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Vehicle-use intensity in China: Current status and future trend

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ABSTRACT

Vehicle-use intensity (kilometers traveled per vehicle per year or VKT) is important because it directly affects simulation results for vehicle fuel use and emissions, but the poor understanding of VKT in China could significantly affect the accuracy of estimation of total fuel use and CO_2 emissions, and thus impair precise evaluation of the effects of associated energy and environmental policies. As an important component of our work on the Fuel Economy and Environmental Impacts (FEEI) model, we collected VKT survey data in China from available sources and conducted additional surveys during 2004 and 2010, from which we derived VKT values and VKT-age functions by vehicle type for China. We also projected the future VKT for China by examining the relationship of vehicle use to per-capita GDP in 20 other countries worldwide. The purpose of this work is to achieve a better understanding of vehicle-use intensity in China and to generate reliable VKT input (current and future VKT levels) for the FEEI model. The VKT results obtained from this work could also benefit other work in the field associated with vehicle energy use and emissions.

1. Introduction

This paper is the second in a series of four papers being developed to project Chinese motor-vehicle growth and consequent fuel use and CO_2 emissions in China, which are important for understanding future energy and environmental impacts of on-road transport and the effects of potential policies. This article will focus on vehicle-use intensity in China.

Vehicle-use intensity, usually expressed in kilometers of travel per vehicle per year (VKT), is a crucial factor in estimating vehicular fuel use and emissions. Modeling energy use and emissions of motor vehicles in a region or country requires total vehicle population (as presented in the first paper of our publication series [Huo and Wang, this issue]), vehicle-use intensity (as presented in this paper), and vehicle fuel-use intensity (usually in liters per 100 km) and emission factors (in grams per kilometer). Thus, accurate assessment of vehicle-use intensity is a necessary step in predicting total energy use and emissions.

The level of understanding of VKT in China is poor, owing to the lack of data and the relatively short history of Chinese motor-vehicle development, especially private-vehicle ownership development. Moreover, unlike many developed countries that release their vehicle-use data on a routine basis, China does not officially publish VKT data. In fact, some municipal transport management authorities in China do possess a mass of detailed VKT information, but restriction of access to these data is widespread. In order to acquire VKT information, researchers in China often have to conduct their own surveys (often with limited numbers of samples) based on their needs. Furthermore, some vehicle-use intensity studies rely on secondhand materials, which make the data interpretation unreliable. Nevertheless, some public sources that are not published for VKT purposes include some VKT-related data. Such sources include annual statistics of commercial transport companies and the transport-development annual reports released by government agencies at various levels. These public sources can provide some hints for a better understanding of VKT. In addition, many research organizations have recently started to address VKT, and valuable VKT information is beginning to be accumulated. However, publicly available VKT data and VKT results of research organizations are scattered and have not been thoroughly analyzed and compared.

VKT information in China is also limited in another respect: previous Chinese studies that estimated vehicle fuel demand and evaluated corresponding polices have overlooked a common phenomenon. That is, vehicles are used less intensively when they get older. According to U.S. statistics and surveys, vehicles of age 15 and older travel 50–70% less per year than new vehicles do (Davis et al., 2009; U.S. Census Bureau, 1977–2002). If this finding

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is true for China, it could cause a misunderstanding, to some extent, of the effect of policies, especially for those policies that will result in vehicle technology differences among vehicles of different ages, such as fuel-economy standards. A good understanding of VKT variation over vehicle lifetime will require large amounts of data on vehicle accumulative kilometers versus age.

Projections of future vehicle use in China are also not well addressed. It is well understood in developed countries that per-vehicle use intensity decelerates as a given vehicle market approaches its saturation point. Our previous studies assumed that Chinese VKT would reach the level of Japan or European countries at some point in the future, because of the similarities in population density and urban growth patterns between China and these countries (Wang et al., 2006; Huo et al., 2007). Many other studies in China follow the same approach when treating future VKT. However, this approach is more qualitative than quantitative, owing to the absence of convincing quantitative analysis.

In order to gain a better understanding of vehicle use in China and make a reasonable projection of Chinese VKT for the Fuel Economy and Environmental Impacts (FEEI) model (see the description of the FEEI model presented in the first paper of this series [Huo and Wang, this issue]), we have (1) collected all available VKT information from Chinese sources and conducted an analysis aimed at a comprehensive understanding of VKT in China; (2) conducted our own surveys in several localities during 2004 and 2010 on VKT for various vehicle types, to examine the variation and trend of VKT over vehicle lifetime and fill in some of the information that is missing from available sources; and (3) analyzed historical trends of vehicle use in developed countries to examine the inherent regularity of VKT with respect to economic factors such as per-capita GDP, so as to develop a basis for projecting the future VKT in China. This work is intended not only to create a clear picture of current and future vehicle use in China, but also to provide reliable VKT input data for the subsequent calculation of fuel use and emissions and policy evaluation with the FEEI model.

2. Current status of vehicle use

Vehicles in China can be roughly classified into four groups based on size and use. These are light-duty passenger vehicles (LDVs), heavy-duty passenger buses, light-duty trucks (LDTs), and heavy-duty trucks (HDTs) (see the first paper of this series [Huo and Wang, this issue] for descriptions of vehicle classifications in Chinese statistics). Because the trip purpose of a vehicle is one of the most important factors influencing how intensively the vehicle is used, we categorize LDVs into three types and heavy-duty buses into two types on the basis of their functions. In sum, the seven major types (with their shares of the 2008 vehicle population shown in parentheses) are private LDVs (56.6%), taxis (2.0%), passenger vehicles owned by government bodies and companies (13.7%; referred to below as business LDVs), buses for urban public transport (0.7%), large- and medium-size passenger vehicles for commercial revenues from long-distance travel (4.2%), LDTs (13.7%), and HDTs (9.0%). Besides highway vehicles, motorcycles (MCs) and rural vehicles (RVs) are also included in this work. It should be noted that the classification methods in this work and the first paper (Huo and Wang, this issue) are compatible with each other, as shown in Table 1.

Table 1
Correspondence between vehicle classifications used in this series.[a]

The first paper of this series (Huo and Wang, this issue)	The present paper
Private LDVs	Private LDVs (or private cars)
Commercial LDVs	Taxis Business LDVs
Commercial buses	Buses for public transport Heavy-duty passenger buses for long-distance travel
Commercial trucks	LDTs HDTs

[a] The first paper (Huo and Wang, this issue) classifies vehicles in China into four groups and this work into seven.

2.1. Average VKT

2.1.1. Light-duty passenger vehicles

We conducted VKT surveys for LDVs in several Chinese cities during 2004 and 2010. Surveys were carried out in several randomly selected residential and commercial parking lots located in cities. To ensure the data quality, the parking lots selected were widely distributed in the target city. For technical details of the VKT surveys, please refer to our previous publication (Huo et al., 2009). We also collected VKT results for some cities reported by other Chinese organizations (Beijing Transport Research Center, 2002–2009; Wuhan Comprehensive Transport Planning Institute, 2005; Shanghai City Comprehensive Transportation Planning Institute, 2001–2005; Shanghai Statistical Bureau, 2009; State Statistical Bureau of China, 2001a; Nanjing Transport Planning Institute et al., 2004; Guo et al., 2009; Huang et al., 2005; Zhang, 2006; Hu and Liang, 2004). Fig. 1 illustrates where and when the surveys were conducted and the VKT results for private LDVs, taxis, and business LDVs. The red plots represent the results derived from our own surveys. As shown in Fig. 1, the surveyed cities are located all over China and cover all city sizes. In many surveys, private and business LDVs were combined because they were difficult to distinguish by the methods used.

The combined VKT of private and business LDVs varies significantly across cities, ranging from 15,000 km to 27,000 km (Fig. 1a). According to the statistical analysis on the survey data, the 90% confidence range of VKT of private and business LDVs is (7600 km, 33,100 km).

The time-series VKT data for Beijing reported by the Beijing Transport Research Center (2002–2009) (Fig. 2) shows that the VKT of private LDVs in China has decreased over a period when private LDV ownership has increased dramatically. The results of the surveys that we conducted in Beijing in 2004 and 2008 (Fig. 1a) independently confirm this trend.

Business LDVs in China (Fig. 1) usually have designated drivers, are operated for multiple business trips in a single day, and travel more than private LDVs do. According to the findings of the Beijing Transport Research Center (2002–2009), the VKT of business LDVs is 30–50% higher than that of private LDVs. Nevertheless, similarly to private cars, as the number of business LDVs has grown in recent years, their VKT has also decreased gradually, from 38,600 km in 2003 to 28,600 km in 2008.

The VKT of taxis in China is very high, as can be simply observed by their much higher fraction in traffic in comparison to their fraction of the total vehicle population. Our surveys in various cities, as well as many other sources, show that taxi VKT in China has been more than 100,000 km in recent years (see Fig. 1c).

Taxis have high VKT values because taxi drivers make profits proportionately to distance traveled, but a particular reason for the Chinese case is the business model of taxi companies in China. In China, taxi companies require taxi drivers to pay a fixed

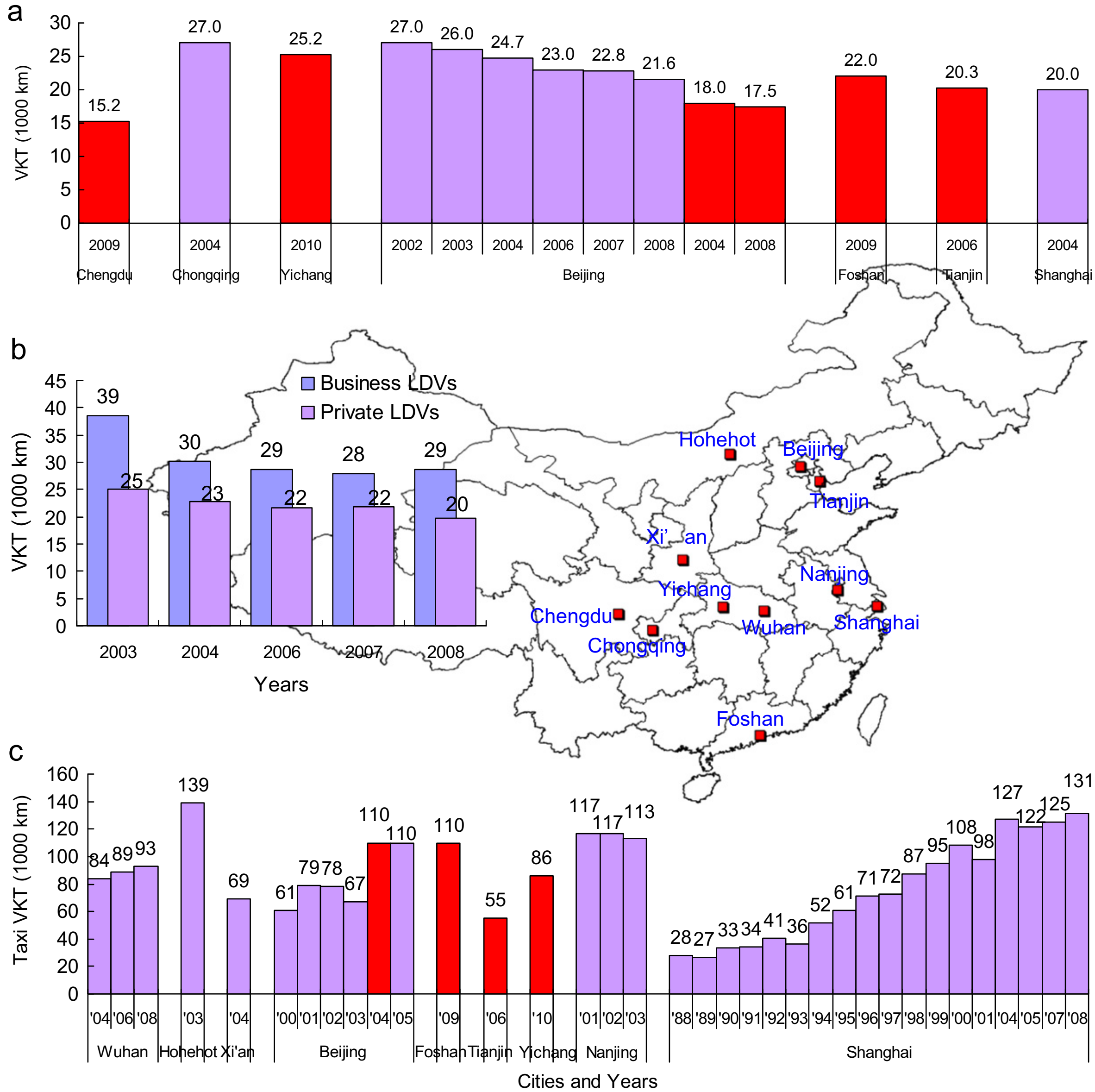

Fig. 1. VKT levels of LDVs in Chinese cities, 1988–2010. *Note*: Red plots represent the results derived from surveys conducted by the authors; blue and purple plots are those summarized by the authors from other available sources. (a) Private and business LDVs together, (b) Private and business LDVs separately and (c) Taxis. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

contract and management fee, which is quite high (for example, 5000–6000 RMB per month in Beijing, which is equivalent to the business profit from driving 3200–4000 km). In many cities, taxi drivers have to extend their daily service hours in order to make a living. Sometimes, two drivers work shifts with a single taxi, which means that the taxi could be in operation 24 h a day. Also, since there are virtually no dispatch services, taxi drivers simply drive around looking for passengers. Unlike private and business cars, the VKT of taxis is increasing in China (Fig. 1c). The reason for the increase is that many cities restrict the number of taxis (e.g., Beijing controls its taxi number at 60,000–65,000), while the demand for taxi rides is increasing. This trend of increase has been apparent in Shanghai over the past 20 years, though it appears that the demand may be approaching a plateau.

On the basis of the available data, we simulated the VKT levels of LDVs in China using

$$VKT_i^T = \frac{\sum_j \left(P_{i,j}^T \times \frac{\sum_k (S_{i,j,k}^T \times VKT_{i,j,k}^T)}{\sum_k S_{i,j,k}^T} \right)}{\sum_j P_{i,j}^T}, \tag{1}$$

where i represents year; j represents the cities where VKT surveys have been conducted; k represents the number of VKT surveys conducted in city j; T represents the vehicle type (private LDVs, business LDVs, or taxis); VKT_i^T is the VKT level of vehicle type T in year i; $P_{i,j}^T$ is the stock of vehicle type T in city j in year i; $S_{i,j,k}^T$ represents the number of samples in the kth survey conducted in city j in year i; and $VKT_{i,j,k}^T$ is the average VKT result of the kth survey conducted in city j in year i.

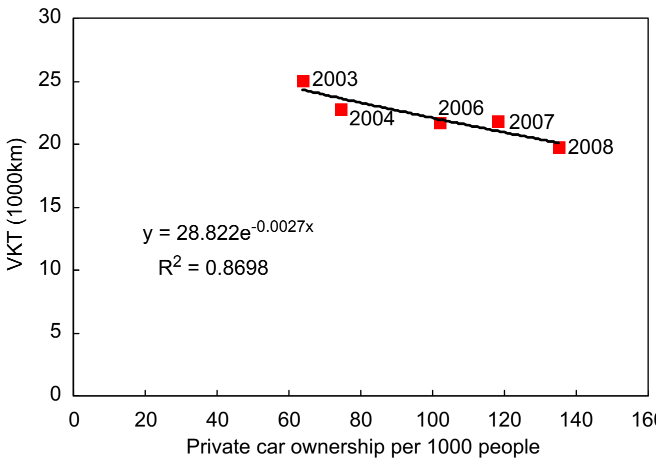

Fig. 2. VKT levels vs. private-car ownership in Beijing, 2003–2008.

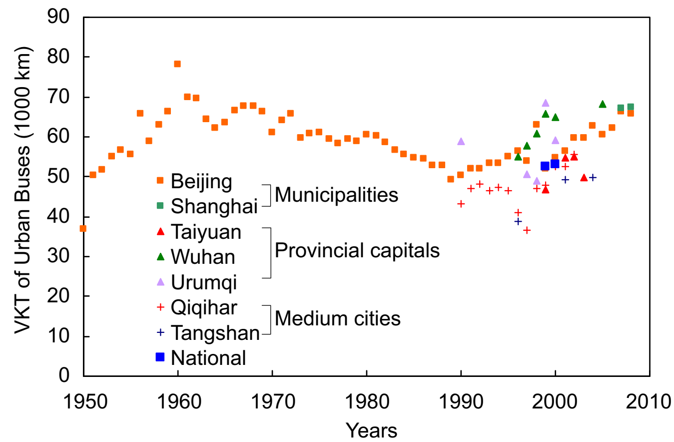

Fig. 3. VKT levels of public buses in China, 1950–2009.

Table 2
VKT levels of LDVs in China from 2002 to 2009 (1000 km).

	Private LDVs[a]	Business LDVs[a]	Taxis[b]	All LDVs
2002	18.5	24.0	74.9	22.4
2003	18.4	23.9	78.3	21.8
2004	18.2	23.7	81.9	21.5
2005	18.0	23.5	85.3	21.1
2006	17.9	23.2	88.8	20.9
2007	17.5	22.8	92.3	20.7
2008	17.2	22.3	95.0	20.3
2009[c]	16.9	22.0	99.2	19.4

[a] Estimated by assuming the VKT ratio of business LDVs to private LDVs is 1.30 (Beijing Transport Research Center, 2002–2009).
[b] Calculated using Eq. (1).
[c] The Yichang result is incorporated into the 2009 results because the survey was done in the first half of 2010.

Using the currently available data, we obtained VKT results for LDVs in China from 2002 to 2009, which are presented in Table 2. These VKT results take into account all available VKT studies done by different academic groups, which together are more reliable than any single survey result from a statistical point of view. Lin et al. (2009) obtained VKT data for more than 430,000 LDVs in 2007 from vehicle "4S" (sales, spare parts, service, and survey) shops and concluded that the average VKT of the national LDV fleet was 26,900 km in 2007, which is 30% higher than our estimate (20,700 km in 2007). As the number of LDVs increased by about a factor of 3.6 between 2002 and 2009 (State Statistical Bureau of China, 2009), the VKT value of an individual LDV decreased by 13% (Table 2). This decrease in VKT with time was not taken into account in previous studies.

2.1.2. Buses

As of 2008, China had a total of 370,000 urban public buses, representing only 0.7% of the total vehicle population in China. However, public buses are still the main means of travel for the Chinese among all motorized transport modes. The VKT data for public buses can be readily obtained because many municipal authorities report the total bus kilometers through their city statistics yearbooks. Fig. 3 presents the bus VKT results for several cities of different population sizes. The VKT of public buses in China ranges from 50,000 km to 68,000 km in municipalities and provincial capitals, and it is 20% lower in medium-sized cities. According to the China Urban Construction Statistics Yearbooks, public buses traveled an average of 53,000 km/year in 2000 (State Statistical Bureau of China, 2001b). The long-time-series VKT data for Beijing buses reveal that the bus VKT has gradually increased since 1990 (Beijing Public Transport Ltd., 2010). Other cities have followed a similar trend.

In addition, some surveys on VKT levels of public buses can supplement the above statistics. One survey conducted by Huang et al. (2005) in Shanghai in 2004 showed that buses traveled 120–130 km/day (or 43,800–47,400 km/year). According to our surveys, the VKT level of public buses was 77,000 km in Tianjin in 2006 and 107,600 km in Foshan in 2009.

VKT data for long-distance buses for inter-city passenger transport are rare and difficult to obtain. To date, no statistics or literature is publicly available to describe the VKT level of this bus group in China. During 2009 and 2010, we conducted VKT surveys for inter-city buses in Foshan and Yichang, respectively. In Foshan, we collected VKT data for 230 medium-size buses and 570 large buses; the VKT levels were 77,700 km and 168,000 km, respectively. The results for Yichang's medium and large buses were 65,000 km (75 samples) and 79,000 km (45 samples), respectively. Yu and Yu (2008) estimated the VKT levels of Chinese buses and trucks based on total passenger/freight traffic volume, load capacity and actual load rate in China in 2006. They found that the VKT of large buses was 169,000 km and that of other buses was 85,000 km, in good agreement with our survey results from Foshan.

2.1.3. Trucks

Recently, the ratio of truck stock to total vehicle stock has decreased significantly as a result of the rapid growth of LDVs. Trucks accounted for more than 40% of the total vehicle population in China in 2002, but this proportion dropped to about 22% in 2008 (State Statistical Bureau of China, 2009). The share of trucks is expected to continue its decline. Even so, one of our previous studies found that trucks would be one of the largest fuel consumers among road transport vehicles through 2050 due to their high VKT level and high fuel-consumption rates (Wang et al., 2006). Nevertheless, much less attention has been paid to trucks and little work has been done to understand their activity and fuel-consumption rates.

In China, trucks are usually operated for commercial purposes; therefore, a high VKT level for trucks is expected. The experiences of Japan and the U.S. show that heavy trucks travel much more than light ones, because large trucks are used more for long-distance transport (Wang et al., 2006). We collected VKT data for trucks in Tianjin in 2006, Foshan in 2009, and Yichang in 2010. According to our surveys, Tianjin's HDTs traveled 82,000 km annually and LDTs traveled 38,000 km (42 samples total); the VKT level of HDTs was 72,300 km in Foshan (270 samples) and 70,500 km in Yichang (200 samples). Some other studies also provided VKT information on Chinese trucks. Huang et al. (2005) reported, on the basis of a 2004 survey, that trucks in Shanghai (4000–15,000 kg in gross vehicle weight) traveled 80–100 km/day (29,200–36,500 km/year). Yu and Yu (2008) estimated the VKT levels of Chinese commercial trucks to be 52,000 km for large trucks and 38,000 km for other trucks in 2006.

Fig. 4 summarizes the findings of our surveys and the other studies described above. We determined the VKT levels of buses and trucks in China by summarizing these results, as shown in Table 3.

2.1.4. Motorcycles

China has a very large population of MCs, with an ownership level of 71.2 per thousand people in 2008 (State Statistical Bureau of China, 2009). Because MCs are not suitable for long-distance travel, their VKT is usually low. Worldwide, the VKT for MCs varies from 1700 km in France; to 3000–4000 km in the United States, Mexico, and Germany; to 6700 km in the United Kingdom during the 1990s (U.S. Federal Highway Administration, 1993–2009). Previous survey studies in China have shown a large variation in VKT for Chinese MCs, ranging from 4000 to 10,000 km (Yang and Yu, 2004; Wang et al., 2002; Hao et al., 2000). We investigated 364 MCs in Foshan in 2009 and found that their average VKT was about 5600 km. Lin et al. (2009) collected VKT data on 3400 motorcycles all over China in 2007 and concluded that the average VKT ranged from 5100 km to 5800 km, depending on the age of the MC.

2.1.5. Rural vehicles

Rural vehicles (RVs) are very popular in Chinese small towns and rural areas as a tool to transport people and goods, owing to many advantages such as their low price, adaptability to poor road conditions, and the ease of driving and maintaining them. The ownership level of RVs is estimated to be 30 per thousand rural people. RVs in China can be classified into 3-wheelers (3-W RVs) and 4-wheelers (4-W RVs). They are all equipped with diesel engines. The gross weight of 3-W RVs ranges from 1000 to 2000 kg, and 4-W RVs from 1000 to 4500 kg, slightly lighter than LDTs (1800–6000 kg). Compared to light-duty diesel trucks, RVs have much less engine power; the designed maximum speed is 50 km/h for 3-W RVs and 70 km/h for 4-W RVs.

According to our investigation, although RVs have low engine power and speed, their VKT levels could be high because they can be used intensively for moving goods. The difficulty of collecting VKT data on rural vehicles is that RVs do not have mileage meters installed. We surveyed about 300 RV owners in rural areas of the Beijing municipality and 500 RV owners in Henan province to make a rough estimation of the daily travel mileage of their RVs (Yao et al., 2011). The results show that 3-W RVs travel 21,000 km/year and 4-W RVs travel 28,000 km; these are close to the findings of the National Pollutants Survey (25,000 km for 3-W RVs and 28,000 km for 4-W RVs) (Vehicle Emission Control Center, 2008).

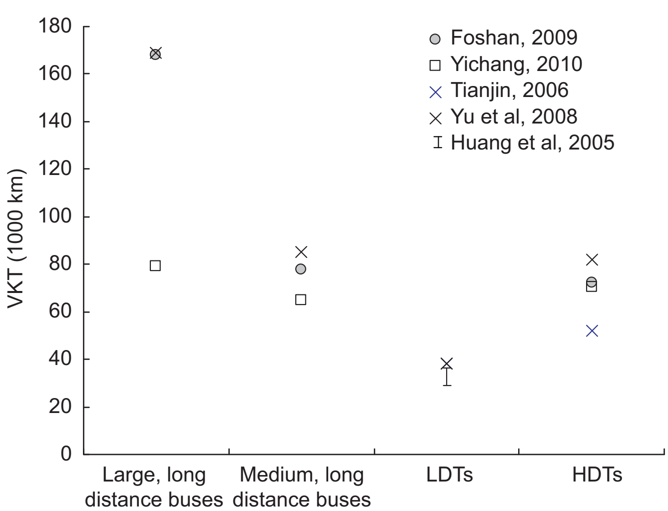

Fig. 4. VKT levels of commercial buses and trucks in China, 2005–2010.

Table 4
Information on the present authors' VKT surveys in Chinese cities.

Vehicle type	Survey year	Survey city	Number of samples
Cars	2006	Tianjin	1200
Cars	2008	Beijing	3500
Cars	2008	Chengdu	1600
Cars	2009	Foshan	2700
Cars	2010	Yichang	4600
Taxis	2009	Foshan	430
Public buses	2009	Foshan	715
Large inter-city buses	2009	Foshan	570
HDTs	2009	Foshan	270
HDTs	2010	Yichang	200

Table 3
VKT levels of buses and trucks in China from 2002 to 2009 (1000 km).

	Urban	Long-distance commercial travel[b]		All buses	LDTs[b]	HDTs[b]
	Public buses[a]	Large buses	Medium buses			
2002	57.2	160	80	106.7	30	60
2003	58.0	160	80	105.1	30	60
2004	58.8	160	80	104.5	30	60
2005	59.7	160	80	104.2	30	60
2006	60.5	160	80	104.9	30	60
2007	61.4	160	80	105.5	30	60
2008	62.2	160	80	106.3	30	60
2009	63.0	160	80	106.5	30	60

[a] The increasing trend in VKT of public buses is regressed on the basis of historical data for 28 Chinese cities.
[b] There is very little information on the VKT variation of these types of vehicles over time, so we assume that their VKT was unchanged from 2002 to 2009.

2.2. VKT variation over vehicle lifespan

It is a common observation that cars are used much less intensively when they get older. However, previous studies of Chinese vehicles have not taken into consideration the VKT variation with vehicle age. To examine VKT changes over vehicle lifetime in China, we analyzed the VKT data from the surveys we conducted in Beijing, Tianjin, Foshan, and Yichang between 2006 and 2010 (see Table 4). We used Eq. (2) to regress the VKT with age to obtain the VKT variation by vehicle type:

$$y_i = y_{i-1} \times \left[1 - \frac{1}{1+e^{(a+b\times c^x)}}\right], \quad (2)$$

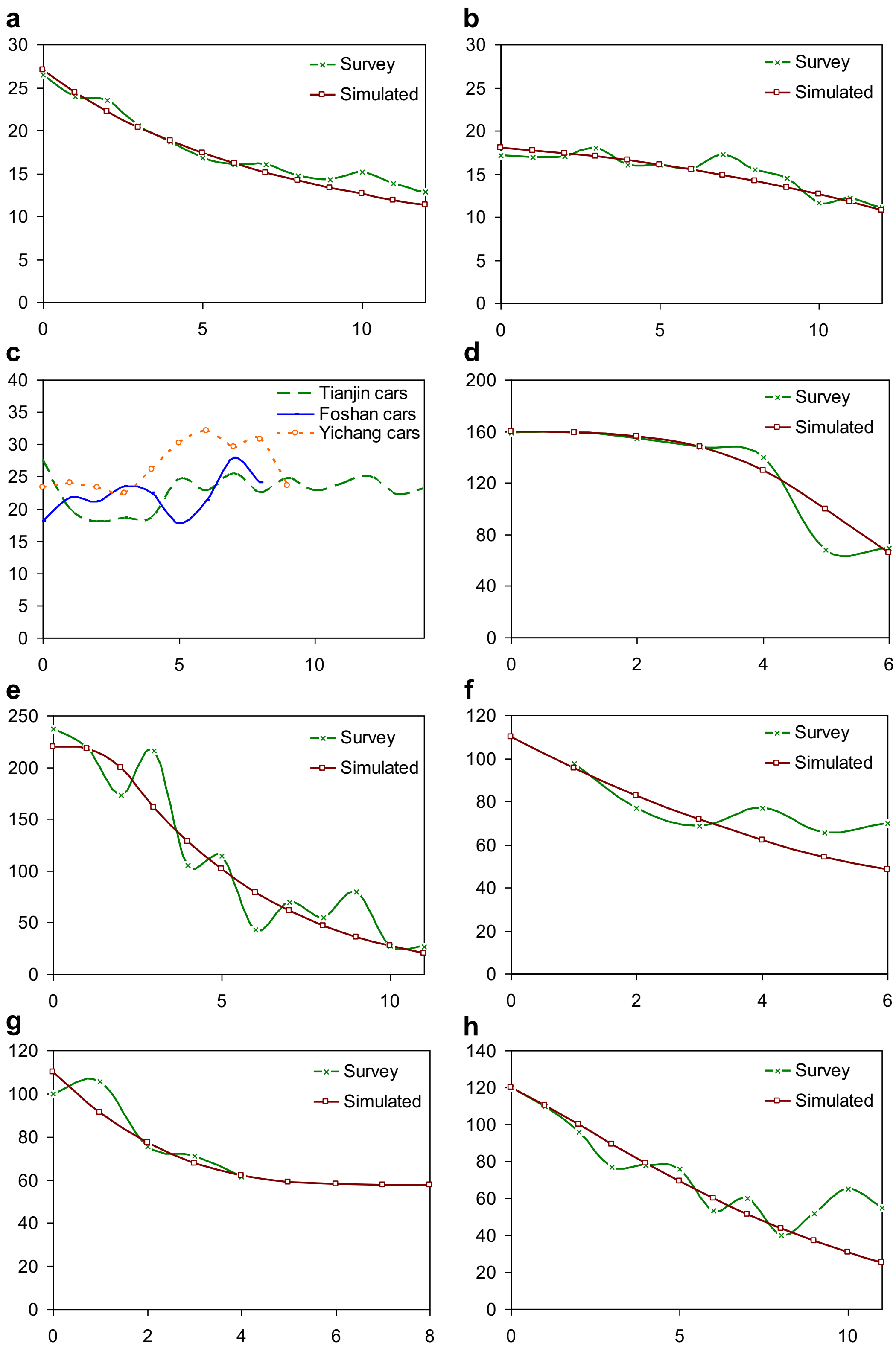

Fig. 5. VKT variation with vehicle age based on survey data; the *x*-axis is vehicle age in years and the *y*-axis is VKT (1000 km). (a) Beijing-Cars, (b) Chengdu-Cars, (c) Three cities - Cars, (d) Foshan-Taxis, (e) Foshan-Large Buses, (f) Foshan-LDTs, (g) Yichang-HDTs and (h) Foshan-HDTs.

where i represents vehicle age; y_i represents VKT for age i; and a, b, and c are parameters that determine the shape of the curve.

Fig. 5 presents the simulation results for VKT variation with vehicle age. Cars in Beijing show an obvious decline in annual travel as they age; cars in Chengdu show a slow decrease in VKT with age, while the VKT values of cars in Tianjin, Foshan, and Yichang do not show a clear declining trend. These patterns imply that Beijing's car fleet (with a very high ownership per 1000 people) is more mature than that of other cities. As shown in Fig. 5, the VKT of other vehicle types decreases gradually as vehicles become older. In particular, this declining trend is more apparent for HDTs and buses than for LDTs and LDVs. For example, the VKT of large inter-city buses in Foshan decreases from more than 200,000 km in the first year to less than 50,000 km ten years later. The results of our VKT survey show that the heavier the vehicles are, the more their VKT will decrease with age, which is consistent with observations in the U.S. Fig. 6 presents the VKT variation with vehicle age for several vehicle types in the U.S. (Davis et al., 2009; U.S. Census Bureau, 1977–2002). Over ten years of vehicle lifetime, VKT decreases by 33% for U.S. cars, by 42% for diesel medium trucks, and by 56% for heavy combination trucks.

From these survey results, it can be concluded that the VMT declines with vehicle age, even in emerging vehicle markets such as the Chinese market. This variation should be taken into account in estimating energy use and emissions of vehicle stock in a particular year. The survey by Lin et al. (2009) of more than 400,000 passenger vehicles also verified that 10-year-old cars travel 20–25% less than new cars do in China.

It is difficult to derive VKT curves versus vehicle age based strictly on the limited survey information available for China. Instead, we determined the VKT variation over vehicle lifetime by using the surveys we conducted and characteristics of VKT variation of the U.S. vehicle fleet as an indication of future age-specific variation for Chinese vehicles. Table 5 presents the ratios we developed for VKT values at different ages to that at age 0–1 for various vehicle types.

3. Future trends of vehicle-use intensity

3.1. Cars

Car use intensity in the future will be affected by many factors including urban growth pattern, operation costs of cars vs. public transport (which are affected by fuel prices, bus fares, etc.), and the extent of the road network, which is difficult to predict. Also, the quantitative relationships between vehicle use and these influencing factors are hard to establish, owing to the data limitations and the qualitative nature of some of the factors. Button et al. (1993) developed a modeling framework to capture the effects of these variables on vehicle use, but the data limitations prevent it from being used for China.

Besides VKT, total distance traveled by vehicles is another important factor in characterizing the vehicle-use level in a region. VKT only represents the travel intensity of one car, but total distance traveled can reflect the overall travel demand in a region. Also, VKT

Table 5
VKT ratios by age for Chinese vehicles.

Age	Cars	Taxis[a]	HDTs	LDTs[a]	Inter-city buses	Intra-city buses
0–1	1.00	1.00	1.00	1.00	1.00	1.00
1–2	0.98	1.00	0.92	0.87	0.99	0.79
2–3	0.95	0.98	0.83	0.75	0.91	0.67
3–4	0.93	0.93	0.74	0.65	0.73	0.59
4–5	0.90	0.81	0.66	0.56	0.58	0.54
5–6	0.85	0.62	0.58	0.49	0.46	0.50
6–7	0.80	0.41	0.50	0.44	0.36	0.48
7–8	0.67	0.41	0.43	0.44	0.28	0.46
8–9	0.52		0.36		0.21	0.44
9–10	0.45		0.31		0.16	0.44
10–11	0.40		0.26		0.12	0.44
11–12	0.37		0.21		0.09	0.44
12–13	0.35		0.17		0.07	0.44
13 and up	0.35		0.17		0.07	0.44

[a] Taxis and LDTs usually serve 8 years before scrapped.

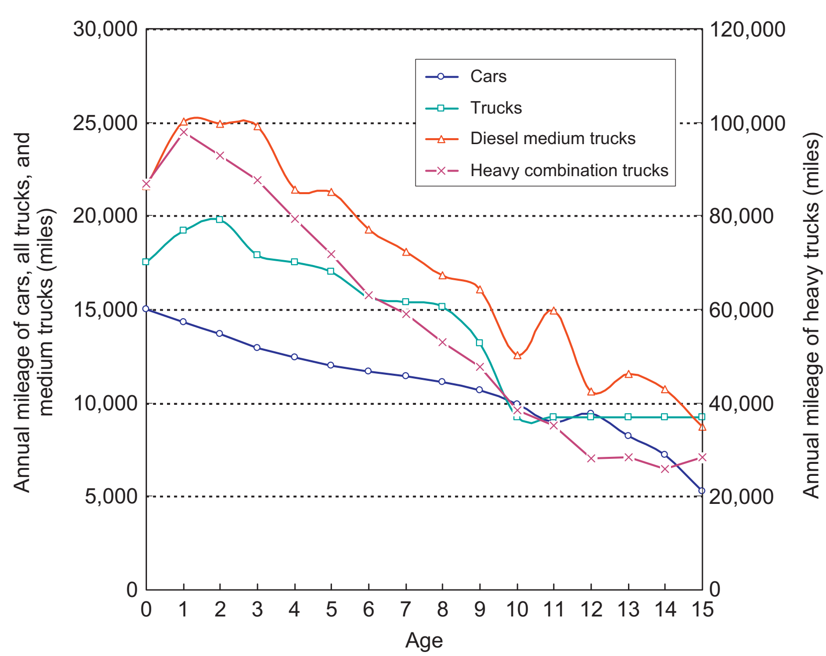

Fig. 6. Annual vehicle miles traveled vs. vehicle age in the U.S.

is less independent than total car distance because VKT is influenced by vehicle stock level, which is another variable in this modeling system. Therefore, in the context of this study, it is more reasonable to project the total distance traveled by cars instead of projecting the VKT of an individual car directly. In this study, we first project total car distance traveled, then calculate VKT by dividing the total car distance by the car stock level that was projected in the first paper of this series (Huo and Wang, this issue).

Total car distance traveled, especially car distance traveled per capita, is related to the economic growth level of a region. Fig. 7 examines the car distance traveled per capita in relation to per-capita GDP in 20 countries worldwide (U.S. Federal Highway Administration, 1993–2009; U.S. Department of Transportation et al., 2008; European Commission, 2003–2009; Capros et al., 2008; Korea National Statistical Office, 2005; Statistics Bureau of Japan, 2007; Bureau of Infrastructure, Transport and Regional Economics of Australia, 2009; U.S. Census Bureau, 2010). As shown, per-capita car distance increases as per-capita GDP rises. At the early stage of GDP growth, car distance per capita increases rapidly; then the rate of growth slows down gradually to eventually reach a relatively stable level. The figure shows that some Eastern European countries are in a period of rapid increase in per-capita car distance traveled, while developed countries (e.g., the U.S. and Japan) have very little increase. The stable level of per-capita car distance varies across countries, and geographic characteristics of individual countries play a large role. For example, the U.S. and Australia have a very high distance level because their scattered urban distribution pattern, large geographic coverage, and lower population density push people to travel more with private cars. Europeans use cars less compared to Americans because European cities and countries are compact and public road and railway transport services are readily available. Car distance per capita in Japan is the lowest, as a result of the fact that Japan's urban public

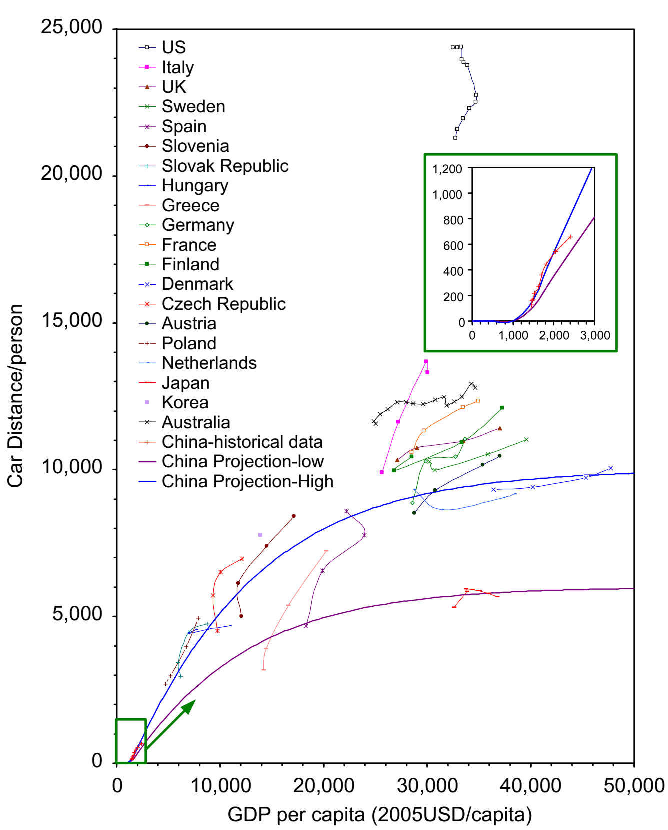

Fig. 7. Growth trend of car distance traveled per capita in selected countries and future car-use scenarios for China.

transport systems are highly developed and most people rely on public transport for travel.

According to the historical experiences of other countries, the urban development pattern, as well as the extent of road network versus railway network, will influence vehicle-use intensity significantly. At present, reinforcement and construction of highways and railways are two strategies to improve Chinese transportation infrastructure. Although there are many future possibilities for Chinese transportation systems, the high population, especially the high population density in Chinese cities, makes it more plausible for China to follow the urban transportation patterns of European countries and Japan. We assume two scenarios for the future car distance per capita in China—a high and a low car-use scenario, in which car distance per capita will follow the trend of European countries and Japan, respectively. Note that these two scenarios correspond to the two car-ownership scenarios assumed in the first paper of this series (Huo and Wang, this issue). The cumulative Weibull function is used to simulate the relationship of per-capita car distance versus per-capita GDP:

$$T = T^{*} \times (1 - e^{-(x-\lambda)^{\gamma}}), \tag{3}$$

where T represents per-capita car distance; x represents per-capita GDP (here we use the projection by the Energy Research Institute of National Development and Reform Commission of China (2009)); λ is the initial per-capita GDP level at which per-capita car distance starts to increase significantly (λ varies by country; for China, from the data in Fig. 7, $\lambda = 1250$ USD/person [2005 dollars]); γ is a shape parameter; and T^{*} is the theoretical stable level of per-capita car distance, assumed to be 6000 km and 10,000 km in the low- and high-use scenarios, respectively (see Fig. 7). With the car distance per capita obtained, the total distance traveled by cars in year i can be calculated by

$$TT_i = \frac{T_i \times POP_i}{\mu_i}, \tag{4}$$

where TT_i represents total distance traveled by cars; T_i represents per-capita car distance; POP_i represents population, as shown in Table 3 of the first paper of this series (Huo and Wang, this issue); and μ is the average load factor for cars, which means the average number of persons carried per trip. For instance, the μ value is about 1.4 in Japan, 1.6 in the U.S. (increasing from 1.59 to 1.64 from 1994 to 2006), and 1.4–1.6 in European countries (1.43 in Germany and 1.55 in France) (Statistics Bureau of Japan, 2007; U.S. Federal Highway Administration, 1993–2009; U.S. Department of Transportation, 2008; European Commission, 2003–2009). To date, there is no information available on the load factor for cars in China. In this study, we assume that the load factor in China is currently 1.5 and will increase gradually to 1.7 by 2050.

Fig. 8 compares the projected total car distance for China with actual data for some developed countries. The total car distance in the selected developed countries shows a very consistent growth trend, and our projection of China's total car distance agrees well with this trend. The total car distance is a comprehensive indicator that is more strongly correlated with fuel demand and CO_2 emissions of cars than car stock level or car VKT. China's total car distance will match the current level of the U.S. (U.S. Federal Highway Administration, 1993–2009) by around 2023 under the high-car-use scenario; the equalization point would be postponed for over ten years under the low-car-use scenario. A comparison with the projections by the U.S. Energy Information Administration (2010) and Singh et al. (2003) on the future total car VKT in the U.S. indicates that China would exceed the U.S. in terms of total car VKT during 2040 and 2050 under the high-use scenario, and impressively, it would remain far lower than the U.S. level under the low-use scenario. Note that the first paper of this series of articles concludes that the stock of private LDVs in China will exceed the

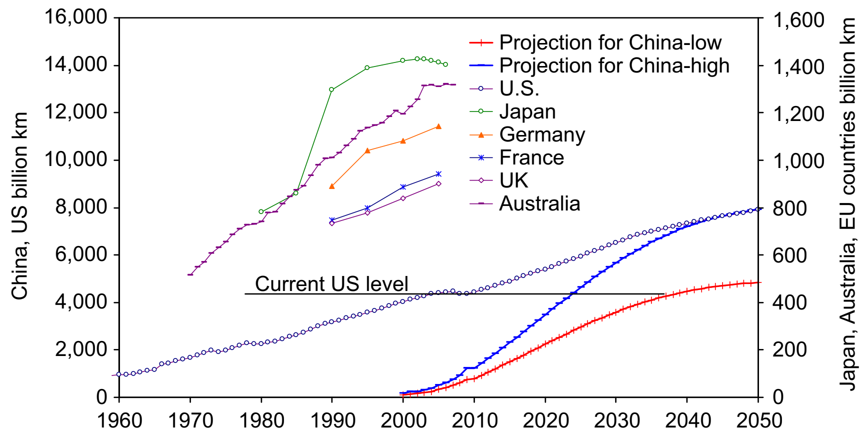

Fig. 8. Total distance traveled by cars in developed countries and projections for China.

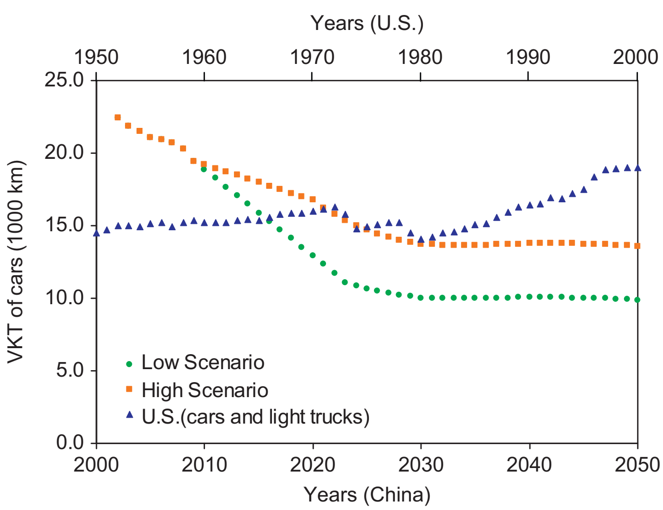

Fig. 9. VKT levels of cars in China under the low- and high-use scenarios, 2000–2050.

concurrent U.S. level by 2022–2024 (Huo and Wang, this issue). High vehicle ownership does not mean high total vehicle distance. This is especially true since we project that Chinese vehicle-use intensity will be lower than U.S. vehicle-use intensity.

The VKT of cars in the future can be calculated from the total distance traveled and the future car stock projected in the first paper of this series (Huo and Wang, this issue). Fig. 9 shows the projected future car VKT in China. During 2000–2050, China's car VKT will gradually decrease over time, as we assumed in our previous studies (He et al., 2005; Wang et al., 2006; Huo et al., 2007). By 2050, the car VKT will be 13,600 km and 9900 km under the high- and low-use scenarios, respectively, compared to the 12,000 km projected in our previous study (Wang et al., 2006; Huo et al., 2007). To the contrary, the VKT of LDVs in the U.S. increased between 1950 and 2000, and is projected to continue to increase until 2030 (U.S. Energy Information Administration, 2010). The trends could be attributed to many factors, such as the differences in national plans for construction of highways and urban railways and the difference in people's choices of transport mode to fulfill new travel needs. China is in a different situation than the U.S. People in the U.S. like to use cars for business, social, and entertainment trips. However, given the foreseeable well-developed railway system, a proportion of people in China would be more likely to take trains for trips, like people in Europe and Japan (Shi and Wu, 2004; Geng et al., 2008). Although previous studies show that people in China tend to drive more for entertainment trips during weekend (Guan et al., 2005), there is little knowledge about the changes in trips for other purposes. Note that the VKT values in Fig. 9 represent lifetime average VKT. In the FEEI model, VKT as a function of vehicle age is calculated on the basis of the average VKT, the decrease in VKT with age (Fig. 5), and the model-year distribution of the car fleet.

3.2. Trucks and buses

Compared to the VKT of cars, the VKTs of truck and buses are related more directly to commercial activities. It is expected that VKTs of trucks and buses will increase as the economy grows. Fig. 10 provides VKT values for trucks and the annual growth rate of per-capita GDP in the U.S. from 1965 to 2005. As shown in Fig. 10, the fluctuation in truck VKT roughly matches the changes in per-capita GDP. We use an economic elasticity method that relates VKT to per-capita GDP to estimate the VKT of trucks and buses for China, as shown by

$$VKT_i = VKT_{i-1} \times f_i(GDP_p), \tag{5}$$

where i represents year and f_i is the economic elasticity, which is related to economic development (per-capita GDP). The subscript p represents per capita.

The f_i is difficult to derive for China because time-series VKT data for buses or trucks are not available. We assume the elasticity values on the basis of historical U.S. data, with a few adjustments. Table 6 presents the projected VKT values of buses and trucks in China. Because there is so little information on actual VKTs of buses and trucks, the results are subject to some uncertainties, and this issue needs to be explored in the future when additional Chinese data become available.

4. Discussion

Because of the lack of extensive VKT surveys and statistics in China, VKT estimates for Chinese vehicles have been substantially insufficient, and these limitations have inevitably affected the accuracy of previous attempts to project total fuel demand and CO_2 emissions from vehicles. This is especially problematic in assessing effects of energy and emissions-abatement policies in the Chinese road transportation sector.

Our study attempts to collect VKT data in China from our surveys and surveys from other Chinese researchers and organizations, compare Chinese data with those from other countries, and explore the variation patterns of vehicle use in different

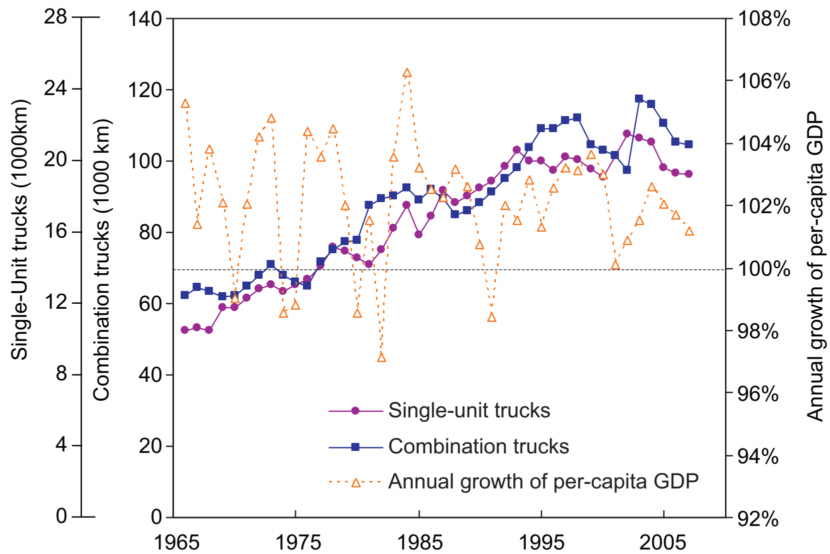

Fig. 10. Variation in truck VKT values and the annual growth rate of per-capita GDP in the U.S., 1965–2007.

Table 6
Projection of VKT values of buses and trucks in China from 2010 to 2050 (1000 km).

	Buses	LDTs	HDTs
2010	106	30	60
2020	111	33	65
2030	116	35	68
2040	120	36	70
2050	125	37	72

countries. We intended to reveal the basic characteristics of VKT in China, which would be beneficial not only to our modeling efforts but also to research efforts by others to examine energy and emission issues for Chinese motor vehicles.

The data we collected have uncertainties, but have improved the current understanding of vehicle use in China. It is important to point out that even though a lot of work has been done in this area, this study is far from achieving an overall and comprehensive understanding of vehicle use in China because (1) the numbers of vehicles sampled in Chinese surveys – including ours – are not sufficient and (2) surveyed Chinese regions are limited. Some important issues are not well addressed in this study because of the data limitation. Such issues include the VKT of commercial buses and HDTs. Thus, the VKT of Chinese vehicles requires further study. A better understanding of the Chinese VKT will require concerted effort and support from various governmental sectors, especially for data accessibility and sharing. Meanwhile, we will continue to expand our surveys geographically, update the VKT parameters on the basis of new results, explore new sources for large-scale first-hand VKT data, and seek collaborations with government authorities and funding agencies.

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