Influence of Urban Railway Development Timing on Long-term Car Ownership Growth in Asian Developing Mega-cities

Kei ITO[a], Kazuki NAKAMURA[b], Hirokazu KATO[c], Yoshitsugu HAYASHI[d]

[a,b,c,d] *Graduate School of Environmental Studies, Nagoya University, Aichi, 464-8603, Japan*
[a] *E-mail: k.ito@urban.env.nagoya-u.ac.jp*
[b] *E-mail: k.naka@urban.env.nagoya-u.ac.jp*
[c] *E-mail: kato@genv.nagoya-u.ac.jp*
[d] *E-mail: yhayashi@genv.nagoya-u.ac.jp*

Abstract: The rapid growth of car use in Asian developing countries causes a variety of problems, such as traffic congestion and increasing environmental damage. The delay of railway introduction is one of the factors for the progress of motorization in each city. This study quantitatively examined the impact on motorization of early urban railway development in Asian developing mega-cities. The impact is modeled using data of metropolises in Japan, China and Thailand. By applying the model to scenarios on railway development in mega-cities of Asian developing countries, the impact of railway development timing is revealed.

Keywords: Motorization, Railway Development Timing, Asian Developing Country, Macro Model

1. INTRODUCTION

The development level of urban mass-transit systems, such as railways, is one of factors that decide the different levels of car use in cities. Car ownership may be kept a low level in a city where a railway system is densely introduced before the growth of car use, as in Tokyo and Osaka. In other words, it can be said that early development of railway system could keep car use at a low level in a long term. Morichi (2005) explained the reason of rapid growth of motorization in Asian developing country that mass transport development is delayed compared with concentration of the population. He also pointed out that reducing passenger car uses becomes difficult when car dependent society appears.

Nevertheless, this hypothesis has not been figured out quantitatively. The spread of car use in motorization has been quantitatively analyzed on different scales. Aggregated data for a city-wide area is used for macroscopic analysis, while disaggregated data for individual behaviors is used for microscopic analysis. Macroscopic analysis is more advantageous for studies on developing countries with the limitation of data availability. In macroscopic analysis, key elements that affect the car ownership and modal share have been accounted for with cross-sectional and time-series data. As a representative example, Newman *et al.* (1999) revealed the relationship between increasing energy consumption and decreasing population density is attributed to increasing car use, using the data of cities all over the world.

For estimating increase in car use in a long-term future of Asian developing countries, such macroscopic analysis can be applied based on the generalized mechanism of motorization progress with more available data for them. Dargay *et al.* (2007) and Tuan (2011) applied macroscopic analysis to forecast long-term growth of car use in Asian developing countries. They analyzed growth in passenger cars for each country with a logistic curve taking GDP as an explanatory variable. Growth in passenger cars can also be modeled with the interactive growth in motorcycles (Leong *et al.*, 2007; Lai *et al.*, 2007). However these models have not reflected the difference in urban structure. Toga *et al.* (2010) estimated long-term changes in car ownership and car use in motorization in large cities in Japan, taking account of the interaction between motorization and urban sprawl. They used the panel data of Japanese large cities in the motorization period of Japan, and estimated CO_2 emissions from passenger cars, which has also been applied to Asian developing cities. However, these studies have not analyzed an impact of railway develop timing on increase in car use.

This study aims to evaluate the impact of railway development timing on reducing growth in car ownership in Asian developing mega-cities with macroscopic analysis. Firstly, we model growth in passenger car ownership to be affected by railway development timing, using the panel data of the largest cities of Japan, China and Thailand. Then, the model is applied to forecasting the long-term growth in car ownership in Asian developing mega-cities.

2. THE MECHANISM OF MOTORIZATION, URABN SPRAWL AND TRANSPORT DEVELOPMENT TIMING

2.1 The General Mechanism of Motorization

Motorization is influenced mainly by economic growth and urban structure change. At first, car ownership rises due to economic growth. Car ownership growth enhances the convenience of movement even in areas with less public transport services, and accelerates the expansion of urban area to suburbs. Interactively, travel distance in cities becomes longer due to urban expansion, and the convenience of car use becomes higher. Car-dependent society is formed by the synergetic effect between urban expansion and car use diffusion. This mechanism of motorization growth could be summarized as follows (Figure 1).

1. Urban sprawl: Urban area is expanded by population growth and road development according to economic growth.
2. Car ownership increase: The rate of car ownership in population increases by rise of purchasing potential due to economic growth. Car ownership increases further by car-dependent urban spatial structure.
3. Road-oriented infrastructure development: Road development is promoted to catch up with growing car traffic demand in car-dependent city.

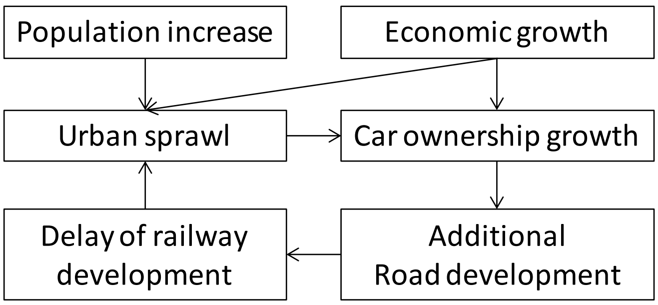

Figure 1. The mechanism of moralization

The mechanism suggests that railway development could calm motorization. In cities with more railway development, it is expected that population density is kept higher thanks to less urban sprawl. Railway users who do not possess cars prefer location close to stations compared to car users. In a city with more urban railway development, high-density residential area is developed around stations. Changes in urban structure are long-term phenomenon because urbanized areas are not easily changed back to undeveloped land. Therefore, early railway development could keep population density higher, which could calm car ownership growth more.

2.2 **Data Overview of Megacities in Asia**

The motorization mechanism can be empirically analyzed with the data of macroscopic indicators. This study uses the data in Tokyo, Osaka, Nagoya, Beijing, Shanghai, and Bangkok. As macroscopic indicators, it took total population, Gross Regional Product (GRP) per capita, urban area, urban population, rail length, road length, and car ownership rate. In Table 1, their data sources used in this study are showed. As an urban area, we defined high population density area in each city. In Japanese cities, Densely Inhabited District (DID) is taken as urban area, which is available as long-term data. DID is defined as an area with population density higher than 4,000 person / km2 and population more than 5,000 person. In the cities of Asian developing countries, we defined urban area as an area with population densities higher than 4000 people / km2. Population density in the cities of Asian developing countries is measured, using time-series population mesh data.

Table 1 The data of macroscopic indicators

City	Indicator	year	Source
Tokyo Osaka Nagoya	Total population	1960-2010	National Census of Japan
	Urban population	1965-2010	
	Urban area	1960-2010	
	Road length	1970-2010	Japan City Statistics
	Railway length	1970-2010	Rail line time-series data: Ministry of Land, Infrastructure, Transport and Tourism
	Car ownership rate	1965-2010	Japan City Statistics
	GRP	1965-2010	
Beijing	Total population	1960-2010	Beijing statistical yearbook
	Urban population	1990-2010	NASA: Population Count Grid, v1 (1990, 1995, 2000) Land scan TM (2000,2005,2010)
	Urban area	1990-2010	
	Road length	1960-2010	Beijing statistical yearbook
	Railway length	1970-2010	Subway history: Beijing Subway <http://www.bjsubway.com/node/199>
	Car ownership rate	1995-2010	China statistical yearbook
	GRP	1965-2010	Beijing statistical yearbook
Shanghai	Total population	1980-2010	Shanghai statistical yearbook
	Urban population	1990-2010	NASA: Population Count Grid, v1 (1990, 1995, 2000) Land scan TM(2000,2005,2010)
	Urban area	1990-2010	
	Road length	1960-2010	Shanghai statistical yearbook
	Railway length	1995-2010	Metro Map: Shanghai Metro <http://www.shmetro.com/node155/node159/201004/con103744.htm>
	Car ownership rate	1995-2010	China statistical yearbook
	GRP	1980-2010	Shanghai statistical yearbook
Bangkok	Total population	1980-2010	Office of the national economic and social development board
	Urban population	1990-2010	NASA: Population Count Grid, v1 (1990, 1995, 2000) Land scan TM(2000,2005,2010)
	Urban area	1990-2010	
	Road length	1960-2010	Land Transport Management Bureau, Department of Land Transport
	Railway length	1995-2010	Structure of Routes and Stations Bangkok Mass Transit System Public Company Limited. <http://www.bts.co.th/corporate/en/02-structure01.aspx>
	Car ownership rate	1995-2010	Land Transport Management Bureau, Department of Land Transport

	GRP	1990-2010	Office of the National Economic and Social Development Board

Figure 1 shows the relationship between GRP per capita and urbanization rate. Urbanization rate is defined with the share of population in urban area respect to the total population of a city. Urbanization rates of cities in Japan have remained high from the early stage of urban growth. Urbanization rates in Beijing, Shanghai and Bangkok are increasing with GRP. The further influx of people to urban area due to the economic growth is expected

Further urbanization would increase the pressure of urban expansion. Figure 2 shows the relationship between GRP per capita and urban area. Changes of urban area in Japanese cities are small. In Beijing, Shanghai, and Bangkok, more expansion of urban area is in progress by more concentration of population into urban area.

Figure 3 shows the relationship between GRP per capita and urban population density. Population density is gradually decreased in Japanese cities, due to urban sprawl. In the cities of Asian developing countries, population density has decreased as a result of urban expansion, but the pace is significantly affected by changes in urban population.

Figure 4 and Figure 5 show the relationship of GRP per capita with respectively road intensity and railway intensity in urban area. Compared to Japan, these intensities have been still at a low level in Asian developing countries. Overall, the intensities have increase as the economy has grown. This tendency is clearer in road intensity. On the other hand, changes in railway intensity vary more by city between Japan and Asian developing countries and even within Asian developing countries, in which Shanghai has the highest increase in the intensity.

Figure 6 shows the relationship between GRP per capita and passenger car ownership rate (1000 capita vehicle ownership). In all cities, passenger car ownership rates have increased with GRP per person but the car ownership rates in Asian developing countries have been rising rapidly than Japan. The difference about the rates of car ownership growth can be explained by the difference in transportation infrastructure development of each city. In particular, the relationship between car ownership and railway intensity is observed with the data. The passenger car ownership rate rises relatively slowly in the city with high railway intensity, and a sharp rise in car ownership has occurred in the cities with low railway intensity.

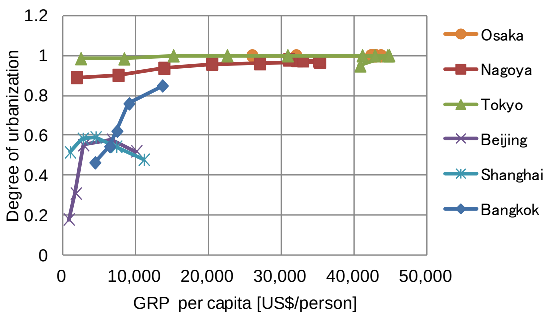

Figure 1 Urbanization rate

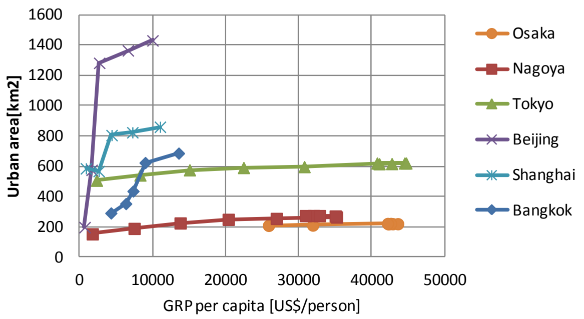

Figure2 Urban area

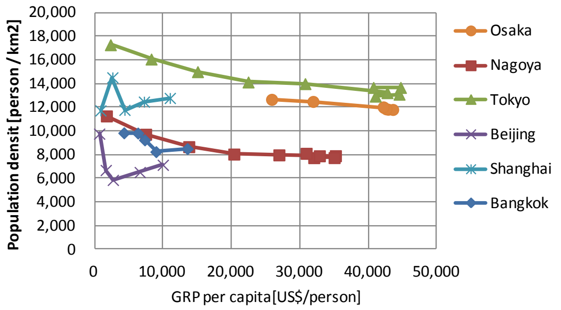

Figure 3 Population density

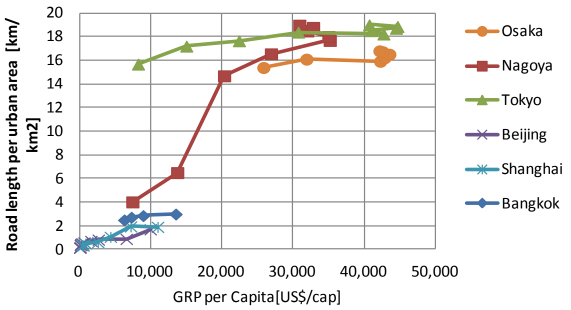

Figure 4 Road intensity

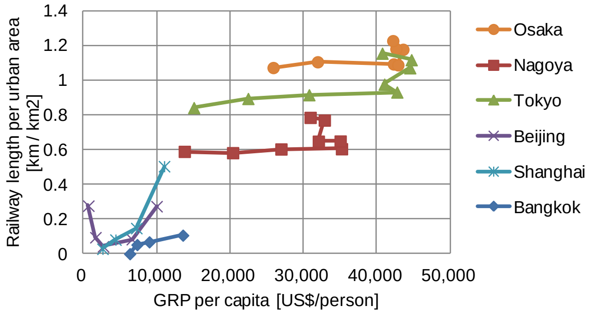

Figure 5 Railway intensity

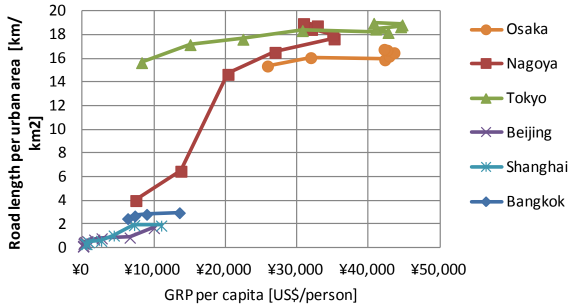

Figure 6 Car ownership

3. MODELING THE MECHANISM OF CAR OWNERSHIP GROWTH

3.1 Model Structure

This study constructs a macroscopic model with the city-wide panel data of Tokyo, Osaka, Nagoya, Beijing, Shanghai, and Bangkok, to simulate the impact on car ownership growth of railway development timing. The model has been originally developed with the data of Japan and has been applied to Asian developing meg-cities (Nakamura *et al*. 2012). This model is advantageous for representing long-term gradual motorization process with macroscopic indices, taking account of the interaction between urban sprawl and car ownership growth. It estimated future growth in car ownership in Asian mega-cities, under the assumption that Asian developing mega-cities would have the similar impact of railway development on car ownership to the impact experienced in Japan. This study has developed the model further by introducing the panel data of Asian mega-cities for the last decades to represent more rapid changes of macroscopic indicators in Asian developing countries.

The estimation model consists of three parts; (1) urbanization model, (2) urban expansion model and (3) car ownership model. Each model represents the process of urban growth and motorization at three stages; (1) urbanization from migration of residents from non-urbanized areas to urbanized areas, (2) urban sprawl from central area in suburbs in urbanized areas, (3) motorization from increased demand for cars.

3.2 Urbanization Model

The degree of urbanization is defined as the percentage of population who live in urbanized areas to the total population in a city. It is modeled in equation (1) with population density in inhabitable areas. Table 2 shows the results of parameter estimation.

$$U = \frac{1}{1 + \beta_1 \cdot \exp(-\beta_2 \cdot D_h)} \qquad (1)$$

U: degree of urbanization (population / total urban population), D_h: population density in inhabitable area (person/ km^2), β: parameters.

Table 2. The parameters of urbanization model

Independent Variables	Parameter	t score
Population density in inhabitable area β_2	$6.06*10^{-4}$	0.848
Constant β_1	11.2	1.66
Adjusted R-squared	0.88	

3.3 Urban Expansion Model

In this model, expansion of urbanized area is determined by the positive impacts of population growth and economic growth and the negative impact of railway development, as in equation (2). Table 3 shows the results of parameter estimation.

$$\Delta_u = \alpha_1 \Delta_p + \alpha_2 \Delta_g + \alpha_3 r + \alpha_4 \qquad (2)$$

Δ_u: Change of urban area, Δ_p: Change of urban population, Δ_g: Change of GRP per capita, r: Railway length per city area, α: parameter.

Table 3 The parameters of urban expansion model

Independent Variables	Parameter	t score
Change of urban population α_1	0.45	5.35
Change of GRP per capita α_2	0.0533	2.21
Railway length per city area α_3	-0.0775	-1.77
Constant α_4	0.00887	2.34
Adjusted R-squared	0.69	

In this model, the data is used for every five years. The model makes it possible to represent the differentiated impact from railway development timing by modeling the level of change in urban expansion. The coefficient value about the change of urban population is more than one, which means that population growth leads to the larger-scale urban expansion. From equation (1) and equation (2), population density in urbanized area can be estimated.

3.4 Car Ownership Model

Car ownership is modeled, referring to the previous model developed by Kato *et al* (1997). This estimation model incorporates indicators of economic growth and changes in urban structure, which can represents income growth, and low density development in Asian developing cities. This model is formulated as Equation (3).

$$C = \frac{K}{1 + \gamma_1 \cdot \exp(-\gamma_2 \cdot G / P_c)} \qquad (3)$$

C: passenger car ownership ratio (person / 1000 units), G: GRP per capita, P_c: car price,

γ: parameter, K: Automobile market potential

Car ownership model is based on a logistic curve to an economic growth variable. Equation (3) represents the economic level as the constraints of car ownership. When the economic level grows, car ownership growth depends more on "Car market potential" K because economic constraint becomes smaller. K is differentiated by city. Kato *et al.*(1997) used a Cobb Douglas function is used to model K with population density and road development level as explanatory variables. In the parameter estimation of this study, only population density is adopted as a variable of K formulated in equation (4).

$$K = \delta_1 D_u^{-\delta_2} \quad (4)$$

Here, D_u: urban population density, δ: parameter.

Table 4. The parameters of car ownership model

Independent Variables	Parameter	t score
GRP per capita/Car price γ_2	4.49	10.0
Constant γ_1	7.81	2.48
Urban population density δ_2	1.18	14.2
Constant δ_1	$1.55*10^7$	12.0
Adjusted R-squared	0.59	

4. ESTIMATION OF LONG-TERM CAR OWNERSHIP GROWTH IN ASIAN DEVELOPING MEGA-CITIES DEPENDING ON RAILWAY DEVELOPMENT

4.1 Socioeconomic and Development Scenarios

We applied the above regression models to Beijing, Shanghai and Bangkok, and estimated car ownership growth in each city from 2010 to 2050. As socio-economic scenario, we set future changes in population and GRP in each city , referring to existing forecasts for them. Figure 7 shows population scenario, and Figure 8 shows scenarios of GRP per capita. Based on the socio-economic scenario, we compared car ownership in 2050 calculated under following development scenarios about railway development, and quantitatively evaluated the inhibiting effect of railway development timing on car ownership growth. In early railway development scenario and later railway development scenario, additional 300km railways are developed in each city. The time lag of railway development is set at 20 years.

1) No railway development : There is no development of new railway beyond 2010
2) Early railway development : To introduce 20km railway annually from 2016 to 2030
3) Later railway development : To introduce 20km railway annually from 2036 to 2050

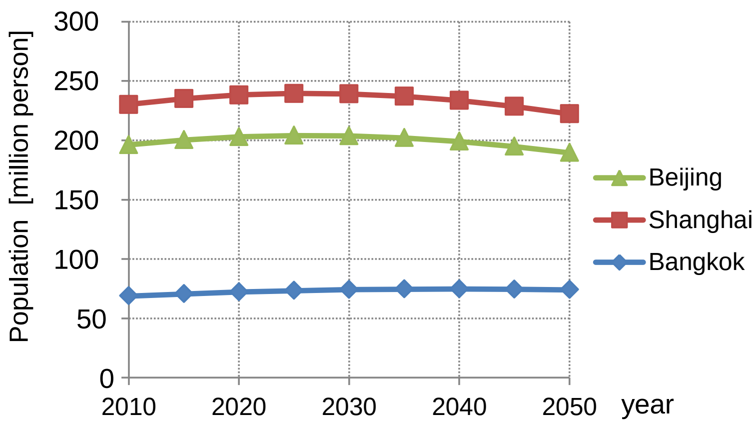

Figure 7. Future scenario of population

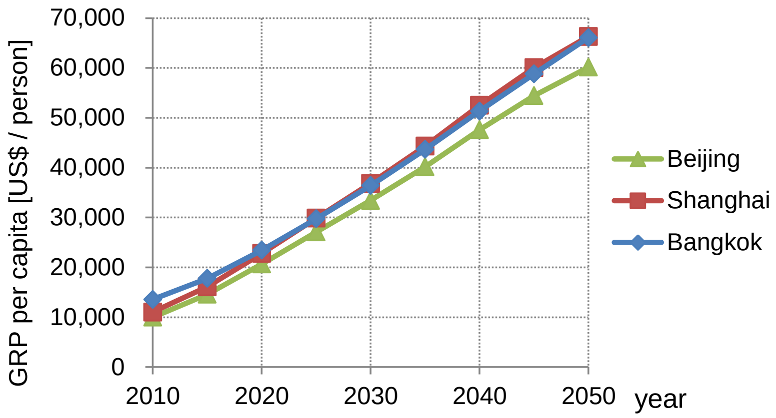

Figure 8. Future scenario of GRP per capita

4.2 Estimation Results of Car Ownership Growth

Figure 4 shows the results of the car ownership estimation in Beijing, Shanghai and Bangkok, by applying the model. Table 5 shows how much passenger car ownership growth could be calmed by railway development in 2) to 3) compared to 1).

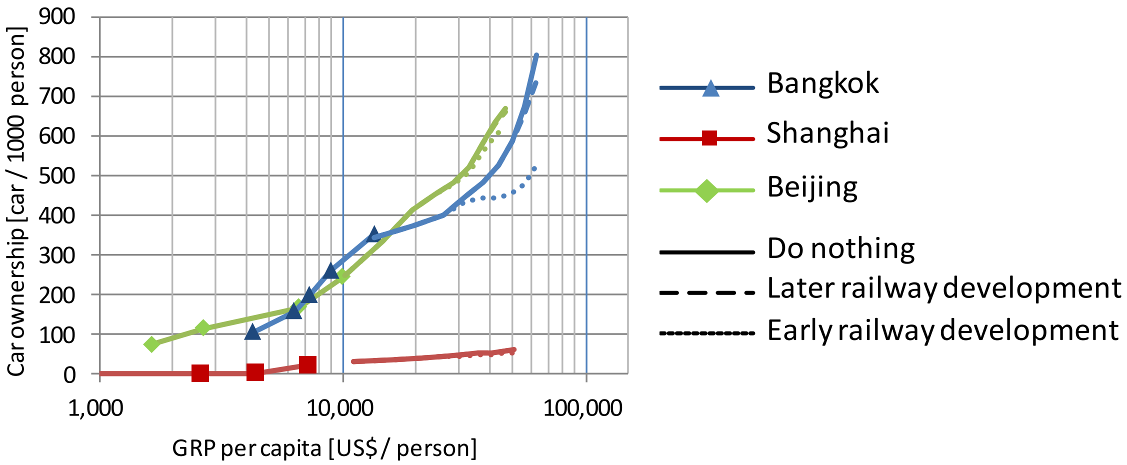

Figure 9. Long-term changes in car ownership growth in mega cities in Asia

Table 5. The difference of the reduction rate of car ownership growth by railway development scenario compared to the No railway development scenario (%)

	Bangkok	Shanghai	Beijing
Early railway development	38.6	7.0	14.3
Later railway development	9.9	1.5	11.1

Car ownership growth is the highest in Beijing with a rapid increase. In the other cities, car ownership growth is equivalent to large cities in Japan. The effect of early railway development on decreasing car ownership growth appears after 2030 significantly, especially in Bangkok. In the early railway development scenario, the car ownership rate in Bangkok would decrease by about 38% than that in No railway development scenario. One reason for this result is that population in Bangkok would be reduced by about 36% from the peak in 2015. Population decline would lead to decreasing the pressure of urban expansion, which is advantageous for improving the effect of railway development. There is the same trend of car ownership growth in Beijing, where car ownership growth would be reduced when population growth becomes stable. The timing of railway development would also significantly affect long-term changes in car ownership growth. The 20-years gap in the timing of railway development between 2) and 3) would lead to the four-times difference of the reduction rate of car ownership growth in Bangkok in 2050.

5. CONCLUSION

In this study, we built a model to test the hypothesis that motorization could be calmed by early railway development. Then, we estimated the long-term change in car ownership considering the development timing of urban railways in mega-cities in Asian developing countries.

As a result, it showed that growth in car ownership could be significantly calmed by early railway development. Early railway development can calm car ownership growth by 5-30%. By implementing such measures earlier, motorization can be calmed more, which is important to achieve low carbon transport systems in Asian developing cities.

ACKNOWLEDGMENT

This research was supported by the Environment Research and Technology Development Fund (S6-5) of the Ministry of the Environment, Japan.

REFERENCES

Morichi, S. (2005) Long-term Strategy for Transport System in Asian Megacities, the 6th International Conference of EASTS, Bangkok, September 21.

Newman, P., Kenworthy, J. (1999) Sustainability and Cities,Island Press, 101

Dargay, J., Gately, D., and Sommer, M. (2007) Vehicle Ownership and Income Growth, Worldwide: 1960-2030, *Energy Journal*, 28(4), 143-170

Tuan, V.A. (2011) Dynamic Interactions between Private Passenger Car and Motorcycle Ownership in Asia: A Cross-country Analysis, *Journal of the Eastern Asia Society for Transportaion Studies*, 9, 541-556

Leong, L.V., Mohd.Sadullah, A.F. (2007) A Study on the Motorcycle Ownership: A Case Study in Penang State, Malaysia *Journal of the Eastern Asia Society for Transportation Studies*, 7, 528-839

Lai, W., Lu, J. (2007) Modeling the Working Mode Choice, Ownership and Usage of Car and Motorcycle in Taiwan, *Journal of the Eastern Asia Society for Transportation Studies*, 7, 869-885

Yang, Z., Feng, T., Jia, P. (2005) Maximizing Car Ownership under Constraints of Environment Sustainability in a City *Journal of the Eastern Asia Society for Transportation Studies*, 6, 3077-3089

Tuan, V. (2011) Dynamic Interactions between Private Passenger Car and Motorcycle Ownership in Asia: A Cross-country Analysis *Journal of the Eastern Asia Society for Transportation Studies*, 9, 541-556

Toga, T., Kato, H., Hayashi Y. (2010) Long-term forecast of passengers transport sector CO_2 emissions considering the process of motorization development in large cities in Asia *The 17th Symposium on Global Environment*, 67-74.

Nakamura, K., Kato, H., Hayashi, Y. (2012) Forecast of motorization progress considering railway improvement timing in Asian developing mega-cities. *Journal of Japan Society of Infrastructure planning and management*, 68(5), I_823-I_830. (in Japanese)

Kato, H., Hayashi Y. (1997) Analyses and Modeling of Passenger Car Ownership Rate Considering Economic Growth Level and Urban Structure Civil *Traffic Engineers*, 32(5), 41-50

United Nation (2011) World Urbanization Prospects, The 2011 Revision

Sachs, G. (2003) Dreaming With BRICs, The Path to 2050, *Global Economics Paper*, 99