A Backcasting Approach to Designing Low-Carbon Urban Transport Systems for Asian Developing Cities - Application to Bangkok -

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Abstract

As Asian developing countries become more responsible for CO_2 emission from the transport sector according to their rapid economic growth, it is more important for them to design desirable low-carbon transport systems. In Asian developing cites, motorisation accelerated by higher car affordability has been making their transport systems more car-dependent and less environmentally friendly. To decouple their motorisation with economic growth, new transport systems need to be introduced as much as developed cities in a leapfrog manner. However, there are difficulties in designing the desirable systems, such as diversity, lack of data and uncertain future of Asian developing cities.

This study develops a system to identify the basic design of desirable low-carbon systems of urban passenger transport for Asian developing cities in 2050 with a backcasting approach by referring to the experience of Japanese cities. Low-carbon transport strategies to reduce travel demand (AVOID), to shift travel to lower-carbon modes (SHIFT) and to improve intensity of transport-oriented emission (IMPROVE) are applied to setting the vision of a desirable transport system and designing a policy package to achieve it. Using the data of Japanese cities and Bangkok over the period of motorisation, a simplified urban model is integrated with a backcasting approach to identify the potential effects of the strategies and the necessary contributions of them to meeting the targeted CO_2 mitigation. The application of the model to Bangkok identifies the required levels of measures by transport strategy for 70% CO_2 mitigation from 2005 to 2050.

INTRODUCTION

As more countries set challenging targets of CO_2 mitigation, it becomes more important to identify desirable systems of low-carbon transport with a backcasting approach than examining probable changes in existing systems with a forecasting approach. Traditionally, land-use transport planning has applied urban models and transport models to estimating the impacts of probable impacts of transport measures on an existing urban land-use transport system as a forecasting approach. In a backcasting approach, more effort is required to identify the necessary impacts of transport measures to achieve the targeted benefits, despite their probability.

This approach is particularly suitable for designing transport systems for Asian developing cities. While Asian developing countries still have many low-carbon cities at the early stage of motorisation, their rapid economic growth could cause more serious environmental problems than developed countries. In order to decouple growth in CO_2 emission from economic growth, it is an important and urgent issue for Asian developing cities to develop low-carbon transport systems. Such a low-carbon transport system should be designed in a leap-frog manner with extensive application of advanced technologies and strong intervention to transport infrastructure development and spatial development.

However, there is difficulty in designing desirable transport systems there. Land-use and transport databases are not well-established in Asian developing cities, which make it difficult to capture the potential effects of localised transport measures. Furthermore, even if the current data is available, it does not help account for uncertain future in Asia, which is expected to change a lot due to the rapid economic growth. Accordingly, it is useful to identify the basic design of desirable transport systems for Asian developing cities in future by referring to the experience of developed cities.

This paper sets the vision of a desirable low-carbon system of urban passenger transport for Asian developing cities by combining three types of low-carbon transport strategies; to reduce travel demand (AVOID), to shift travel to lower-carbon modes (SHIFT) and to improve intensity of transport-oriented emission (IMPROVE). These strategies are suggested to be effective for Asian developing cities (1). This study is aimed at developing a system to identify the desirable combination of low-carbon strategies for urban passenger transport to achieve the target of CO_2 mitigation for Asian developing cities in 2050 with a backcasting approach. First, the future vision of desirable low-carbon transport systems for Asian developing cities and a policy package to achieve them are designed based on low-carbon transport strategies. Then, a simplified urban model is developed to analyse the potential effect of each transport strategy on CO_2 mitigation in Asian developing cities. Finally, the model is applied to identifying the required levels of measures of low-carbon transport strategies to achieve 70% of CO_2 mitigation in Bangkok from 2005 to 2050.

STRATEGIES TO ACHIEVE A DESIRABLE LOW-CARBON TRANSPORT SYSTEM

There are two key aspects of a backcasting approach; setting future visions of transport systems and designing policy packages to realise the visions (2). First, the future vision of a low-carbon transport system is set in a desirable manner. The vision could cover a range of factors, which is hardly defined with specific ones. As for the concept of the desirable system, CO_2 mitigation is not the only benefit, but there are some other benefits, including accessibility and mobility. Although these benefits need to be considered in designing the system, this study is focused only on the benefit of CO_2 mitigation for simplification.

In terms of the physical form of a desirable low-carbon transport system, this study set the vision based on the combination among three types of low-carbon transport strategies; to reduce travel demand (AVOID), to shift travel to lower-carbon modes (SHIFT) and to improve intensity of transport-oriented emission (IMPROVE) (Fig.1). These strategies were originally proposed in a project called CUTE (Comparative study on Urban Transport and the Environment) conducted by WCTRS (World Conference on Transport Research Society) SIG11 for Transport and Environment. The project classified transport measures according to strategies and instruments in a systematic way as the CUTE matrix (3). This strategic classification has become popular and been generally used in academic research and policy making.

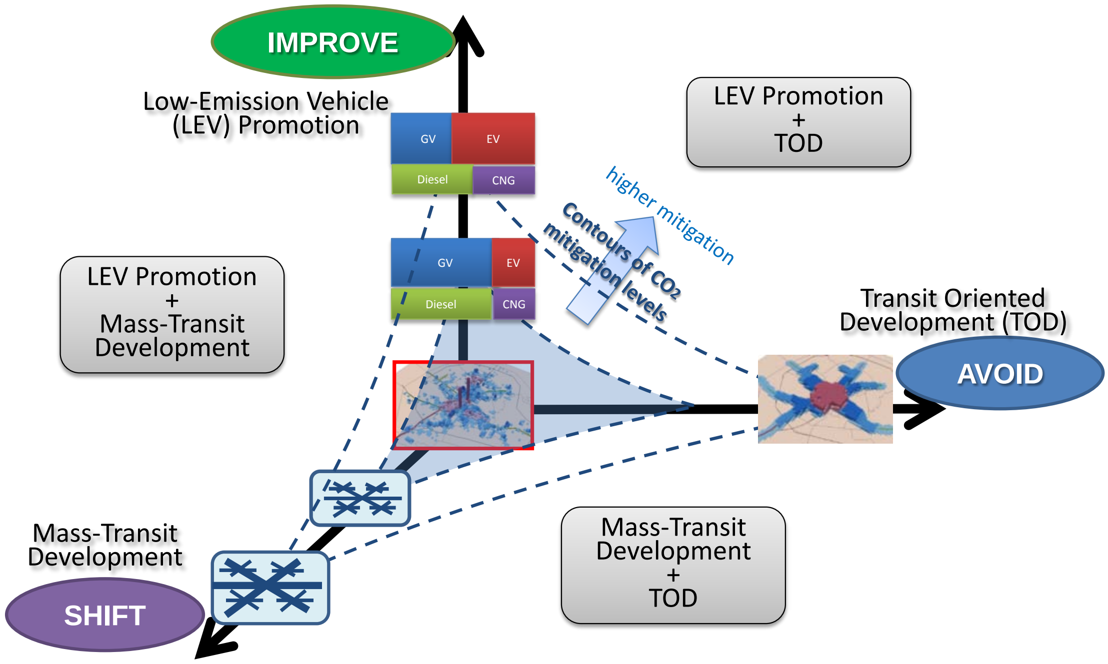

FIGURE 1 An approach to setting the future vision of a low-carbon urban transport system.

By setting the vision of a low-carbon transport system with the strategies, the design of policy packages to realise it is translated into identifying the levels of measures by transport strategy to meet the target of the total CO_2 mitigation. The CUTE matrix classifies transport measures in each strategy into technological, regulatory, informational and economic instruments. Their effects are significantly affected by the existing levels of transport infrastructure development and spatial development. Thus, transport measures suitable for Asian developing cities need to be identified.

Improve

The IMPROVE strategy may be the most straightforward approach, as vehicle technologies have kept improved for less CO_2 emission. Conventionally, the regulation of emission standards has been introduced into many Asian countries. However, CO_2 has been unlikely to be covered by them. In Japan, both of fuel economy and emission intensity have been regulated for the last decade by a top-runner programme, in which latest technology levels will be set as minimum requirements for future production in 5 years.

The regulation has helped to develop Low Emission Vehicles (LEV), such as Hybrid Vehicles (HV) and Electric Vehicles (EV). Asian car industries have been strong, led by Japan and Korea, and have become stronger with rapid growth in developing countries, particularly China. In fact, fuel economy in these Asian countries is relatively high in the world (4). It reflects the high potential of LEV development, as the Japanese and Korean governments have invested in it. The high level of vehicle technologies may increase their availability for nearby Asian developing countries.

Recently, economic instruments to promote LEVs have become increasingly popular in combination with regulatory instruments. In Japan, the government has provided subsidies to purchase LEVs. Thanks to them, the number of HVs was doubled from 2009 to 2010.

Shift

While mass-transit systems have already been developed in developed cities, they need to be developed in developing cities to provide sufficient levels of mobility to meet their growing demand. This is especially the case of Asian developing cities which face rapid growth. They have increased their investment in transport infrastructure development to establish city-wide transport networks. However, to reduce traffic congestion caused by growing motorisation, many of transport policies in Asian developing countries have prioritized road development over railway development. This approach would rather induce more car traffic in the long term and consequently more CO_2 emission as shown in the high level of growth in car ownership there (Fig.2).

Since the late 20th century, mega cities in Asian developing countries have started to develop urban railway networks. Bangkok's planning in the 1960s was designed for a car-dependent city based on American-style development, as in Los Angeles, by constructing large roads with many lanes, while railway development was almost ignored. However, despite extensive road development, their road capacities could not meet the growth of road traffic demand. As a result, many of employed population took several hours for commuting, where roads were fully packed with cars for years. Recently, public transport development has started in Bangkok. They opened Skytrain in 1999, underground in 2004 and airport rail in 2010, which has amounted to approximately 80km.

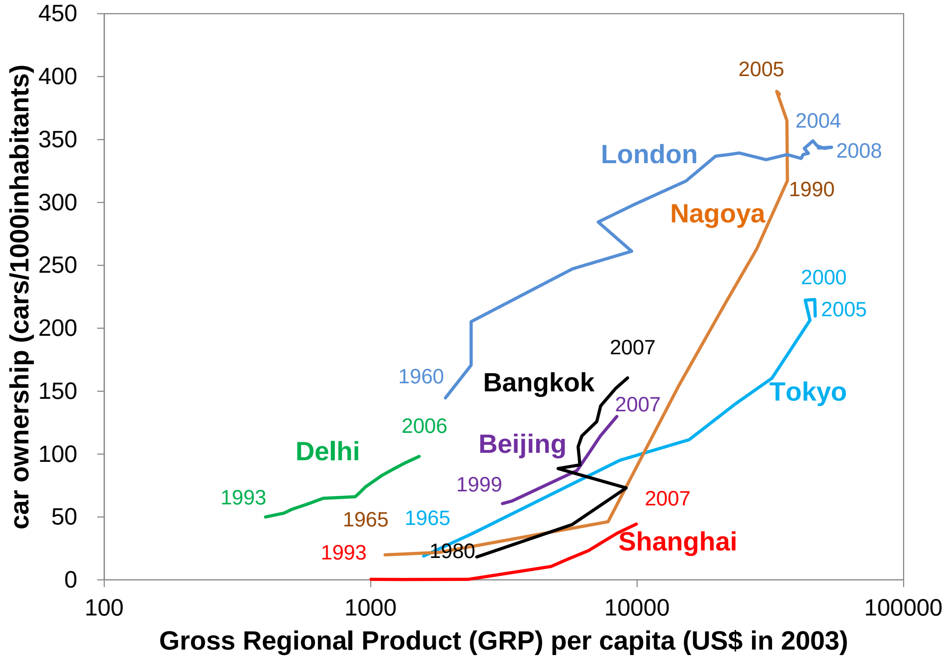

FIGURE 2 Changes in car ownership according to economic growth

The scale of road construction has been greater in Chinese cities. Chinese government has actively supported domestic car industries as their key sector of economic growth. In China, the amount of investments in road development is 4 times larger than the amount in public transport development (5), which enables them to construct highways at an exceptionally high pace, around 4,000km per year. While their investments in public transport development are not as much as the investments in road development, the large amount of investments has also been made into railway development. For urban public transport, investments in underground have amounted to 1 and 1.7 trillion US$ per year respectively in Beijing and Shanghai. Shanghai has developed the largest-scale underground network in the world, 420km in total in 2010, to prepare for the EXPO, which still continues to develop further extension.

However, mega infrastructure development is not always affordable. In South America, some developing cities have introduced Bus Rapid Transit (BRT), which is a bus system with the extensive network of dedicated lanes, giving their priority to the development of low-cost public transport. While the BRT network is as large as a railway network, it does not need extensive infrastructure construction. Thus, it can provide a city-wide transport system with reasonable cost, in which the development cost is around 10-30% of that of normal railway.

BRT was introduced into Curitiba, Brazil, in 1974, as the earliest example, and into Bogota in 2000. Bogota's system is operated without help of public subsidies. Curitiba has successfully increased the ridership of BRT by 2.3% per year in average for the last 20 years (6), in which 28% of BRT users shifted from cars (7). The modal share of Bogota's BRT has been increased from 6% in 2001 to 18% in 2006, while that of cars has dropped from 15% to 11% (8).

BRT has become popular in Asian developing cities, such as Bangkok and Jakarta. Jakarta's BRT, which was open in 2004, has been developed to the largest-scale network in the world.

Avoid

High-density development has strategically been introduced along transit lines. In Japan, urban railway companies have taken initiative to develop new towns around their lines by themselves to secure railway users as their customers since the early 20th century. Singapore implemented a masterplan to expand the city by concentrating development along transit lines in 1970 together with development of mass-transit trunk lines. In South America, Curitiba introduced a zoning system of high-density development along the BRT lines. In this development, high-density zones are designed on 2 street blocks from the BRT lines for less-car-dependent areas, while the density is lower in areas farther from the lines (8). These can be seen as preceding examples of Transit Oriented Development (TOD).

While the effects of such compact development on CO_2 mitigation are suggested to be limited in developed cities these days (9), they may be more effective in Asian developing cities because of completely different socio-economic trends. Asian developing cities are likely to have exceptionally large amount of new development as motorisation and urban sprawl are accelerated by rapid economic growth. Bangkok city has expanded their built-up area 4 times larger for the last 40 years, which has become equivalent to the scale of the region of Greater London. According to the estimation from ATRANS (10), per-capita car trip distance in Bangkok has become nearly double than that in London. This difference may be caused by the failure of transport policies in Asian developing cities by prioritising road development. Although some of them might be too motorised and sprawled to be developed in compact urban forms, there are many Asian cities which are still at the early stage of motorisation and urban sprawl. Thus, compact development can be much more effective through railway development to concentrate new development around stations in developing cities than in developed cities.

CO_2 EMISSION CAUSED BY ECONOMIC GROWTH AND THE EFFECTS OF TRANSPORT MEASURES ON THE MITIGATION

In drawing road maps to realise the desirable visions, the expected effects of low-carbon transport strategies need to be captured. Comparative studies on CO_2 emission among international cities have been likely to analyse the cross-sectional relationship between factors of an urban land-use transport system affecting the emission, as in the well-known relationship between population density and energy consumption (11). As the simplified causality mechanism of emission, Kaya's Identity (12) has captured the impact of economic growth and been popularly applied to accounting for the level of emissions with a set of key factors, such as population, GDP per capita, energy use per unit of GDP and emissions per unit of energy consumed. In transport, key factors affecting emissions are identified as trip generation (travel distance), car dependency (modal split) and technology level (emission factor), which are respectively associated with the AVOID, SHIFT and IMPROVE strategies.

However, these approaches do not sufficiently consider paths of dynamic changes in factors of land-use and transport. The paths may be different between developing cities and developed cities. In developing cities, transport measures can significantly affect the paths due to prospective economic growth. To capture the impact of transport measures on the paths, each of trip generation, car dependency and emission factor needs to be further decomposed to more detailed factors affecting them, which individually affects the level of emissions. Changes in one factor could affect other factors, which would consequently affect the effect of CO_2 mitigation in a complex way. Accordingly, policy packages among transport measures can be designed to make the path in a low-carbonised way.

In this aspect, a backcasting approach is not necessarily incompatible with urban modelling. As urban models are popular in a forecasting approach, they are advantageous to estimate the dynamic impacts of transport measures on an urban land-use transport system. In fact, it is suggested that urban modelling needs to be improved to be applicable to a backcasting approach (13).

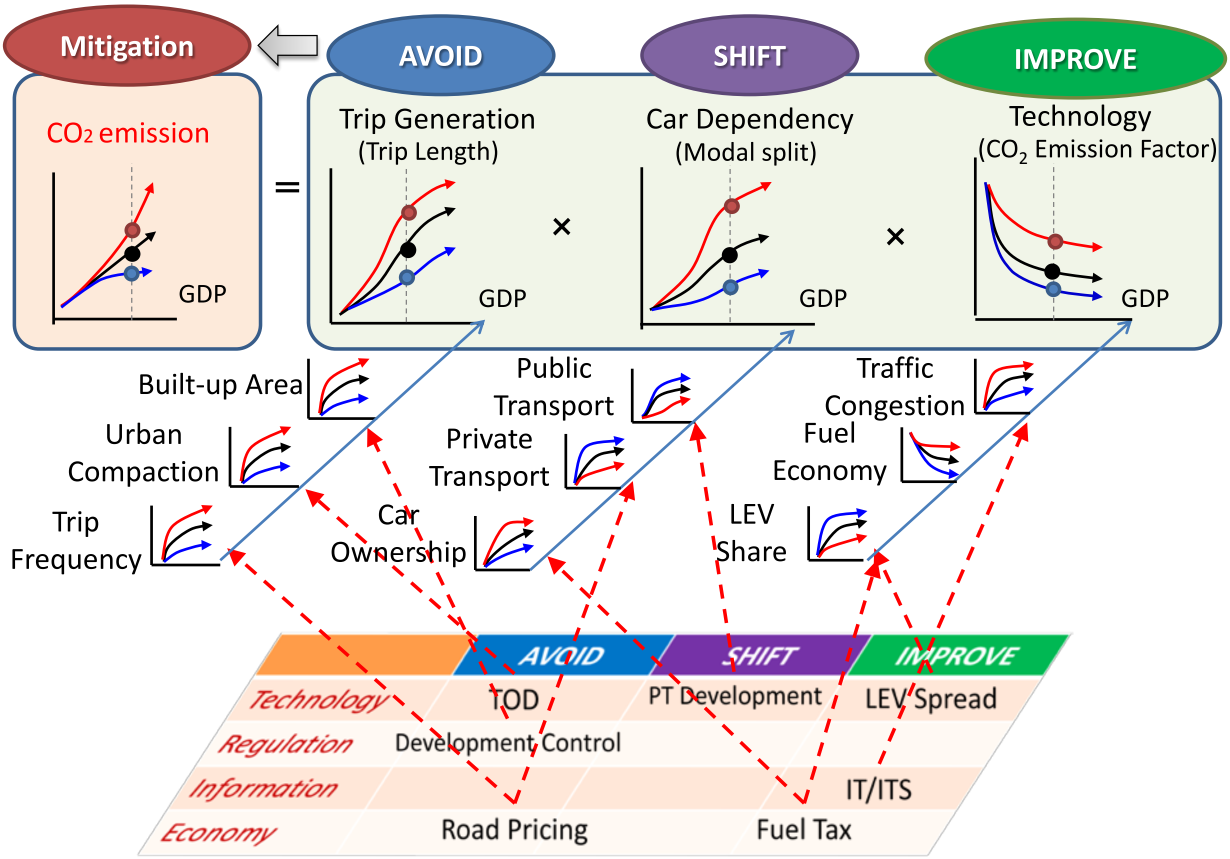

FIGURE 3 CO_2 emission mechanism in an urban land-use transport system and the impacts of transport measures

Accordingly, this study applies a simplified urban model, which models the relationship among key factors of land-use, transport and technologies, to identifying necessary measures by transport strategy to meet the targeted level of CO_2 mitigation in Asian developing cities (Fig.3). It is focused on the effects of vehicle technology advancement for IMPROVE, mass-transit development for SHIFT and compact development for AVOID. To analyse these effects of low-carbon transport strategies, it estimates CO_2 emission from intra-city trips by passenger cars by modelling motorisation, urban sprawl and technology advancement (Fig.4). The aim of the modelling is not to estimate probable changes in land-use and transport, including technologies, with current data, but to estimate the potential changes based on the hypothesised causality of CO_2 emission from urban passenger transport. This model is run every 5-year periods from 2005 to 2050.

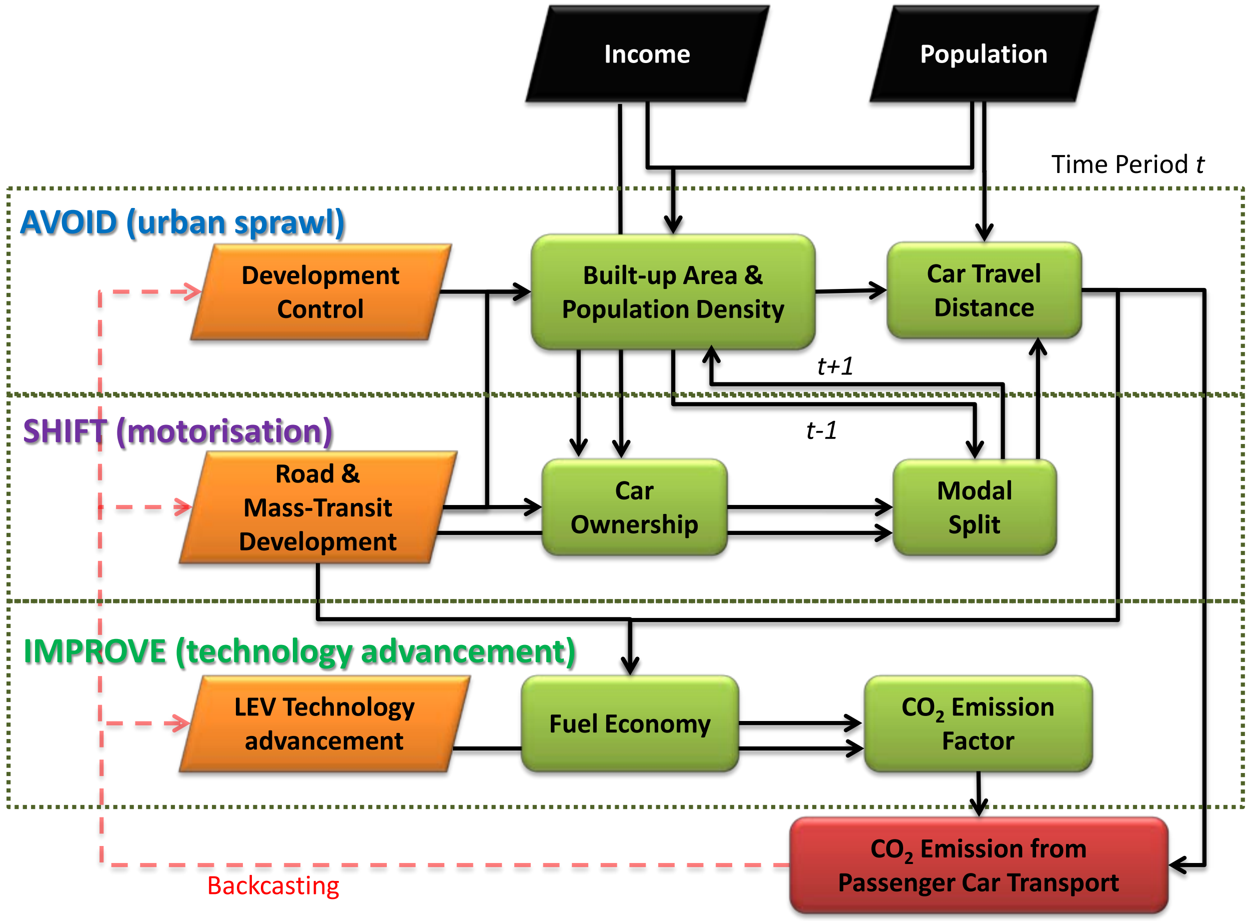

FIGURE 4 The framework of the models for motorisation, urban sprawl and technology advancement

Data for Modelling Analysis

While urban models are likely to be data-intensive, this study develops a simplified urban model, consists of a transport model and a residential location model, with generally available primary data of Asian developing cities. While transport models often input configuration of transport networks, this model is simplified with the input of city-wide data by translating transport networks into road length and station density to built-up area. The advantage of this simplified model is better applicability to Asian developing cities to capture the generic impact of economic growth on the emission from urban transport without detailed input data which are unlikely to be available there.

In this study, the data for the transport model was complemented by Japanese panel data over the period from 1960s to 2000s based on the assumption that Asian developing cities would have similar changes in travel behaviour from economic growth to Japanese cities. City-wide data of Japanese large cities in their motorisation period was collected from person-trip surveys and socio-economic, transport and land statistics, which include the number of trips, trip distances, modal split, vehicle speeds and CO_2 emission factors by vehicle type in addition to their population, income and land-use data.

This study collected data of Bangkok as the case study city. The available statistic data for the last decade includes population, income, car ownership, road lengths, the number of stations and vehicle-type shares. A residential location model is developed with more spatially-detailed data. Population data, including moving population, is available by district. While it is much more difficult to collect land-use data, built-up area by district can be collected from GIS land-use data and the share of domestic use can be estimated with population density.

The Model for Motorisation

This model accounts for the mechanism of motorisation in such a way that economic growth and road development would increase car ownership and consequently car use. On the other hand, it models the impact of urban railway development on calming motorisation by increasing railway use. Urban railway represents mass-transit modes, including BRT.

The parameters of this model are calibrated with data of Japanese largest cities and are adjusted to match the estimation with available data of Asian cities (14). As railway use is much lower in Asian developing cities than in Japanese cities at the same economic level, the parameters are adjusted. For future forecast, the model assumes that railway use become more popular as the networks are developed more. Accordingly, the parameters are set to be changed proportionally to the relative level of station density to the density of Tokyo in 2005.

Car ownership C (1000 cars/household) is estimated with population density d (people/km^2), road length per person r (m/person) and household income standardised by vehicle price I. In this model, car ownership would be increased by income growth and road development, whilst calmed by high-density development.

$$C = \frac{9.31 \cdot 10^5 \cdot r^{0.142} \cdot d^{-0.869}}{1 + 8.26 \cdot \exp(-0.578 \cdot I)}$$

Using the estimation, modal share is modelled for the three ranges of distance per trip, the shortest (0-2km), middle-distance (2-13km) and longest (13km-) ones. The overall modal share is calculated by multiplying the share of trip distance with modal share within each distance range. Each share of trip distance, TS_s for the shortest, TS_m for the middle and TS_l for the longest, is estimated with population density and built-up area S_b (km^2).

$$TS_s = 1 - TS_m - TS_l$$
$$TS_m = -0.348 \cdot d + 3.6$$
$$TS_l = 0.131 \cdot S_b - 0.414$$

The model estimates modal share P_m of each transport mode m, such as car use and railway use, at a city-wide level, taking account of the impact of economic growth and infrastructure development. The share is estimated with their general characteristics chr_m along with parameters π_m, as car use and railway use are increased respectively by increases in car ownership and station density to built-up area.

$$P_m = \frac{1}{1 + \exp(\pi_{m1} \cdot chr_m + \pi_{m2})}$$

The Model for Urban Sprawl

In the model for urban sprawl, the impact of motorisation on spatial development is modelled to estimate increase in car travel distance through expansion of built-up area, which is fed back to further motorisation as the interactive process. Development control can be introduced by controlling the percentage of new development not allowed to expand built-up area. The model takes account of the impact of railway development on growth in built-up area, where railway development can slow sprawl by locating more households around stations.

This model estimates growth in built-up area with a change in spatial distribution of households by modelling residential location choice of move-in households mainly over 50 districts in Bangkok Metropolitan Area (BMA) with an aggregate logit model. The number of move-in household HI in each district i in the time period t is estimated with probability to choose residential location of the total number of households in the study area HIT_t, depending on their preferences for locational characteristics $X_{t,i}$ and the existing number of households $H_{t-1,i}$.

$$HI_{t,i} = HIT_t \cdot \frac{H_{t-1,i} \exp(\alpha \cdot X_{t,i} + attr_i)}{\sum_k H_{t-1,k} \exp(\exp(\alpha \cdot X_{t,k} + attr_k))}$$

Location behaviours of car-dependent households and rail-favoured households are differently modelled. The number of each type of households is estimated from the estimated modal share of urban transport in the previous time-period. To account for urban sprawl, the location of car-dependent households is modelled for their preference for a larger land plot per household. On the other hand, to account for the impact of railway development, the location of rail-favoured households is modelled for their preference for less travel time to a city centre by railway. To estimate future changes in location choice, this model assumes that changes in the locational behaviour of rail-favoured households would start from 2025 when urban railway networks are sufficiently established. The parameters for preference α for land plot size and residual locational attractiveness *attr* are calibrated with the current data of BMA. The parameter for preference for public transport access is set based on the previous survey for accessibility in Japan (15).

Growth in built-up area ΔS_b in each district is estimated with growth in households there by modelling the supply side of land development, which is summed up as the total growth in the study area. While land is developed as the location demand becomes higher, land plot size is decreased as more households are located in the district. The sensitivity of land plot size to the number of households β is calibrated from the current trend of BMA. This model considers land constraint in each district not to allow development beyond available land for new development AL_i.

$$\Delta S_{b,t,i} = \left(\beta \cdot \frac{H_{t,i}}{H_{t-1,i}} - 1 \right)$$
$$s.t. \quad AL_{t-1,i} \geq \Delta S_{b,t,i}, \ \ H_{t,i} > H_{t-1,i}$$

In this model, growth in built-up area and more road development would increase the average car-trip distance l_{car} (km/trip). The total car-ravel distance L_{car} (km/year) is calculated by multiplying the average trip distance by population *pop* and the number of trips per person *tp*. In this model, the number of trips per person per day is set around 2 to be fixed. In Japanese cities, the number of trips per person has not significantly been changed despite economic growth over the period of motorisation. Growth in built-up area would also increase car ownership and use in the next period by decreasing population density and increasing longer trips.

$$l_{car} = 0.0219 \cdot S_b + 2763 \cdot r + 0.383$$
$$L_{car} = 365.25 \cdot l_{car} \cdot pop \cdot tp$$

The Model for Technology Advancement

The model for technology advancement estimates changes in CO_2 emission from passenger cars with changes in car travel distance and emission factors by vehicle type by forecasting advancement of vehicle technologies and LEV spread. CO_2 emission factor is estimated with traffic congestion, fuel economy and LEV spread. Traffic congestion is modelled in a simple way to estimate the average on-road vehicle speed v (km/h) with the balance between the total vehicle distance L_v (km) and the total road length R (km). The total vehicle distance includes those of cars, motorcycles and freight vehicles, which are estimated in a similar or more-brief way.

$$v = 12.3 \cdot \ln\left(\frac{L_v}{R}\right) + 129$$

Fuel economy f (km/l) is estimated with traffic speed and vehicle technologies tec. For future levels of vehicle technologies, this model considers the technological improvement of Tank-to-Wheel (TtW) efficiency and vehicle weight. CO_2 emission factor e (g-CO_2/km) is calculated by dividing emission intensity CF (g-CO_2/l) by fuel economy.

$$e = \frac{CF}{f(v, tec)}$$

Emission intensity depends on the composition of vehicles by fuel type, where LEV spread can reduce emission intensity. This model classifies passenger cars to gasoline vehicles, HVs and EVs, focusing on emission intensity of gasoline and electricity. While emission intensity of gasoline is fixed in the model, the intensity of electricity is estimated with the intensity of electric power generation, considering changes in the composition of power generation sources over time, such as coals, petrol, natural gas, nuclear, water and biomass. The total CO_2 emission E (Mt-CO_2/year) from passenger cars is calculated by multiplying the emission factor by car travel length.

$$E = e \cdot L_{car} \cdot 10^{-12}$$

A DESIRABLE POLICY PACKAGE OF LOW-CARBON TRANSPORT STRATEGIES FOR BANGKOK

Models developed in the previous chapter are applied to identifying a desirable policy package of low-carbon transport strategies for Bangkok by estimating their potential effects.

The Case Study City

The case study city is Bangkok Metropolitan Region (BMR), including BMA and the neighbourhood sub-region as an example of Asian mega cities with rapid economic growth. Population growth in Thailand is not significant as is expected to become aged society with population decline by 2050. It is suggested that the total population of BMA, including floating people, amounts to 10 million. As no official data of the floating population is available, this study assumes that 5% of population of the remaining regions in Thailand would live in BMA as floating population. As a result, the whole population of BMR is set 14 million in 2005 and to be increased by 7% from 2005 to 2050, where around 70% of the BMR population live in BMA and the increase rate of the population is similar between BMA and the neighbourhood sub-region.

In Bangkok, urban sprawl is more serious than other Asian mega-cities. While population density of BMA is higher than the neighbourhood sub-region, the overall density of BMR is around 12,800 (people/km^2). It is lower than that of Tokyo, 15,000, and other Asian mega-cities, such as Shanghai and Delhi, 20,000. In terms of station density to built-up area, BMA has the much lower density, 0.06 (stations/km^2) in 2005, than Tokyo, 1.26 (stations/km^2). The network of urban public transport has been developed for approximately 50km in 2005 and is planned for extension to 300km in 2020. On the other hand, road development in BMA, 0.5 (m/person) in 2005, is at a more comparable level to that in Tokyo, 1.4 (m/person). These urban sprawl and road-based development has led to higher car ownership in BMA than Japanese cities and even than other Asian mega-cities at the same economic level (Fig.2).

Policy Options and Technological Scenarios

This study compares a CO_2 mitigation scenario based on low-carbon transport strategies with a Do Nothing Scenario (DN) which is a scenario without any technology advancement, railway development and development control from 2010.

For the IMPROVE strategy, the future level of technology advancement, such as Tank to Wheel (TtW) and vehicle weight, and LEV spread is assumed based on the forecasting study for Japan (16). In Asian developing countries, although the technology advancement may be less than in developed countries, a leap-frog approach is required for designing low-carbon transport systems by actively introducing advanced technologies. Accordingly, this study assumes that the same level of technology advancement as Japan would be available in Asian developing countries from 2020. This technological scenario sets TtW efficiency to be improved by 284% and vehicle weight to be lighter by 24% from 2005 to 2050. In terms of LEV spread in 2050, the shares of HVs and EVs in passenger cars are set to be respectively 35% and 65%, while the current share of EVs is quite small.

The future composition of power generation is also set based on the existing forecast for each Asian country (17). In this forecast, the power source would be shifted from petrol and coal to biomass. This shift could reduce the emission factor of power generation by 32% in Thailand from 2005 to 2050. With these inputs, the model estimates that the single application of the IMPROVE strategy can reduce CO_2 emission by 75% from DN in 2050 as the highest effect among the strategies.

The SHIFT strategy is designed with urban railway development. As mentioned in the previous section, despite the recent extensive development of railways, the levels of development in Asian developing cities are still lower than those in developed cities. This study assumes that future development would increase station density to built-up area at a same pace from 2010 to 2050. If railway would be developed to the equivalent level to Tokyo in 2005 in terms of the station density, the density would be 25 times higher than the current density of Bangkok in 2005, increasing the number of stations 9 times higher than the planned level in 2020. The development is estimated to reduce CO_2 emission by 37% from DN in 2050.

Urban compaction is designed for the AVOID strategy with land-use control on new development. This study assumes that development control would reduce the rate of expansion of built-up area from 2010. In DN, built-up areas are estimated to be expanded by 53% from 2005 to 2050. According to the model estimation, the strongest development control not to allow any urban expansion from 2010 can reduce CO_2 emission by 39% from DN in 2050.

A Desirable Policy Package

The required contribution of each strategy to CO_2 mitigation is identified as a backcasting approach to meet the targeted mitigation. This study sets the target of 70% reduction in CO_2 emission in 2050 from the level of year 2005. The model estimates growth in CO_2 emission by 185% in Bangkok for the period in DN.

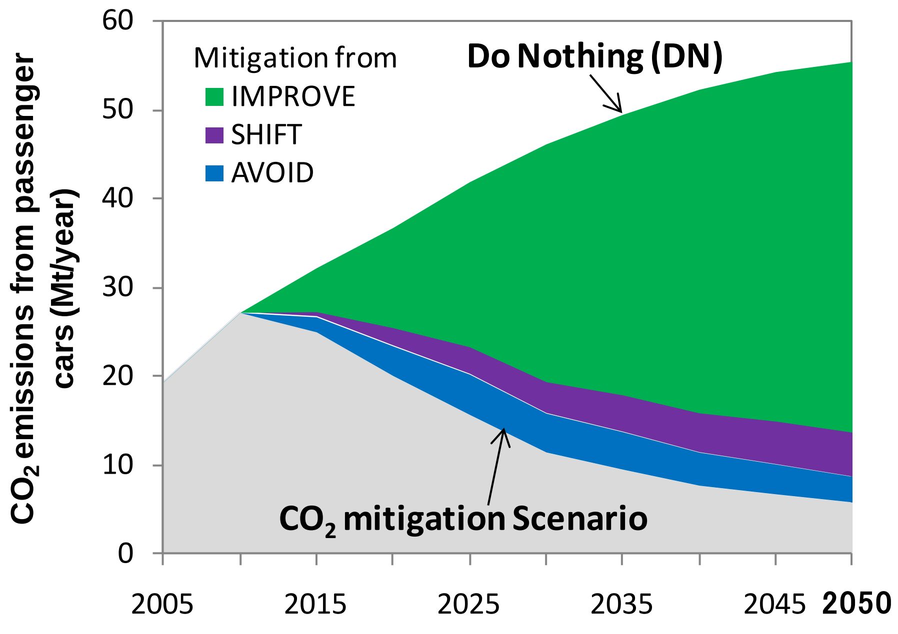

FIGURE 5 The 70% CO_2 mitigation from a package of low-carbon transport strategies in Bangkok

While there are a number of ways to combine these strategies as a policy package, this study simply introduces each strategy in the order of social acceptance, IMPROVE, SHIFT and AVOID. After the application of the IMPROVE strategy, railway development for SHIFT is applied up to the level of Tokyo in

2005, which follows the application of development control for AVOID up to no urban expansion. If the application of all the strategies is not sufficient, railway development is further increased to meet the targeted mitigation.

Accordingly, the contributions of low-carbon transport strategies to the 70% mitigation of CO_2 emission are identified for Bangkok (Fig.5). While the levels of CO_2 mitigation from IMPROVE are significant, they are not sufficient to meet the mitigation target. In addition to the 75% mitigation from IMPROVE from DN in 2050, the SHIFT strategy is required to reduce the emission by 9%. The remaining 5% reduction is achieved by the AVOID strategy.

According to the contribution of each strategy to the 70% mitigation, this analysis identifies the necessary levels of transport measures as the policy package to realise the contribution. It is revealed that drastic changes both in railway development and spatial development are required to achieve the mitigation target. Railways need to be developed up to the 9-times larger scale than the planned level in 2020 and only 2% of new development is allowed to expand built-up area from 2010.

The achievement of CO_2 mitigation does not necessarily compromise the other benefits of accessibility and mobility, which are as important factors for cities as the environmental benefits. This result suggests that accessibility and mobility can be improved with a low-carbon urban system. Indeed, as the average car-trip distance would increase by 18% from 2005 to 2050 in the mitigation scenario, the average vehicle speed would decrease by 12%. However, compared to DN, the mitigation scenario could improve traffic congestion by increasing the speed by 67% in 2050 in the mitigation scenario. This is enabled by significant increase of railway use to 35% in the modal share, which is 7 times higher than the share in 2005.

Nevertheless, the identified policy package may not be realistic for implementation. This implies that Bangkok might be too sprawled and motorised to be made compact, which requires the extensive level of railway development for low carbonisation.

CONCLUSIONS REMARKS

The discussions and analyses of this paper are concluded as below.

1) Desirable low-carbon transport systems can be set as combination among transport strategies for AVOID, SHIFT and IMPROVE. Accordingly, policy packages to achieve the desirable system can be designed with measures by transport strategy. For each of the IMPROVE、SHIFT and AVOID strategies, technology advancement of vehicle technologies and LEVs, mass-transit development, particularly BRT, and high-density development along mass-transit lines are identified to be suitable for Asian developing cities.
2) In designing the policy packages for a desirable low-carbon transport system for Asian developing cities, the potential effects of transport strategies need to be identified, taking account of the impacts of economic growth. Urban modelling is useful to estimate the generic effects by modelling dynamic changes in an urban land-use transport system over the period of motorisation. With the data of both

developed and developing cities, the model for Asian developing cities can be developed in a simple way. The simplified model may have a limitation to analysing local contexts of Asian developing cities, but it is more appropriate for strategic design of their urban systems in the long-term futures.

3) The contributions of transport strategies to the targeted CO_2 mitigation can be identified by adjusting inputs of transport measures in the model estimation of the potential effects. To achieve the target of 70% CO_2 mitigation from 2005 to 2050, the result of this analysis suggests that strong intervention to land-use transport planning is necessary with the 9-times higher scale of mass-transit development than the planned level and the development control on 98% of new development. In this policy package, the level of technologies also needs to be advanced as much as Japan. Although Bangkok might be too motorised to be low-carbonised, the design of these policy packages is useful for many Asian cities which are still low-carbon cities and can avoid excessive environmental emission from economic growth with early implementation of these measures. These results are expected to contribute to more specific assessment for environmental, economic and social benefits in future transport systems of diverse Asian cities.

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REFERENCES

1. Hayashi Y., X. Mai, and H. Kato. *The Role of Rail Transport for Sustainable Urban Transport*. In Rothengatter W., Y. Hayashi, and W. Schade (Eds.) *Transport Moving to Climate Intelligence*. Springer, New York, 2011.
2. Banister D., and R. Hickman. *Low-Carbon Transport in a Developed Megalopolis: the Case of London*. In Rothengatter W., Y. Hayashi, and W. Schade (Eds.) *Transport Moving to Climate Intelligence*. Springer, New York, 2011.
3. Nakamura H., Y. Hayashi, and A. May. *Urban transport and the environment: an International Perspective*. Elsevier Ltd, Amsterdam/Tokyo, 2004.
4. ICCT. *Passenger Vehicle Greenhouse Gas and Fuel Economy Standards: a Global Update*, 2007. http://www.theicct.org/pubs/PV_standards_2007.pdf. Accessed June 8, 2011.
5. Pucher, J., Z-R.Peng, N. Mittal, Y. Zhu, and N. Korattyswaroopam. Urban transport trends and policies in China and India: Impacts of rapid economic growth. *Transport Reviews*, Vol.27, No.4, 2007, pp.379-410.
6. Rabinovitch, J. and J. Hoehn. *A sustainable transportation system; the surface Metro in Curitiba*, Brazil, EPAT/MUCIA, Madison, 1995.
7. Goodman, J., M. Laube, and J. Schwenk. *Curitiba's bus system is model for rapid transit*. Race, Poverty &

the Environment, winter 2005/2006, pp.75-76.

8. Hidalgo, D. Why is TransMilenio still so special? *the City Fix*, 2008. http://thecityfix.com/why-is-transmilenio-still-so-special/ Accessed Feb. 1, 2011.
9. ATRANS. *An Analysis of Vehicle Kilometers of Travel of Major Cities in Thailand*. http://www.atransociety.com/2010/research.html#2009_2010 Accessed July 1, 2011.
10. TRB. *Driving and the Built Environment: the Effect of Compact Development on Motorized Travel, Energy Use and CO_2 Emissions*. TRB Special Report 298, 2009.
11. Newman, P., and J. Kenworthy. *Cities and Automobile Dependence: an International Sourcebook*. Gower, Aldershot, 1989.
12. Kaya, Y. *Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios*. Paper presented to the IPCC Energy and Industry subgroup, Responses strategies working group, Paris,1990.
13. Wegener, M. The Future of Mobility in Cities: Challenges for Urban Modelling. *The Proceedings of the 12th WCTR*, Portugal, 2010.
14. Toga, T., H. Kato, and Y. Hayashi. Long-term Forecast of CO_2 Emission Trend from Passenger Transport Sector in Asian Mega-Cities considering Motorization Progress. *Proceedings of the 18th Symposium of Global Environment*, Japan Society of Civil Engineers, 2010.
15. Togawa, T., Y. Suzuki, S. Nishino, H. Kato, Y. Hayashi, Y. Kawamura, and Y. Kawase. An Evaluation of Smart Shrink Policy of Urban Area based on Triple Bottom Line Perspective. *The Proceedings of the 42th Meeting of Infrastructure Planning and Management*, 2010.
16. Yamamoto, M., H. Kato, and K. Ito. Evaluation of the Effect on Amount of CO_2 Emissions from Transport Sector by Technological Progress of Vehicle and Energy Technology in the Future. *Proceedings of the 18th Symposium of Global Environment*, Japan Society of Civil Engineers, 2010.
17. National Institute of Environmental Studies. *Low Carbon Society Scenarios towards 2050*. http://2050.nies.go.jp/ Accessed July 1, 2011.