A Comparative Study on Urban Transport system and Related Environmental Impact in Asian Mega-cities: Beijing, Shanghai and Tokyo

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1. Introduction

Rapid urbanization is a distinctive feature of Asia, especially for East Asia. During 1980 and 2000, the annual average urban population growth rate was about 3.6% for East Asia, 1.5 times the world average level. In particular, the potential of urban growth is tremendous in China. After the Open Policy, the urban population in China increased with a growth rate of 5% every year. The urbanization of China accelerated with the urbanization level increasing from 18% in 1978 to 31% in 1999, and is estimated to be 48-50% in 2020 [IMURA, 2000; DRCSC, 2002].

Development of megacities in East Asia region is another distinctive feature. In 1950, there was only one city with the population over 10 millions in the world, New York. By 1975, that number had risen to five, and two (Tokyo and Shanghai) were in the East Asia region. In 2000, Beijing and Seoul became another two megacities with more than 10 million inhabitants. Tokyo is the largest city in the world, with 26.4 million inhabitants in 2000, and it is estimated to maintain its leading status through to 2015, although its population may be not increasing. Beijing and Shanghai, the largest cities in China in terms of both urban area and population, develop most rapidly and both play significant role on Chinese economic and social development. Urbanization combined with rapid industrialization has been particularly pronounced in Korea over the past 40 years. In 1998 the population of Seoul is about 10.3 million, about one-fourth of the total (WCSD, 2001; World Bank, 2000a). Table 1 compares the socioeconomic characteristics of the four cities (BSB, 2002; SSB, 2002; Zhu, 2001; STPG, 1997; Lu, 2000; World Bank, 2000b)

In the urban development, transportation system stands on a crucial position for its indispensable role on urban economic activities. Transport system not only greatly facilitates the commercial activities and improves the communion efficiency, but also improves the life quality of the citizens by offering convenient and fast journal and bringing them the commodity thousands of miles away. As the rapid progress of urbanization, the transport sector develops rapidly with increasing motor number, passenger and freight traffic volume. In the meantime, transport sector gradually becomes the largest contributor on oil consumption and urban air pollution, and becomes a concern of oil depletion, GHGs emission and local air deterioration, which greatly impacts the human health and sustainable development of the cities, and has further negative influences on the human development.

Table 1. Socioeconomic characteristics of the study cities, 2001

	Beijing	Shanghai	Tokyo	Seoul
GDP/capita (US$)	3060	4500	32700*	8870*

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Population (million)	13.6	16.0	26.4	10.6
Population Density (pop./km²)	2526	2872	5384	9285
Vehicle Ownership (per 1000 capita.)	110	48	450	222
Journey frequency (times/pop. Day)	1.80 (1986) / 2.20 (2000)	1.79 (1986) / 1.95 (1995) / 3.00 (2001)	2.8 (1988) / 3.4 (1998)	-
Percentage of Journal for Work (%)	30.2 (1986)	27.7 (1995)	16.0 (1998)	-
By Private Transport (%)	-	1	29	-
By Public Transport (%)	-	37	49	-
By Motorcycle, Bicycle and foot (%)	-	62		-

* National level

This paper aims to study the environmental impact of transport system of three East Asian megacities: Beijing, Shanghai, and Tokyo. There are four sections in this paper. The first part describes and compares urban and transportation system among these four megacities (Seoul is included in this part). In the second part, the experiences on fuel consumption control and mobile emission control are summarized and their future planned efforts are analyzed, then the future environmental impacts (including oil consumption, CO_2 emission and key pollutant emissions) are simulated, this part of computation will be finished by a mathematical model, which is developed by the authors. The third part mainly compares the simulation results and analyzes the transport develop trend, then policy suggestions are provided for the development of high efficiency, clean, safe and sustainable transport system of these megacities. Finally, Prospective and suggestions for future work are provided at the end of this paper.

2. Characteristics of urban transportation system

2.1 Vehicle population

Figure 1 shows the vehicle population and vehicle ownership per 1000 persons in the four cities. Vehicle population increase most rapidly in Beijing with an annual growth rate of 17%. Because of the strict policy of private car development, the increase trend of vehicle population is much slower in Shanghai even with relative high GDP level. In Seoul, the increase rate of vehicle population began to slow down recently. While vehicle population in Tokyo seems to reach saturation point in 1990 and trended to be stable after 1990. The year in which the vehicle population reached to 1 million in Tokyo, Seoul, Beijing, and Shanghai is 1961, 1990, 1997, and 2010 (estimated), respectively. At present, the vehicle ownership in Tokyo is about 500 per 1000 persons, 2.5 times in Seoul, 5 times in Beijing, and 10 times in Shanghai.
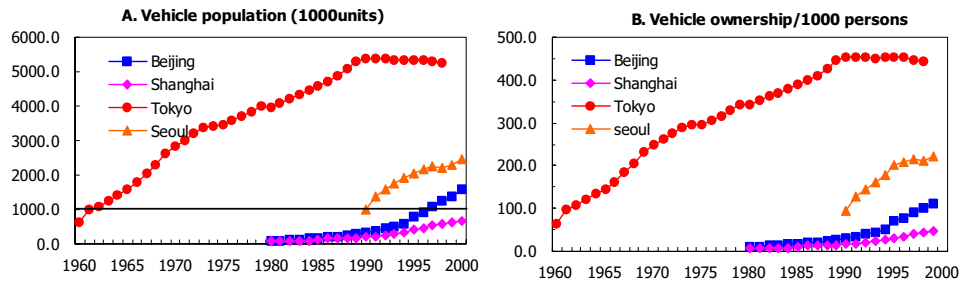
Figure 1. Vehicle population in the four cities

2.2. Urban transport infrastructure

2.2.1 Road

Urban roads play a critical role in forming the basic urban framework. In the cities, a lot of investment has been made to widen existing roads and to build new roads, including urban freeways. Figure 3 compares the urban transport infrastructure in the four cities. The characteristics of urban transport infrastructure are quite different among the four megacities. The road area per capita is the largest in Tokyo, about 12 square meters, while is very low in Shanghai and Beijing. However, the road area per capita in Shanghai has increased rapidly since 1990.
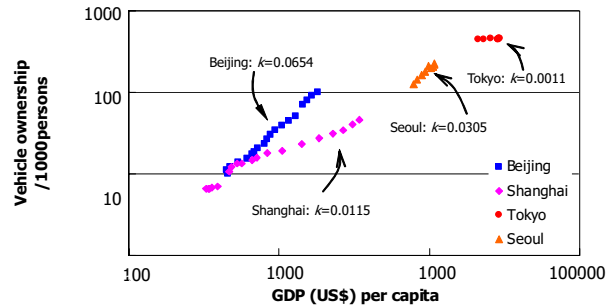

Figure 2. Vehicle ownership per 1000 person Vs. GDP per capita

As Figure 3B shows, generally speaking, the vehicle population per km road length is increasing in all the cities. This increase trend is the extremely obvious in Beijing, indicating that transport infrastructure has not been able to keep up with the significant growth in the number of vehicles in Beijing. Between 1979 and 1999, Beijing's road length increased nearly 100%, while Beijing's vehicles increased about 17-fold to 1.46 millions, and passenger travel volume by 4.4 times to 98.8 million person-times during the same period. Figure 4 shows the urban road net of Beijing and Seoul.
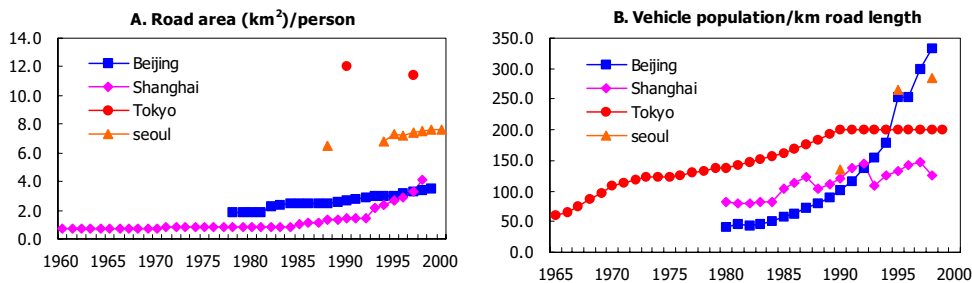

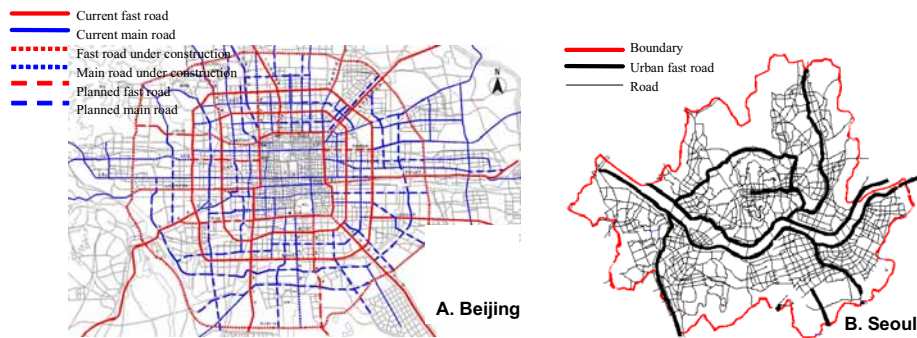**Figure 3.** Comparison of road infrastructure

Figure 4. Urban road network

2.2.2. Urban railway

Table 2 compares the urban subway construction in the cities. In Beijing and Shanghai, the urban railway system is immature, with the sum of railway length only half of that of Tokyo. Figure 5 shows the urban railway net of Beijing, Tokyo, and Seoul. Beijing will make great effort to develop urban railway system. Besides the current 3 lines of urban rail, Beijing plan to construct 10 more lines by 2008, as shown in Figure 5-A. At that time, the total urban railway length will be 252 km. In Seoul, The total urban railway length in operation is 134km. At present, the Seoul government began new construction of four more lines. When completed, the whole subway length will be 280km. Tokyo has the most perfect urban railway system in Asia, even in the world. The Tokyo Metropolitan Region (TMR)'s rail network totals 2,143 km in route length, by far the world's largest.

Table 2. Information about urban rail construction

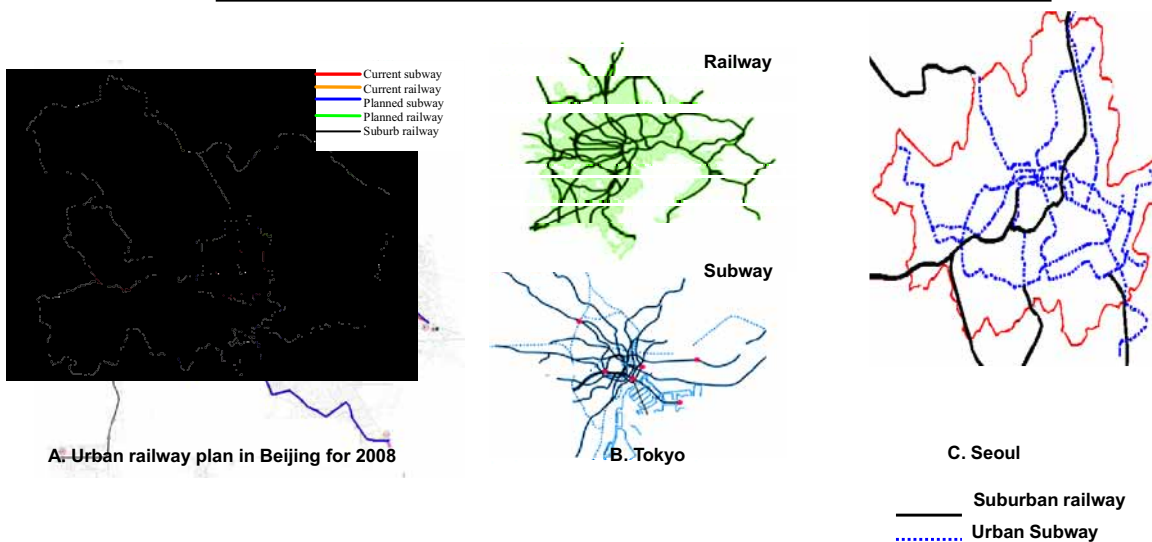|	Beijing	Shanghai	Tokyo	Seoul
Total length (km)	55.1	65.0	248.7	134
Number of station	45	48	235	115
Number of line	3	3	12	4

Figure 5. Urban railway network

2.3 Transport mode

Figure 6 compares the transport mode in the cities as measured in passenger-times. In Beijing and Shanghai, transport mode have been changed greatly during the 1990s, while in Tokyo and Seoul, it didn't change a lot. In Beijing and Shanghai, Non-motorized transport mode, such as by bicycle and by foot, was the main mode but was decreasing during the 1990s. Public transport, including bus and subway decreased greatly, while private transport mode, such as taxi and private car increases gradually, which inevitably pushed heavy pressure on the urban road transport system. A distinguishing feature of Tokyo's transportation system is its extremely high dependence on railways in comparison with other cities. In Tokyo rail transport accounts for about 45% of total passenger transportation, compared with a 70% dependence on road transport in Seoul and more than 95% in Beijing and Shanghai.
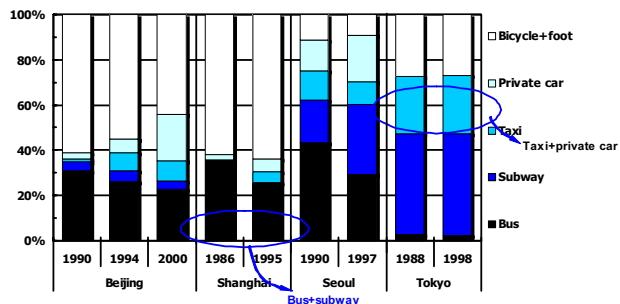

Figure 6. Variation of transport mode in the study

Figure 7 shows the variation of the passenger volume of the public transport system in Beijing and Shanghai during 1990 and 1998. Generally speaking, the passenger volume of the public transport in Beijing increased slightly every year, while decreased greatly in Shanghai. The percentage of buses was the largest, but it was decreasing gradually even with the increasing number of buses during the same period. This imbalance of passenger vehicle number and traffic volume reveal the problems of construction and management in public traffic sector. On the other hand, the passenger volume of taxis increased greatly. For limited coverage of subway, the passenger volume of subway did not vary a lot. Increasing passenger volume of taxis reflect that taxi did satisfy the journey demand of persons with different incomes but also indicated that the lag of public traffic development in Beijing and Shanghai had resulted in the fact of large amount of taxis running on the road. The road area per passenger of taxis is very large, about 5 times that of buses. And, the fuel consumption and pollutant emission per passenger of taxis are also very large, about 10-50 times that of buses. This increase on taxi's passenger volume is adverse to smoothness and cleanness of the cities' transport. Therefore, development of highly efficient mass public transport system to attract passenger should be the orientation of the public transport system. This is the only way for solving the transport congestion issue in Beijing and Shanghai.
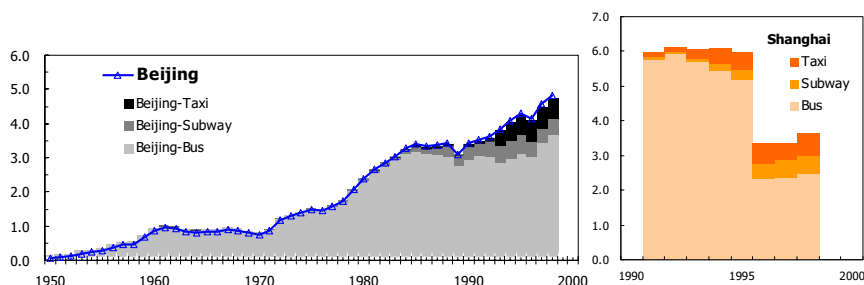

Figure 7. Public transport volume (billion person.times)

3. Simulation of environmental impact of urban transport

3.1 Methodology

The model is a multiple-page Excel spreadsheet with table-formatted inputs, calculations, and a graphical display for presenting results. The spreadsheet model requires the data of vehicle population, fuel efficiency and emission factors of new vehicles, and vehicle kilometers traveled. The model also need some related parameters about fuel specification. The model chooses 6 pollutants, CO, NOx, HC, SO2, PM10, CO2. The latter one reflects the influence on global climate.

A concept of Fuel Economy Deterioration (ratio of the fuel economy of in-use vehicles to the level when they are new ones) is introduced in this model to compute average fuel economy of the vehicle fleet. Base on the age distribution, the fuel economy of new vehicles and the fuel economy deterioration level, the average fuel economy can be computed as following expression:

$$AFE_n = \frac{\sum_{i=1}^{15}\left(VP_n^i \times NFE_{n-i+1} \times DFE_{n-i+1}^i\right)}{VP_n} \tag{A}$$

Where, n-year; i-vehicle age; AFEn-average fuel economy in year n; VPn-vehicle population in year n; VPin-number of vehicles with age of i in year n; NFEn-fuel economy of new vehicles in year n; DFEin-fuel economy deterioration level of vehicles which are initially used in year n and have age of i.

There are a lot of factors that influence the emissions factors like the amount and quality of road infrastructure, age of vehicles, and speeds. Knowing the amount of new vehicles coming in to the fleet and the number that is being scrapped, their new vehicle emission standards and deterioration level for all the types of vehicles, the average vehicle emissions factors can be calculated for each year by a quick rollback method. The method is:

$$AEF_n = \frac{NVP_n \times NEF_n + [VP_{n-1} - NVP_{n-15}] \times AFE_{n-1} + \sum_{i=1}^{15}\left(VP_n^i \times DEF_{n-i+1}\right)}{VP_n} \tag{B}$$

Where, AEFn-average emission factor in year n; NEFn: emission factor of new vehicles in year n; DEFin- emission deterioration level of vehicles which initially used in year n.

This formula is used to computed emission factors of NOx, CO, HC, and PM10. The emission factors of SO2 and CO2 is computed based on the fuel economy and fuel specification. The methods are:

$$SO_2 = S \times f \times \frac{64}{32} \tag{C}$$

$$CO_2 = \left[\left(f - EF_{HC}\right) \times C - EF_{CO} \times \frac{12}{28}\right] \div \frac{12}{44} \tag{D}$$

where: SO2-emission factor of SO2, g/km; S-sulfur content of the vehicular fuel; f-fuel efficiency, g/km; 64, 32-molecular weight of [SO2] and [S] respectively. CO2-emission factor of CO2, g/km; C-carbon content of the vehicular fuel; EFHC, EFCO-emission factor of HC and CO respectively, g/km;12, 28, 44-molecular weight of [C], [CO] and [CO2] respectively.

For a certain year *j*, the Vehicle mileage traveled (VMT) of trucks are calculated as:

$$VMT_{i,j}^F = 10 \times \frac{\gamma_{i,j} \times FTV_j}{\beta_{i,j} \times T_{i,j} \times VP_{i,j}} \tag{E}$$

where, *i* is truck type; $VMT_{i,j}^F$ presents the VMT of freight vehicle of type *i* (10000 km), FTV_j is freight traffic volume (billion ton-kms), $\gamma_{i,j}$ is the ton-km share of vehicle type *i*, $T_{i,j}$ is average load capacity (tons), and $\beta_{i,j}$ is actual load rate of trucks.

The VMT of buses and cars for urban transport in year j is calculated as:

$$VMT_{i,j}^{urbanP} = 10^4 \times 365 \times WH_{i,j} \times Speed_{i,j} \qquad (F)$$

where, i presents vehicle types for urban passenger transport, VMT_i^{urbanP} is VMT of urban passenger vehicles (10000 kilometers); WH_i is work hour per day for vehicle type i (hour/day), for public buses, it is estimated based on public passenger traffic volume (person-times/day), carry capacity, average time for one passenger to finish one journey and number of public buses, $Speed_i$ is average speed (km/h) of vehicle type i.

3.2 Data preparation

3.2.1 Vehicle population

Figure 8 shows the estimation of vehicle population by type in the cities. In Tokyo, the vehicle population increase trend is very slow, and, with the construction of urban railway, the number of buss and trucks will decrease gradually. It is assumed that the percentage of car in Beijing and Shanghai increase most rapidly and the percentage of heavier vehicles decrease steadily. In 2020, the vehicle population in Tokyo, Seoul, Beijing and Shanghai will be 5.34, 3.06, 3.03, and 1.73 respectively. In Beijing and Shanghai, the number of car will be 71% and 69% respectively in 2020, increasing from 44% and 30% in 2020.

3.2.2 Fuel economy

At present, China hasn't any national vehicle fuel economy standards, but related researches are going on. The standards will be implemented in near future and car and small bus will be the target vehicles. For the vehicles fleets not being regulated by the standards, the labeled fuel consumption level will be used as its fuel economy of new vehicles. The fuel economy of cars and small bus in 2020 will be 70% and 60% improved from current level respectively. The years when the standards are going to be implemented are 2006, 2013 and 2018. For other types of vehicles, the fuel economy will be improved 1.5% per year during 2000 and 2005, and 1% during 2006 and 2020. The Japanese government has established a set of fuel economy standards for gasoline and diesel-powered light duty passenger and freight vehicles, with fuel economy targets based on vehicle weight classes. These targets imply a 22.8% improvement in gasoline passenger vehicle fuel economy (15.1 km/l in 2010 vs. 1995 level of 12.3 km) and a 16.0% improvement in diesel passenger vehicle fuel economy (11.6 km/l vs. 10 km/l) compared to the 1995 fleet. Figure 9 shows the variation of vehicle fuel economy in China and Japan.
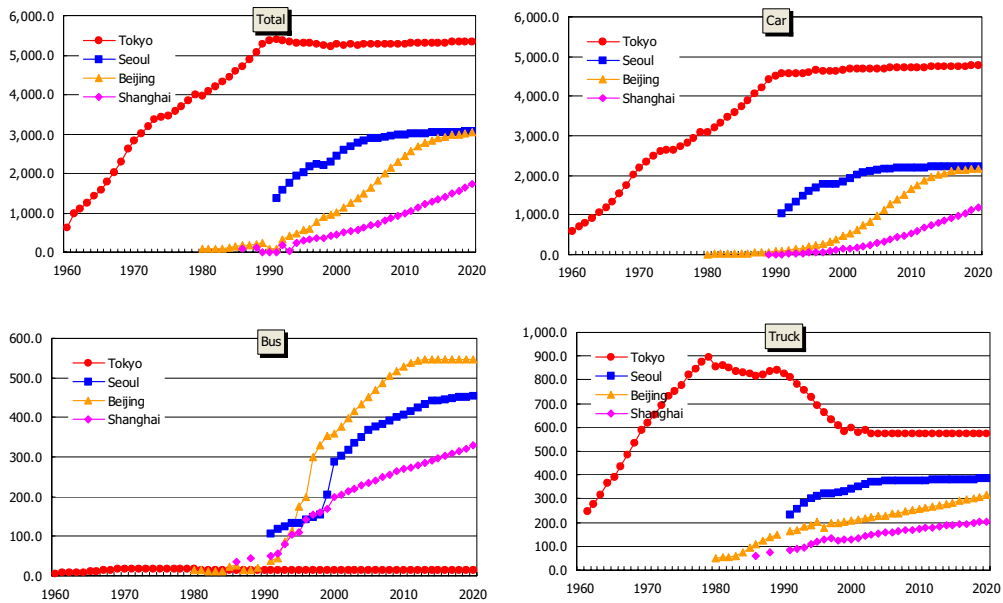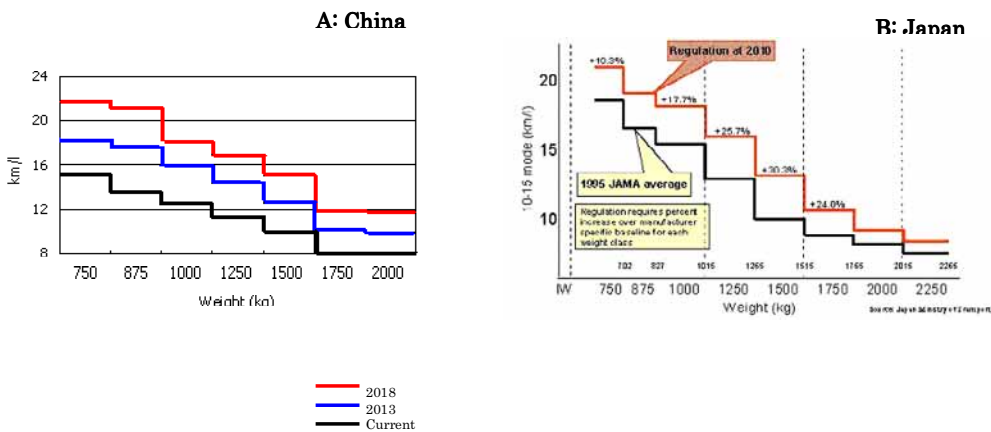
Figure 8. Vehicle population by type (Thousands)

A: China   B: Japan

2018
2013
Current

Figure 9. Fuel economy level of new cars

3.2.3 Vehicle emission control level

Table 3 shows the average emission factors in Beijing (1995), Shanghai (1995) and Tokyo (2000). The 29th Olympic Games will be held in Beijing in 2008 and the municipal government will implement a series of measures to improve the air quality. The methodology takes the national or municipal emission standards as the emission factors of new vehicles. In the future, the government will implement the following measures for vehicle emission control. Table 4 is the vehicle control scenario for Beijing and Shanghai city.

Table 3. Average emission factors in Beijing (g/km)

	Beijing			Shanghai			Tokyo		
	NOx	CO	HC	NOx	CO	HC	NOx	CO	HC
Car	1.5	44.2	5.2	2.19	43.67	6.88	0.19	1.23	0.08
Large bus	17.3*	164.6*	29.6*	74.02	160.09	63.39	5.927	2.541	1.042
Small bus	3.2	34.5	5.5	3.2	34.5	5.5	0.19	1.23	0.08

Large truck	9.71	38.48	33.19	9.71	38.48	33.19	3.066	1.764	0.70
Small truck	1.29	1.5	0.1	1.29	1.5	0.1	0.70	4.31	0.343
Motorcycle	0.1	14.4	2.0	0.37	2.58	2.6	0.19	1.23	0.08

* Gasoline vehicles

Table 4. Vehicle control scenario in Beijing and Shanghai

New vehicle	EURO 2, EURO 3, EURO 4, and EURO 5, will be implemented in 2003, 2005, 2010, and 2015 respectively
In-use vehicle	Implementation of ASM inspection since 2001; Development of inspection operating condition suitable for China in 2002; Adoption of remote control inspection Realization of its supervision function in I/M system; Defected vehicle callback system; Establishment of bidding system; Special inspection companies taking in charge of vehicle I/M; Certification of maintenance station; Vehicle obligatory maintenance system; and Remote inspection supervision.
Other	25%, 50%, 75% and 100% of the public buses are refitted into CNGV in 2003, 2005, 2007 and 2010; In 2007, all local taxies are refitted CNGV, LPGV or reach stricter new vehicle standards; Completion of 200 km urban railway; Only vehicles with green label are allowed to ride within the 3nd Ring Road; Only vehicles with green environment protection label are allowed within the 4th Ring Road during air pollution forecast alert; Durability of 160,000km; Improving transportation and increase vehicle speed from 23km/h to 35km/h; Promotion of HEVs and FCVs and encouraging the application of zero-emission vehicles; and Defected vehicle callback system.

On the other hand, Japanese standards for passenger cars fueled by gasoline or LPG have been stable for many years. For gasoline trucks, new standards were implemented around 1994.

3.2.4 Vehicle mileage travel

According to the Formula (E) and (F), VMT is most relevant to total traffic volume (including passenger volume and freight volume) and its structure. Beijing and Shanghai are in the period of rapid development and rapid construction transport infrastructure, the VMT of vehicles will vary greatly in the future. While large variation will not occur in Tokyo. In Beijing and Shanghai, the journey frequency of residents will continue to increase, while development of the urban railway system can share larger part of total passenger traffic volume.

3.3 Simulation results and analysis

3.3.1 Fuel consumption

Figure 10 shows the average fuel economy by type in the three cities. Figure 11 compares the average fuel economy in 2000 and 2020. The fuel economy in Beijing and Shanghai is half that in Tokyo. Figure 12 shows the total fuel consumption and annual oil consumed per vehicle. At present, the vehicle population in Beijing and Shanghai is about 1/10 of that in Tokyo, while their total fuel consumption is only 1/3-1/2 of Tokyo's, which is because of the lower fuel economy and larger VMT in China. In the future, fuel economy should be further improved, and urban transport should be well developed, especially large-scale public transport.
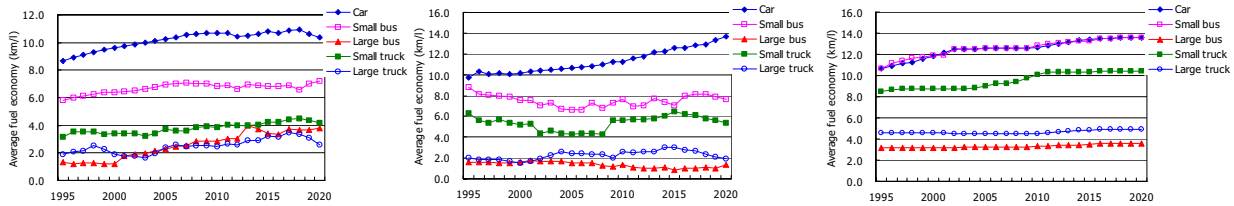
Figure 10. Variation of average fuel economy in Beijing, Shanghai, and Tokyo
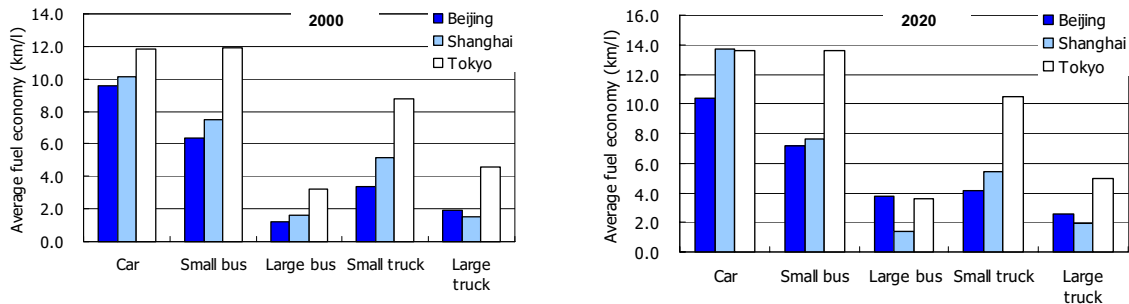

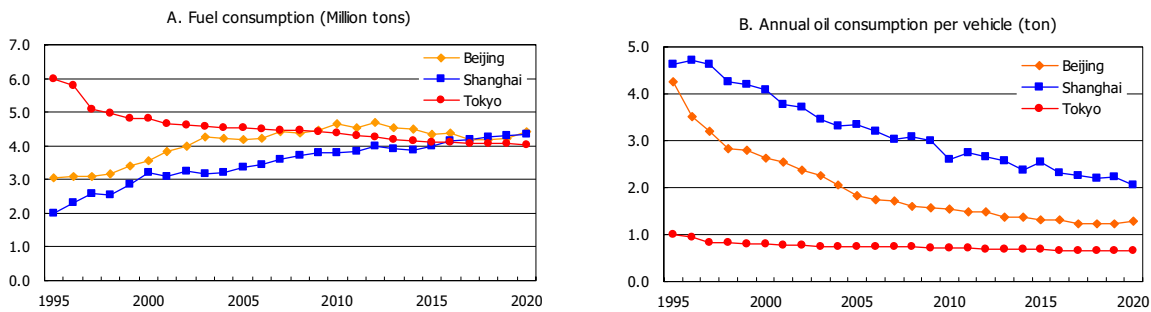**Figure 11**. Comparison of average fuel economy in 2000 and 2020

Figure 12. Fuel consumption in the cities

3.3.2 Pollutants emission

Figure 13 shows the simulation results of vehicular pollutant emission in the three cities. In Beijing and Shanghai, much smaller vehicle fleets emit more amount of pollutants. Therefore, Beijing and Shanghai should further reduce the VMT of vehicles and strengthen control of in-use vehicles, and the former will be depend on the development perfect urban transport system.
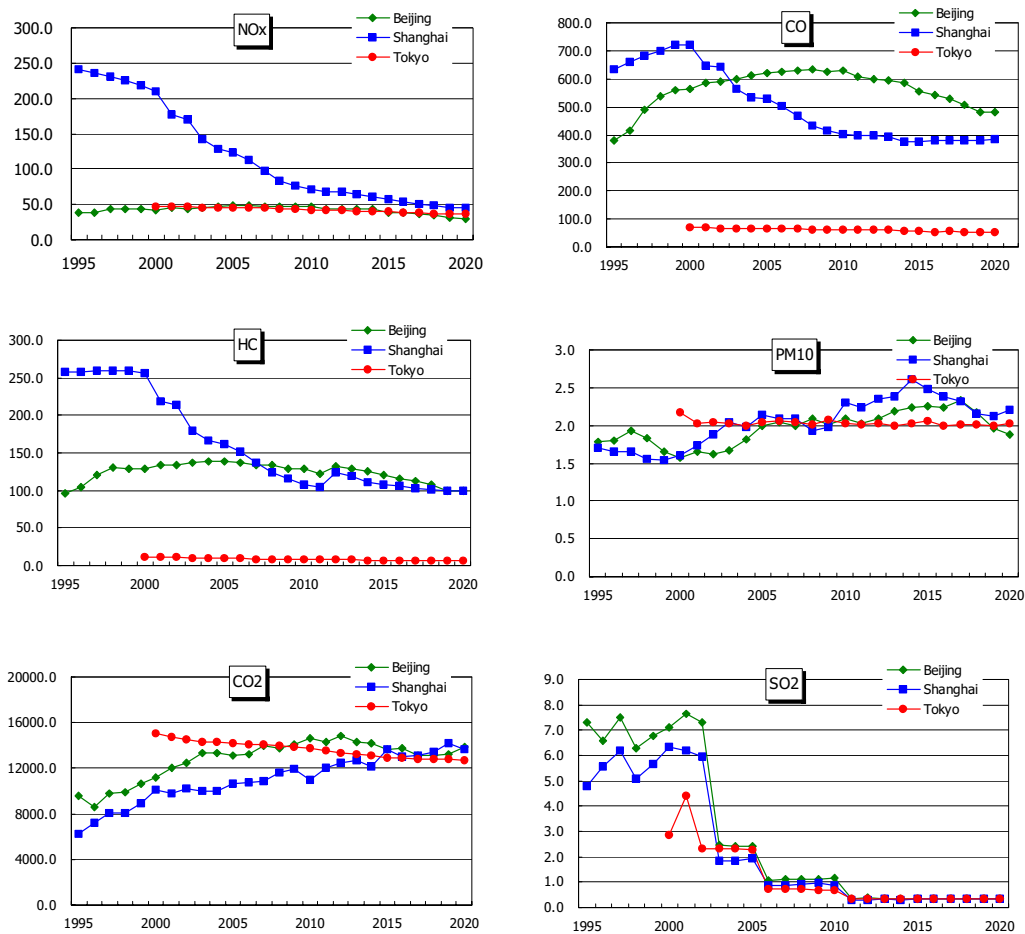
Figure 13. Pollutant emission in the three cities (1000 tons)

4. Perspectives of the future work

The next phase of research work will be focused on the following items:

Improve the data

Improve the scenario

Complete the Seoul case in the simulation

Improve the methodology by integrating urban transport plan in the computation

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