 4. Relationship between economic development and level of mobility.

with increasing income; and the rate of increase slows down in stage 3 followed by a stable state in stage 4 when vehicle ownership no longer increases as income increases. Since the motorization process is similar to the Gompertz growth function curve, the Gompertz model [4,7] was used in this study to model the relationship between economic development and the level of mobility.

Letting V denote the long-run equilibrium level of the vehicle/population ratio, and G denote per-capita income, the Gompertz model can be written as:

$$V(G) = \gamma e^{\alpha e^{\beta G}} \quad (1)$$

where: γ is the saturation level, α and β are negative parameters.

Taking the logarithm on both sides twice, the model becomes:

$$\text{In}(\text{In}\gamma - \text{In}(V)) = \text{In}(-\alpha) + \beta G + \varepsilon \quad (2)$$

The elasticity of the vehicle/population ratio with respect to per-capita income is defined as:

$$\eta = \frac{Ey}{Ex} = \lim_{\Delta x \to 0} \frac{\Delta y / y}{\Delta x / x} = \lim_{\Delta x \to 0} \frac{\Delta y}{\Delta x} \frac{x}{y} = f'(x) \frac{x}{y} = f'(G) \frac{G}{V} \quad (3)$$

Since

$$f'(G) = \frac{\mathrm{d}(V)}{\mathrm{d}(G)} = \beta \alpha e^{\beta G} \gamma e^{\alpha e^{\beta G}} = \gamma \alpha \beta e^{\beta G} e^{\alpha e^{\beta G}} \quad (4)$$

The elasticity can be written as:

$$\eta = \gamma \alpha \beta e^{\beta G} e^{\alpha e^{\beta G}} \frac{G}{\gamma e^{\alpha e^{\beta G}}} = \alpha \beta G e^{\beta G} \quad (5)$$

By taking derivative of the Equation (5) with respect to G and letting it be 0, we can identify the inflexion point where the elasticity is at maximum:

$$G_{\text{InflexionPoint}} = -1/\beta \quad (6)$$

By using the data from eight countries, the United States, Japan, France, Britain, Italy, Brazil, India and China, the relationship between ownership rate and per capita GDP is developed. The γ value for developed countries is the maximum value of the vehicles/1000 population. Because developing countries have bigger populations than developed countries, the vehicle ownership saturation generally is lower than developed countries, which results in a γ value of 333 (1 vehicle/3 persons). **Table 2** lists the result of regression modeling. The value of R^2 is bigger than 0.8. The last column of the table lists the F value used for model inspection. It is demonstrated that most countries' long-term relationship between ownership rate and per capita GDP is similar to the average development curve, which is derived in Equation (7). The GDP Elasticity Inflexion point is $4626.

$$V(G) = 557e^{-1.92852252e^{-0.00021619G}} \quad (7)$$

Figure 5 shows that the curve basically fits to the curves derived for the majority of the countries.

3. Economic Development and Highway Construction

Unlike vehicle ownership, highway infrastructures are public property managed by governments at different levels. The size of a highway network is closely related

Table 2. Regression result.

Countries	γ	α	β	R	F	GDP elasticity inflexion point (USD)
U.S.A.	829	–0.76304634	–0.00009398	0.908	206.988	10,641
Japan	593	–1.92095842	–0.00010639	0.881	128.432	9399
France	597	–1.52758916	–0.00014423	0.886	149.729	6933
U.K.	575	–1.46723562	–0.00013075	0.947	354.555	7648
Italy	668	–2.25896832	–0.00018335	0.841	99.326	5454
Brazil	333	–2.26956154	–0.00016990	0.820	89.721	5886
India	333	–0.55660547	–0.00086406	0.950	381.877	1157
China	333	–4.65366855	–0.00025840	0.932	204.452	3870
Average	557	–1.92720418	–0.00024388	-	-	4100

Note: The data for U.S.A. and Japan are from 1960 to 2005, the data for China is from 1978 to 2010, the data for other countries are from 1963 to 2005.

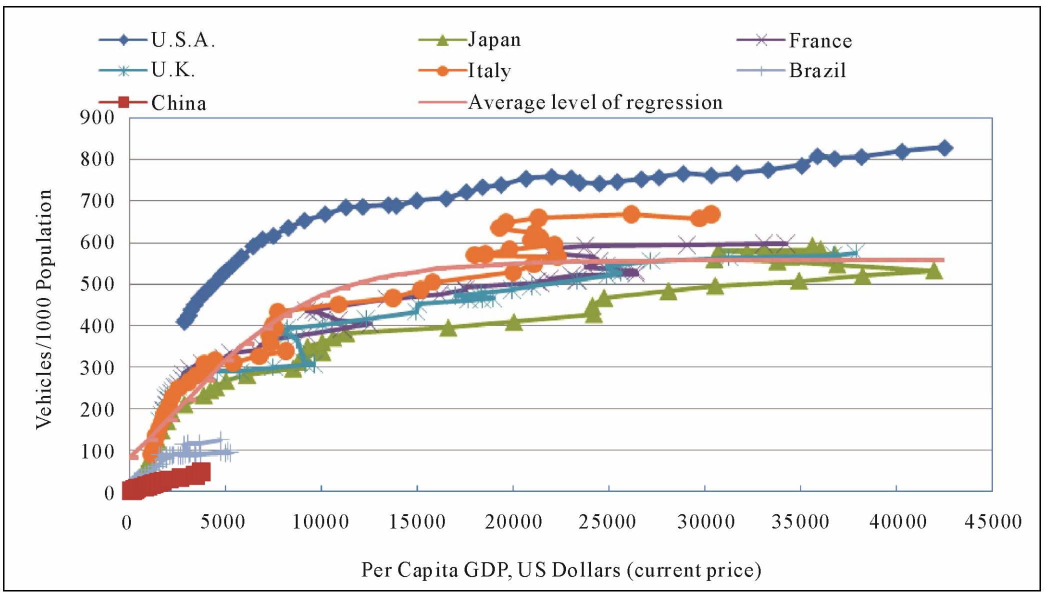

Figure 5. Relationship of per capita GDP and vehicles/1000 population in selected countries (Source: references [11,12]).

to a country's territory, economic development, population, income and population density. Generally speaking, a country's highway infrastructure is not as closely related to the economic development as its motorization [13]. **Figure 6** illustrates the data collected by this study from I.R.F. World Road Statistics [12], which shows the size of highway infrastructure remains constant after economic development reaches a certain level based on the developed country's history. Highway mileage still increases as economic development increases in developing countries. Since rural highway system development generally keeps pace with the country's economic development, excessive and persistent traffic congestion would not occur on highways outside urban and suburban areas.

The relationship between economic development and highway infrastructure development is different in urban and suburban areas. Because of the high population density and high construction costs, the impact of economic development on urban roadway infrastructure is smaller than it is on vehicle ownership in metropolitan areas. The increase rate of roadway infrastructure is generally slower than the rate of population growth while the demand for vehicle travel grows much faster than the rate of roadway construction. Additionally, lack of efficient traffic management strategies in restricting car use, rapid construction of high-rise residential units, and insufficient public transport services have all contributed to traffic congestions in most urban areas of China.

4. Predicting Future Motorization Development

In order to predict the future of motorization development in China, it is important to review the history of some developed countries' developments. For that purpose, **Figure 7** was created to show the relationship between the elastic coefficient defined by Equation (5) and per-capital GDP. In general, the lower level of motorization, the higher influence of GDP, as in China and Brazil. It is also clear that the higher level of economic development correlates to the higher GDP elasticity inflexion point. Although the Chinese economy rose sharply in recent decades, its GDP per capita still lags far behind the GDP per capita in developed countries as well as its automobile ownership. From the regression results, the GDP elasticity inflexion point for China is 3870 US Dollars (current value). By 2010, China's per capita GDP was about $4382, right on the inflexion point. In 2009 and 2010, in order to deal with the international financial crisis, the Chinese government developed a plan to adust and rvitalize the Chinese auto industry with four trillion dollar investment projects, The plan greatly stimulated the consumption of automobiles. The growth of automobile market is obviously higher than the GDP growth rate, which results in a higher elasticity peak value. In that perspective, it is reasonable to claim that the Chinese auto market is shifting from stage 2 to stage 3. The inflexion point happened in the United States in the year 1979, Japan in the year 1981, France in the year 1979, U.K. in the year 1980, Italy in the year 1979, Brazil in the year 2009, and India in the year 2006. It is interesting to see that most developed countries reached the inflexion point in and around 1970's, and developing countries reached the inflexion point in and around 2010.

Macroscopically speaking, vehicle ownership affect by the elasticity of GDP will lessen after 2011, and the Chinese auto market will enter a slower growth time period. However, due to the ever increasing oil prices in the world, road congestion, insufficient traffic management and policies, motorization in China presents a huge challenge to society in many aspects.

Many predictions about vehicle ownership in China

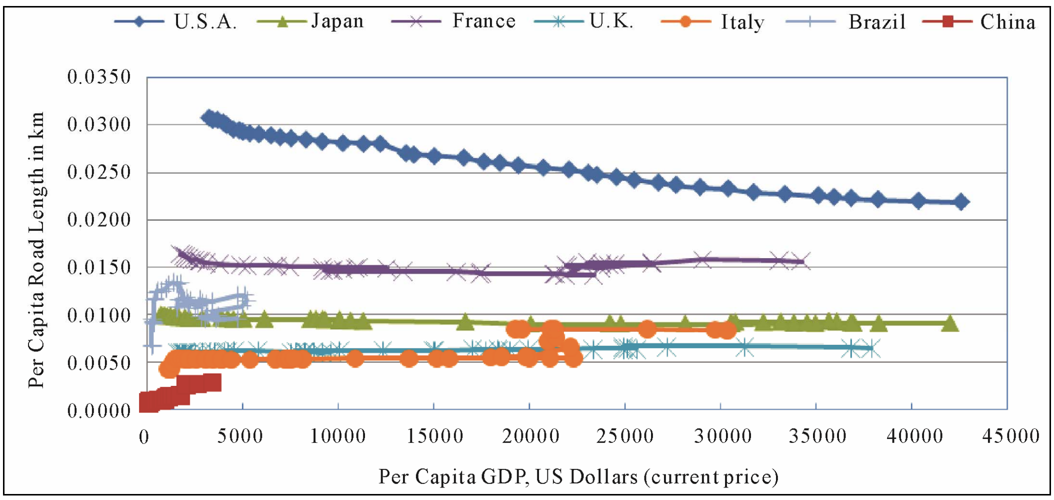

Figure 6. Relationship of per capita GDP and per capita road length by selected countries.

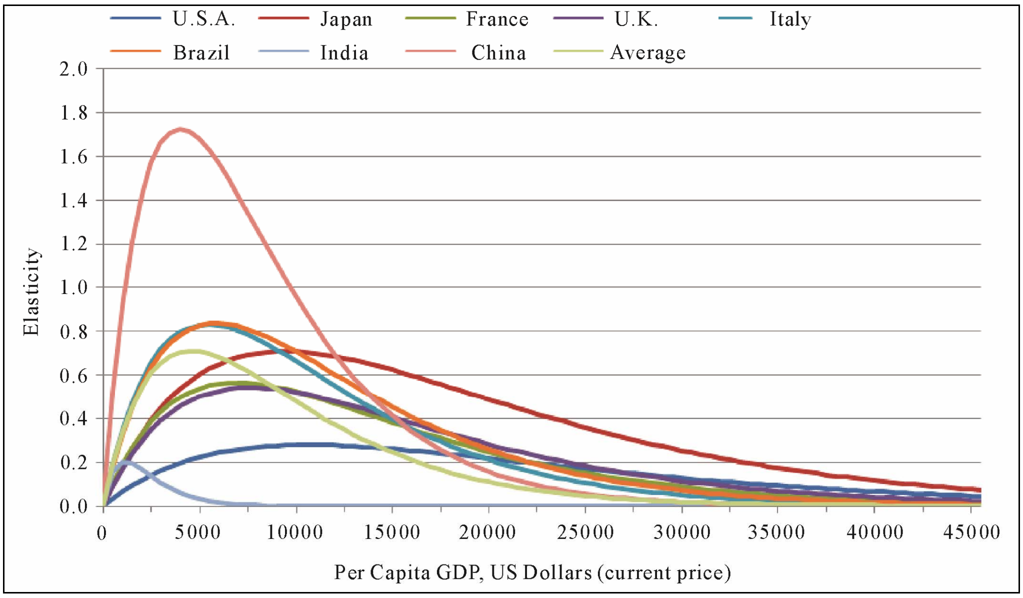

Figure 7. Per capita GDP elasticity.

were made based on the data collected before 2009. The spike in vehicle ownership in 2010 made all previous predictions irrelevant. For instance, the maximum vehicle ownership in 2015 was predicted as 0.15 billion by China Motorization trend. But it is certain that this number will be reached in 2015.

In addition to GDP, other factors also affect the future motorization level in China, such as gasoline cost, potential taxes, policy on restricted vehicle usage, culture, characteristics of Chinese consumers and etc., which in turn would affect the GDP growth. To better predict the future motorization level, two scenarios were developed with different GDP growth rate. The targeted GDP growth rate is seven percent based on the "National 12th Five-Year Plan" (2011 to 2015). In this paper, two per capita GDP growth rates, nine and seven percent (including price factor), were used in predicting future vehicle ownership rate to reflect the potential fluctuations in GDP development by the equation:

$$V(G) = 333e^{-4.67692581e^{-0.00003683G}} \quad (8)$$

The nine percent growth rate scenario results a ownership rate of 146.9 vehicles per 1000 population in 2015, which indicates that the total number of vehicles will reach 196 million, and a ownership rate of 241.6 vehicles per 1000 population in 2020, which indicates that the total number of vehicles will reach 322 million. The seven percent growth rate scenario results in an ownership rate of 128.2 vehicles per 1000 population in 2015, which indicates that the total number of vehicles will reach 171 million, and an ownership rate of 201.1 vehicles per 1000 population in 2020, which indicates that the total number of vehicles will reach 268 million. **Figure 8** illustrates both scenarios.

5. Critical Issues

The unprecedented motorization development in China is making a huge impact on all aspects of the society, including negative consequences that can't be ignored. Traffic congestion, air pollution, and dependency on imported oil are huge emerging problems threatening Chinese sustainable development. Although these problems occurred and still exist in many other developed and developing countries, they are more acute in China today.

5.1. Dependency on Imported Oil

Figure 9 illustrates the need for oil imports by year. In 2009, Chinese civilian vehicles consumed 56.6 million tons of gasoline (84.4% by highway transportation) and 61.0 million tons of diesel oil (44% by vehicles) [14]. The consumption of gasoline and diesel oil rise with the increasing number of vehicles. However, the production of crude oil does not increase, remaining at about 200 million tons. The imported petroleum exceeded more than 50 percent in 2009. With the increase of vehicle ownership, China must import more and more petroleum from other countries. Dependency on imported oil is considered a threat to a nation's security. The demand for oil has already put tremendous pressure on the government.

5.2. Predicted Future Demand for Oil

The future demand for gasoline will be based on several factors, such as vehicle fuel efficiency, urban transportation policy, transportation tax, and residence travel behavior.

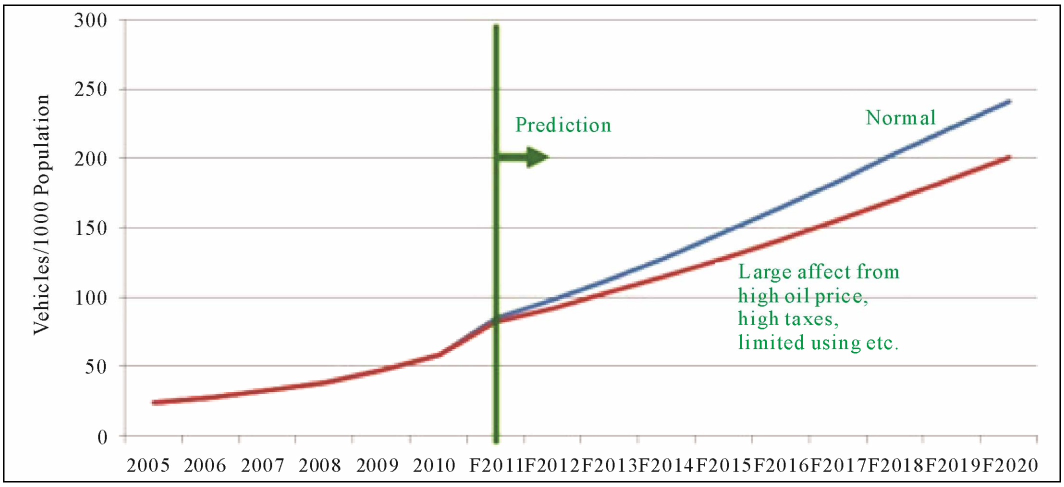

Figure 8. Predicting the vehicle ownership in China (Indicate curve by 9% and 7%).

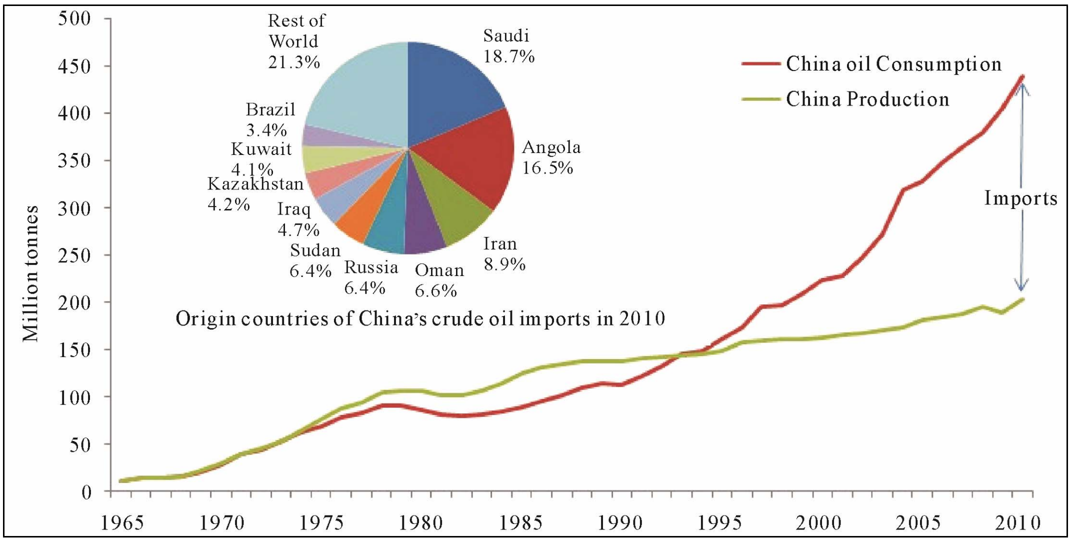

Figure 9. Annually oil consumption and production in China and the contries expported oil to China in 2010 (Source: references [15,16]; Note: one ton of crude oil ≈ 7 barrels of crude oil).

In 2009 the 73% of vehicles using gasoline consumed about 1.17 tons gas per vehicle per year. Considering future demand of private vehicles that use gasoline, gasoline consumption vehicles will increase to 78% in 2015 and 83% in 2020. The annual gasoline consumption per vehicle will be reduced because of several reasons. First, the government has requested the consumption of gasoline for 100 kilometers must be decreased from the current 8 liters to 5.9 liters for all new vehicles, resulting a 26% improvement in fuel economy.

The government promoting public transit polices also encourages more commuters to choose mass transportation options during rush hours, which reduces the use of private vehicles. Increased taxes on gasoline and parking fees along with restrictions on the use of vehicles during weekdays (by vehicle's license plate number) would also reduce vehicle use. Another factor contributing to the lower usage of vehicles is that the majority of vehicles are sold to private citizens, not to companies or government agencies; private vehicles are driven less than business owned vehicles. Because of the above stated factors, it is predicted that the average vehicle gasoline consumption per 100 kilometers will decrease about 26% by 2015. It is predicted that technology improvement in fuel economy will result in a 5% decrease annually in gasoline consumption, and reduced vehicle travel would result in a 2% decrease in gasoline consumption.

Similar to vehicles using gasoline, the annual average diesel consumption will also decrease significantly for vehicles using diesel oil because: 1) the proportion of higher fuel efficiency heavy trucks will increase; 2) technology improvement increase gas mileage; and 3) lighter trucks reduce fuel consumption. It is predicted the average diesel oil consumption per vehicle will drop 30%

in 2015 from the 2009 level.

The predicted fuel consumptions are summarized in **Table 3**, which shows that the percentage of fuel consumption increase will be smaller than the increase in vehicles.

With 90% of total gasoline consumption for automobiles and 45% of total diesel consumption for diesel vehicles, the demand for crude oil with the 9% growth rate scenario will be 0.70 billion tons in 2015 and 0.79 billion tons in 2020. The demand for crude oil with the 7% growth rate scenario will be 0.61 billion tons in 2015 and 0.66 billion tons in 2020. If crude oil production in China will only increase by 20 million tons each year, the total production of domestic crude oil will be 0.22 billion tons in 2015 and 0.24 billion tons in 2020, which makes China heavily reliant on imported oil. China will need 68.6% of oil imported from other countries in 2015 and 69.5% in 2020 with the 9% growth rate scenario. China will need 64.1% of oil imported from other countries in 2015 and 63.4% in 2020 with the 7% growth rate scenario. It is clear that the motorization development forces China heavily depend on imported oil, which puts the country in a very vulnerable and uneasy position.

5.3. Traffic Congestion

At the present time, severe traffic congestion has already become a way of life in most urban areas throughout China. Because of the income gap between urban and rural, regional income gaps are very big, most vehicles are running in big cities where population densities are high. Roadway construction in urban areas is far behind the vehicle growth rate; meanwhile, Chinese city planning, transportation planning and traffic management lack forward-thinking and long-term planning. Most of the plans have underestimated automobile growth, which partly explains why traffic congestion is so bad in the cities. Traffic congestion greatly extends travel time, increases travel cost, pollutes air quality, and induces noise pollution.

Table 3. Predicted fuel consumption in 2015 and 2020.

Year	Vehicles 10,000	Gasoline vehicles 10,000	Gasoline consumption 10,000 tons	Diesel vehicles 10,000	Diesel consumption 10,000 ton
2009	6281	4617	5400	1663	5822
The first scenario					
2015	19603	15290	9727	4313	10567
2020	32241	26760	11907	5481	11415
The second scenario					
2015	17110	13346	8490	3764	9223
2020	26836	22275	9911	4562	9502

The speed of economic development is much faster in large cities that attract an influx of laborers to cities, which worsens the traffic situation. Based on the data from four large cities administrated directly by the national government, the roadway mileage per person is either status-quo or decreases while the vehicle ownership increases rapidly, as shown in **Figures 10** and **11**. This trend will continue for the near future in China.

5.4. Traffic Safety

According to statistics from Ministry of Public Security, in 2010 there were 3,906,164 recorded roadway traffic accidents, up 35.9% from the last year, and 65,225 traffic fatalities, down 3.7% from the last year. At present, China is number one in recorded traffic fatalities. The fatality rate in terms of number of fatalities per 10,000 vehicles is three to five times higher than the rates of developed countries, as shown in **Figure 11** [17].

Rapid motorization development will expectedly increase traffic accident frequency in China although the accident rate may be reduced with massive government highway safety improvement projects. The challenges in highway safety come from not only the rapid motorizetion development, but also poor safety awareness, overloaded trucks, and sometimes insufficient roadway design standards.

If the current fatality rate is used to predict future accident frequencies, the situation is very worrisome. The fever for automobile ownership is shifting from major cities, such as Beijing and Shanghai, to other medium (population is between 10 and 15 million) and small urban areas (population less than five million). Safety awareness is much weaker in these cities along with weak safety education programs and other roadway design and traffic control problems. Accidents on rural highways crossing the country are also increasing in number in recent years.

5.5. Environmental Protection

In 2009, pollution by motor exhaust was 51.4 million tons, in which CO was 40.1 million tons, HC was 4.8 million tons, NO_x was 5.8 million tons, and particulate matter was 0.6 million tons. Most pollutants are emitted by automobiles. In many cities, especially large and medium-sized cities, air pollution presents a characteristic that the combined pollution of coal smoke and automobile exhaust makes it very difficult to control atmospheric pollution. Meanwhile, some areas of China often experience atmospheric pollution problems, such as acid rain, gray haze and light chemicals, with one area experiencing more than 200 days of gray haze weather. These problems are directly related to vehicle emissions

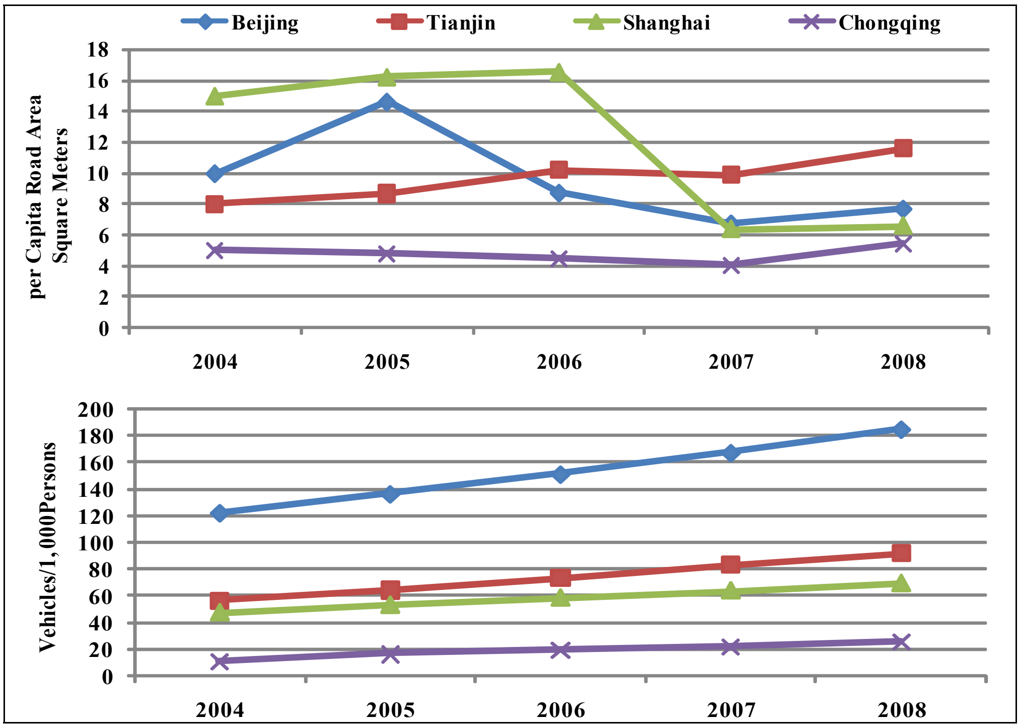

Figure 10. Average roadway length per resident in four cities (Source: reference [18]).

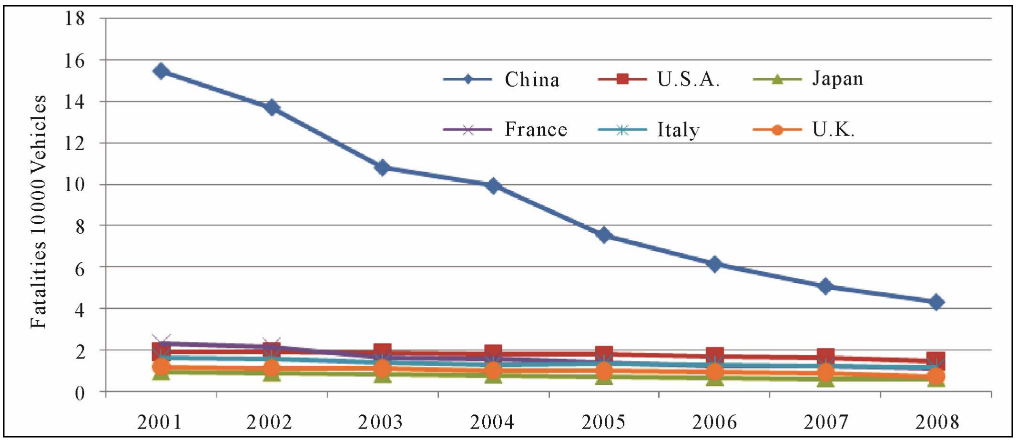

Figure 11. Fatalities rate per 10,000 vehicles from selected countries.

producing the nitrogen oxides and fine particulate pollutants. As pointed out by the Ministry of Environment Protection [19], with the increase in motor vehicle quantities, motor vehicle emissions impact on the environment is more serious, adding to the pressure of city and regional air quality.

6. Discussion

After three decades of high speed development, China is at a critical point in history in many aspects, including transportation development. Using the data collected from various published sources, this paper predicts the motorization development for the next decade in China and reviews the emerging critical issues because of the motorization development. The negative impact of high speed motorization in energy conservation, traffic congestion, traffic safety, environmental protection needs urgent attention and must be dealt with seriously.

It is imperative for China to fully recognize the emerging challenges of growing global energy demands, the socio-economic implications, stresses of domestic motorization development, and urgent environmental protection needs. The gravity of the situation calls for immediate action. The emission standards must be improved for traditional vehicles currently operating in China whose emission performance would not be acceptable in the U.S. and other developed countries. Being a newly modernized country, China is and should be always thinking forward to the development of new energy efficiency vehicles. With increasing urban population in the next decade, the country needs new and innovative ways to reduce traffic congestion through a combination of actions in city planning, mass transportation networks, and new traffic control techniques. As for traffic safety, China needs to establish sustainable objectives on how to reduce crash rates, not just to concentrate on crash numbers, since the crash numbers may still increase with the mobility surge in the next few years. Excessive emphasis on crash numbers would lead to less accurate crash data reporting.

REFERENCES

[1] State Statistical Bureau, "China Statistical Yearbook-2010," China Statistics Press, Beijing, 2010.

[2] State Statistical Bureau, "Statistical Communiqué of the People's Republic of China on the 2010 National Economic and Social Development," State Statistical Bureau, Beijing, 2011.

[3] Ministry of Transport of the People's Republic of China, "Statistical Communiqué on the 2010 Highway & Waterway Traffic Transportation Industry Development," Ministry of Transport of the People's Republic of China, Beijing, 2011.

[4] China Automotive Technology & Research Center, "China Automobile Industry Yearbook," 2010.

[5] H. F. Chen, *et al*., "Prediction Model of Car Production Based on Linear Multivariate Regression," *Automobile Industry Research*, Vol. 6, 2009, pp. 22-23.

[6] X. Y. Xu and G. Shi, "The Application and Research of System Dynamics to the Prediction of Automobile Market," *Journal of Shandong University of Technology*, Vol. 6, 2007, pp. 5-8.

[7] J. Dargay and D. Gately, "Income's Effect on Car and Vehicle Ownership, Worldwide: 1960-2015," *Transportation Research Part A*, Vol. 33, No. 2, 1999, pp. 101-138. doi:10.1016/S0965-8564(98)00026-3

[8] F. F. Qi, "Forecasting Research on the Consumption Demand of Civilian Vehicle in China Based on Panel Data Model" University of Science and Technology of China, 2010.

[9] Y. N. Wang, "Car Ownership Forecast in China—An analysis Based on Compertz Equation," *Research on Financial and Economic Issues*, No. 11, 2005, pp. 43-47.

[10] "World Motor Vehicle Statistics in 2011," Japan Automobile Manufacturers Association, Inc., 2011.

[11] World Bank, "World Development Indicators," 2011.

[12] International Road Federation, "I.R.F. World Road Statistics Database, 1963-2010," International Road Federation, Geneva, 2011.

[13] K. Gregory and Z. Liu, "Determinants of Motorization and Road Provision," World Bank, Washington DC, 2011.

[14] China Automotive Technology & Research Center, "China Automobile Industry in 2010," China Automotive Technology & Research Center, 2010.

[15] X. Y. Yan and R. J. Crookes, "Energy Demand and Emissions from Road Transportation Vehicles in China," Progress in Energy and Combustion Science, Vol. 36, 2010, pp. 651-676. doi:10.1016/j.pecs.2010.02.003

[16] BP, "BP Statistical Review of World Energy June 2011," 2011. http://www.bp.com/sectionbodycopy.do?categoryId=7500&contentId=7068481

[17] Ministry of Public Security of the People's Republic of China, "Statistical Yearbook on Road Traffic Accidents-2010," Ministry of Public Security of the People's Republic of China, Beijing, 2010.

[18] State Statistical Bureau, "China City Statistical Yearbook from 2005 to 2009," State Statistical Bureau, Beijing.

[19] Ministry of Environmental Protection of China, "China Vehicle Emission Control Annual Report in 2010," Ministry of Environmental Protection of China, Beijing, 2010.

