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LOW-CARBON LAND-USE TRANSPORT TO IMPROVE LIVEABILITY FOR ASIAN DEVELOPING CITIES

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ABSTRACT

Asian developing countries are increasingly required to develop low-carbon transport systems to decouple their economic growth with emission growth. Such systems can be designed with strategies to AVOID unnecessary travel demand, to SHIFT travel modes to lower-carbon ones and to IMPROVE energy efficiency in transport. The key elements of a low-carbon transport system to be analysed are railway development (SHIFT) and urban compaction to concentrate population around stations (AVOID), given technology advancement (IMPROVE). This paper is aimed at examining the long-term effectiveness of railway-oriented development and urban compaction for developing cities in Asia on transport-related CO_2 mitigation and liveability improvement based on accessibility and amenity. First, it summarises the generic mechanism of effects of railway development in Asian developing cities. Then, an urban transport model is developed to estimate long-term changes in travel demand up to 2050 in Asian developing cities by integrating multi-scale models to be applicable to assessment for the impacts of transport development on CO_2 emissions and liveability measured as Quality of Life (QOL). A long-term future scenario for Bangkok is set referring to growth experience in Japanese cities, assuming that people's preferences for mode choice and residential location in Asian developing countries could become similar to the current preferences in Japan according to economic growth and transport improvement. By applying the model to the scenarios, the long-term effects of railway development and urban compaction are examined. In the result, it is found that, even if technologies are advanced, road-oriented development may have difficulty in mitigating CO_2 emissions. Moreover, railway-oriented development can generate much more benefits not only for CO_2 mitigation, but also for liveability improvement in combination with the appropriate level of urban compaction.

Keywords: Low carbon transport, Land-use, Accessibility, Amenity, Asia

INTRODUCTION

As rapid economic growth could cause serious environmental problems in developing countries, it is an important and urgent issue to decouple economic growth from growth in CO_2 emissions. Low-carbon transport systems for Asian developing cities need to be developed to calm motorisation as a main cause of transport-related CO_2 emissions. Measures to realise such a low-carbon transport system should be designed in a leap-frog manner by strongly intervening to land-use transport planning and extensively applying advanced technologies. These measures are classified into 3 strategies in the ASI framework (GTZ, 2007); to reduce unnecessary travel demand (AVOID), to shift travel modes to lower-carbon ones (SHIFT) and to improve energy efficiency in transport (IMPROVE). These strategies have increasingly received attention in Asian developing countries (UNCRD, 2010). Railway development is identified as one of the primary measures for SHIFT for Asia developing cities because it is more effective to expand their transport capacities to meet growing travel demand (Hayashi et al., 2011).

However, transport planning in Asian developing cities insufficiently takes account of these issues. To reduce traffic congestion caused by growing motorisation, many of their transport policies have prioritised road development over railway development. Despite road-oriented development, their road capacities could not meet the growth of road traffic demand. Moreover, road development would rather induce more car traffic and, consequently, more CO_2 emissions. Furthermore, lack of land-use planning has resulted in promoting urban sprawl in an unplanned manner, which makes car use more convenient. This existing approach is far from leap-frog development which leads to serious economic and environmental damage.

Since the late 20th century, mega cities in Asian developing countries started to develop urban railway networks. Bangkok opened Skytrain in 1999, underground in 2004 and airport rail in 2010, which has amounted to approximately 80km. In Beijing and Shanghai, largest-scale underground networks in the world have been developed with the length of around 400km in total in 2010. Nevertheless, there is a lack of integrated transport planning to promote railway development over road development. To change their ways of planning, it is necessary to identify co-benefits of railway development, as CO_2 mitigation is not the priority.

Liveability improvement is one of the important co-benefits. A low-carbon land-use transport system needs to be attractive for people in order to adapt themselves to it without extraordinary efforts. Banister (2008) suggested that the conventional approach of transport planning to minimize transport costs for traffic efficiency should be shifted to an approach to improve social accessibility based on people’s values. Moreover, a land-use transport system may affect not only accessibility, but also amenity of living environments, both of which are key components of liveability.

This study is aimed at examining the long-term effectiveness of railway-oriented development and urban compaction, compared to road-oriented development, for Asian developing cities to reduce more CO_2 emissions and improve liveability based on accessibility and amenity. It starts with the 2nd chapter of a literature review on necessary approaches to analyse effective low-carbon land-use transport systems. The 3rd chapter summarises a theoretical framework of the analysis for Asian developing cities. In the 4th chapter, an urban model to empirically examine the effectiveness, accounting for motorisation considering long-term changes in travel demand, is explained for its application to assessment for CO_2 mitigation and liveability improvement, measured as Quality of Life (QOL), in urban transport development in Bangkok. The 5th chapter sets future scenarios in 2050 to represent road-oriented development for IMPROVE and railway-oriented development for SHIFT along with urban compaction for AVOID. In the 6th chapter, the effects of these long-term developments are assessed with the model by estimating their impacts on CO_2 emissions and liveability in the constraint of development cost. The findings of these results are discussed in conclusion as the final chapter.

LITERATURE REVIEW

Research on the development of a low-carbon transport system has been increasingly analysed in a backcasting approach. As more countries set challenging targets of CO_2 mitigation, more attention has been paid to exploring pathways to desirable futures with a backcasting approach rather than predicting a likely future with a forecasting approach. A backcasting approach has been introduced into transport research since the late 1990s (POSSUM, 1996; OECD, 2000). There are 2 key aspects of a backcasting approach; setting visions of transport systems in a long-term future and designing policy packages to realise the visions (Banister and Hickman, 2011). Various visions of low-carbon transport systems have been analysed in previous studies (POSSUM, 1996; OECD, 2000; Crozet and Lopez-Ruiz, 2010; Banister and Hickman, 2011). These visions are generally set with scenarios of long-term behavioural changes and technology advancement, such as decrease in travel distance, increase in public transport use and LEV (Low-Emission Vehicle) spread.

A range of policy options to realise the vision have been systematically summarised. WCTRS SIG11 for Transport and Environment established a comprehensive framework of measures as the CUTE (Comparative study on Urban Transport and the Environment) matrix by capturing the general causality mechanisms of environmental emissions from urban transport (Nakamura et al., 2004; WCTRS, 2011). The CUTE matrix classifies types of low-carbon transport measures into 2 axes, “Strategies” and “Instruments” to implement the strategies. In the CUTE matrix, each of instruments in the ASI strategies is further classified into ones relating to a) technology (e.g. infrastructure planning, vehicle technologies and alternative fuels), b) regulation (e.g. transport management, control and services), c) information (e.g. information provision, raising awareness and communication technologies) and d) economy (e.g. pricing and taxes). What combination of measures is more desirable for Asian developing cities is decided mainly by the level of economic growth and an existing land-use transport system. Mass-transit development and Transit Oriented Development (TOD) in technological and regulatory instruments are suggested to be more effective for them because they need to expand the capacity of transport for growing demand in a planned way at the early stage of urban growth (Nakamura and Hayashi, 2012).

In order to identify the level of necessary measures to realise a low-carbon transport system, some studies modelled their long-term impacts on transport demand. In developing such models, it is more important to set a scenario of behavioural changes in long-term futures than to calibrate parameters of them with current data. A model for backcasting is aimed not at conventional accuracy improvement of forecasting, but at illustrating the range of future scenarios, based on an assumption that long-term futures are uncertain. Crozet (2010)

developed a nation-wide transport model for France by introduces explanatory scenarios of long-term behavioural changes in travel according to economic changes. Wegener (2010) modelled the impacts of fuel price rises on long-term changes in travel behaviours by applying constraints of cost and time budgets of individual travel as relatively stable indicators over a long term to a microscopic urban model.
On the other hand, more simplified models are required for analyses on Asian developing cities. Data availability is generally limited there, and, moreover, their behavioural changes could be unpredictably drastic according to rapid economic growth. ITPS (2012) identified the balances of necessary policy implementation among the ASI strategies by global region, taking account of the local contexts of behaviours, planning policies and technology levels. Nakamura et al (2011, 2012) examined the necessary level of policy implementation for a low-carbon transport system for Asian developing cities by setting behavioural changes referring to Japanese experience. These studies concluded that the necessary level of railway development for Asian developing countries is extremely high.
Accordingly, the balance between road development and mass-transit development within a budget constraint needs to be examined. A range of benefits from such development, including time saving, energy saving and air pollution, is important for Asian developing countries (Zusman et al., 2012). However, the benefit of CO_2 mitigation is not their top priority and is often underrated in a monetary term (Sutomo et al., 2012). To promote transit development, co-benefits of a low-carbon transport system need to be improved.
Liveability improvement based on individual's values is one of potentially most convincing ways to promote low-carbon transport systems by enhancing public acceptance. To measure liveability with economic, social and environmental benefits, the indicators of Quality Of Life (QOL) have been developed in the UK since 1990s (DETR, 1999). Craglia et al. (2004) defined QOL in a way that does not simply mean satisfaction or availability of resources but also easy access or ability to use services as opportunities. Hayashi et al (2004) classified components of liveability into "economic opportunity", "safety and security", "service and cultural opportunity", "spatial amenity", and "environmental benignity", and summarised their indicators attributed to infrastructure development. In this approach, evaluation methods for QOL have been developed to assess land-use transport systems by scoring QOL as composite measurement of types of accessibility, amenity and safety indicators weighted by people's values identified from questionnaires (Kachi et al., 2005; Doi et al., 2008).

THEORETICAL FRAMEWORK OF ASSESSMENT FOR ROAD DEVELOPMENT AND RAILWAY DEVELOPMENT

The effects of road development and railway development on CO_2 mitigation and liveability are theoretically compared, taking account of the generic contexts of Asian developing cities. Hayashi et al (2011) summarised the theoretical framework of effectiveness of railway development on time saving over road development. In making urban transport policies in developing mega-cities, investment tends to be made on expanding road capacity to relieve road traffic congestions. However, it is often overlooked that improving rail transit system could also absorb the traffic demand and therefore relieve road congestion by reducing the car usage demand.

Which one is better to invest, directly in road or indirectly in rail, can be discussed theoretically, using demand and supply curves in road and rail markets. Fig.1 shows these curves on 4 axes to represent key factors to distinguish the differences of effectiveness of two policy scenarios: investment on improving road capacity or rail capacity. The axes represent average travel time of car and rail trips, their total passenger travel distances, development cost of construction and operation to provide transport services, and the levels of co-benefits of the mode provision, such as emission mitigation and liveability improvement. Road and railway development to enlarge the transport capacities can reduce on-road travel time (ΔT_{ro} and ΔT_{ro}) and increase passenger travel distance (ΔV_{ro} and ΔV_{ra}) by shifting their supply curves from S0 to Sro1 and Sra1 to the demand curve D. In the ranges of larger passenger volumes, a supply curve for roads (Sro1) is steeper than one for railways (Sra1), as traffic congestion slows travel speed. Moreover, railway development can not only improve access to stations, but also absorb on-road traffic demand into rail use, and reduce travel time both in rail and car trips. Thus, the time-saving benefit of railway development ΔT_{ra} is expected to be more significant than the benefit of road development ΔT_{ro}.
These time-saving benefits can be made by investments of road and railway development (ΔC_{ro} and ΔC_{ra}). Rail transit systems have higher construction cost at the very starting point of service provision. However, although construction cost per road distance is lower than the cost per railway distance, the cost for expanding rail transport capacity per person-km is often less than that of roads, as a rail carrier is able to accommodate more passengers. This suggests that the more significant time-saving benefit can be achieved by less investment in railway development ΔC_{ra} than investment in road development ΔC_{ro}. Thus, it is clear that the investment in railway development can generate a better investment return.

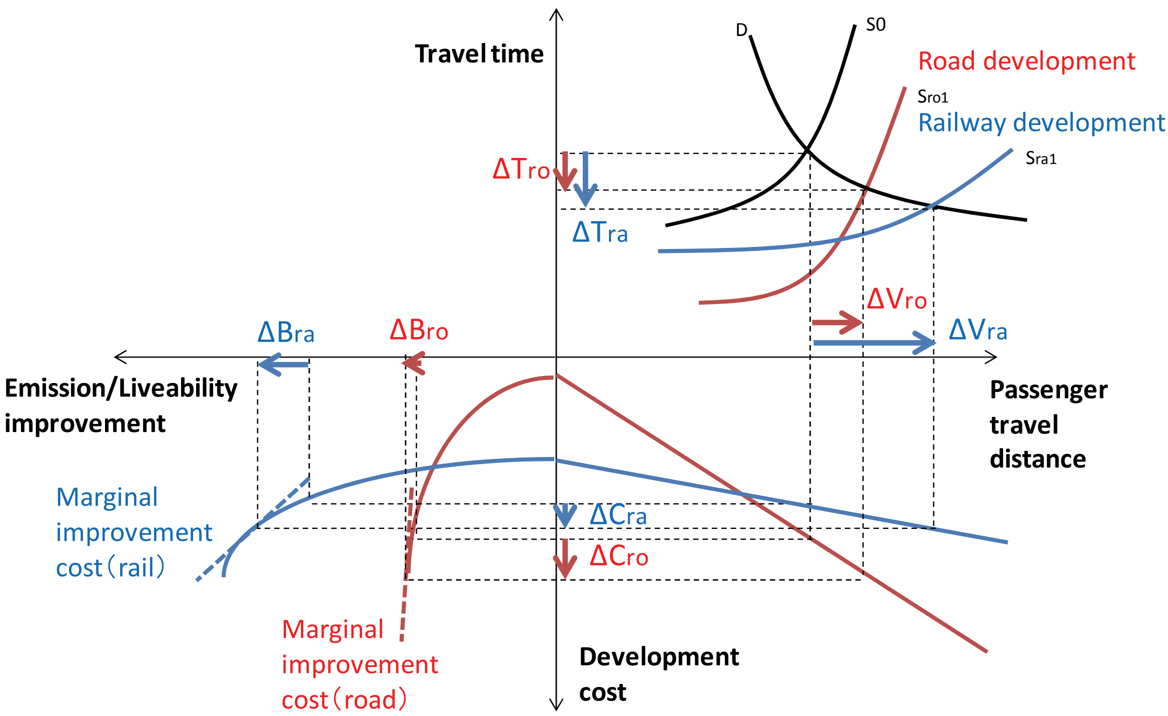

Figure 1 – Theoretical effectiveness of railway development

This theory is applicable to effectiveness on CO_2 mitigation and liveability improvement. Road development can reduce traffic congestion and CO_2 emissions by ΔB_{ro} by improving traffic efficiency (IMPROVE). Railway development can reduce congestion and the emissions by ΔB_{ra} by shifting car users to rail users (SHIFT). The effectiveness of railway development depends on demand for rail use. If a rail carrier is occupied by the certain number of passengers, per-capita emissions can be lower in rail use than in car use. In the previous study, railway is identified as a low-carbon mode for high-density cities, while one for low-density cities is car (Ito et al., 2012). Although the higher time-saving benefit might increase passenger travel distance more, the contribution of lower per-capita emissions from rail transport to the total emissions is generally overwhelming. Accordingly, the higher level of emission mitigation with lower investment is expected from railway development. In other words, railway development has the higher effectiveness of emission mitigation with lower marginal improvement cost which divides the level of mitigation by development cost.

Liveability improvement depends on the balance among various co-benefits from road development and railway development. The balance between accessibility improvement and amenity improvement is one of key trade-off relationships of the co-benefits. More time saving from railway development can lead to higher accessibility improvement. On the other hand, lower-density development from road development might improve amenity more in residential places by enabling more people to live in larger houses in greener areas in suburbs. This is attributed to the different impacts of road development and railway development on an urban form. Railway development is more likely to draw higher-density residential development within accessible distances from stations, which is expected to interactively strengthen the effects of railway development.

Although many of Asian developing cities have prioritised road development as a short-term measurement to traffic congestion, it is important for them to conduct longer-term assessment, considering long-term land-use transport changes. In Asian developing megacities, excessive road development has induced more traffic and worsened traffic congestion, and lack of railway development has resulted in poor access to stations and low ridership. While such road development could contribute to better amenity provision, land-use transport systems need to be designed to balance these co-benefits.

MULTI-SCALE URBAN TRANSPORT MODEL FOR ASIAN DEVELOPING CITIES

To assess the impacts of land-use transport development on CO_2 emissions and liveability, urban transport demand in a long-term future needs to be estimated with an urban transport model considering economic growth. Simpler macro-scale models are more feasible for Asian developing countries, as data is more available. To analyse a more spatially disaggregated urban system, this study introduces an intra-city spatial model integrated with macro-scale models by adjusting parameters to be consistent with the macroscopic estimation and data. Various models are applicable to such multi-scale modelling depending on data availability. This study focuses on how to capture the generic mechanism of motorisation and urban sprawl in Asian developing cities by integrating models on multi scales, rather than explaining the detail of each model (Fig.2). The model is applied to Bangkok Metropolitan Region (BMR).

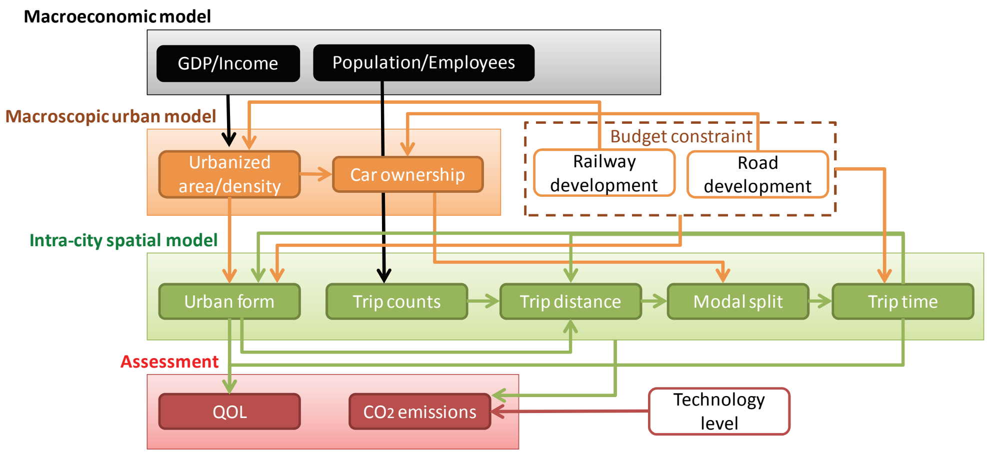

Figure 2 – A Flow of an urban transport model for long-term economic growth

Transport demand models

This model uses the macroscopic inputs of socio-economic characteristics from a macroeconomic model (Fujimori et al., 2011) and motorisation level from a macroscopic urban model (Nakamura et al., 2012). The macroeconomic model estimates future economic growth from technological changes in production in the world up to 2050, in which production and GDP by industry sector are modelled by country in Asia with Computable General Equilibrium (CGE) model. In this study, while the input of population changes is from the existing forecast of Bangkok, GDP, income and employment by industry is set from the output of the macroeconomic model.
Prospective urban sprawl and motorisation in economic growth in Asian developing cities have been modelled with a macroscopic urban model, using city-wide panel data of Japanese cities for the motorisation period. In this model, income and population growth (ΔI and ΔPOP) would increase urbanised area ΔS_u and decrease population density d as urban sprawl, which leads to an increase in car ownership C as motorisation. On the other hand, railway development would slow the pace of decreasing urban density, and consequently calms growth in car ownership. This study introduces a budget constraint of development for roads and railways to compare the effective balance between them.

$$\Delta S_u = \sigma_1 \cdot \Delta I + \sigma_2 \cdot \Delta POP + \sigma_3 \cdot st + \sigma_4$$

$$C = \frac{\gamma_1 \cdot r^{\gamma_2} \cdot d^{-\gamma_3}}{(1 + \gamma_4 \cdot \exp(-\gamma_3 \cdot I))}$$

, where
ΔS_u: increase in urbanised area;
ΔI: increase in income;
ΔPOP: increase in population;
st: density of stations in habitable area;
C: car ownership (cars/inhabitants);
r: road length per capita;
d: population density;
σ_1, σ_2, σ_3, γ_1, γ_2, γ_3: parameters.

These macroscopic data is input into an intra-city spatial model to estimate a) trip counts, b) travel distance, c) modal split and d) travel time with a 4-step model. In trip generation, economic growth increases the number of trips. Passenger trip counts per capita by purpose are set to represent increase in non-commuting trips based on the existing future forecast (the World Bank, 2007). In addition, freight trips between industries are estimated based on their production outputs from the macroeconomic CGE model. As it is difficult to collect such freight data in Thailand, the number of trips per employee by industry sector is set based on the data of Japan. By setting the future number of employees by sector in Bangkok from the estimated growth of country-level macroeconomic output, this model estimates the total number of freight trips to be generated by each sector. It also estimates the incoming passenger and freight trips by allocating generated trips to each sector as transport destinations, depending on distribution of passenger travel purposes and transactions among sectors. While the CGE model analyses a range of industry sectors, the urban model aggregates them mainly by primary, secondary and tertiary sectors, which is the level of data availability of intra-city spatial distribution of employment by sector.
To estimate travel distance and modal split, this study applies logit models for destination choice and modal choice. The decay parameters of trip distribution θ_1 and $attr1_{d,p}$ are calibrated to match the city-wide data of travel distance for passenger and freight transport with the estimation. The parameters of modal split $\theta_2$and $attr2_m$ are calibrated to match the city-wide data of modal split for passenger transport with the estimation, while it is assumed that freight transport is made only by road transport.

$$PrT(d|p,i) = \frac{exp\ (-\theta_1 \cdot (DU_{i,d} + ln(A_{p,d}) + attr1_{p,d}))}{\sum_l exp\ (-\theta_1 \cdot (DU_{i,l} + ln\ (A_{p,l}) + attr1_{p,l}))}$$

$$DU_{i,d} = -\frac{1}{\theta_2} \cdot ln \sum_k exp\ (-\theta_2 \cdot (gc_{k,i,d}))$$

$$PrT(m|i,d) = \frac{exp\ (-\theta_2 \cdot (gc_{m,i,d} + attr2_m))}{\sum_k exp\ (-\theta_2 \cdot (gc_{k,i,d} + attr2_k))}$$

, where
PrT(*d*|*p*,*i*): probability to choose destination *d* of origin *i*;
$DU_{i,d}$: travel disutility from origin *i* to destination *d*;
$A_{p,d}$: scale-dependent attractiveness of destination *d* for travel purpose *p*, measured with the numbers of employees by industry or population of each destination;
$gc_{m,i,d}$: generalised travel cost of transport mode *m* from origin *i* to destination *d*, including time and cost;
PrT(*m*|*i*,*d*): probability to choose mode *m* of origin *i*;
θ_1, θ_2: decay parameters;
$attr_{d,p}$: residual attractiveness of destination *d* for travel purpose *p;*
$attr_m$: residual attractiveness of transport mode *m*.

In trip distribution, trip distance is increased by the level of urban sprawl. In setting the urban form input, population and employees are distributed into 3km by 3km cells. Future changes in the distributions are estimated with a simple land-use sub-model to account for changes in residential location with a logit model based on the level of accessibility improvement from 2005 to 2050. The accessibility improvement is measured with a change in travel disutility by mode $\Delta DUM_{m,i}$ for the period.

$$DUM_{m,i} = -\frac{1}{\theta_1} \cdot ln\,(\sum_p \sum_l \exp\,(-\theta_1 \cdot (gc_{m,i,l} + l\,n(A_{p,l}) + attr1_{p,d})))$$

$$dDUM_{m,j,i} = \Delta DUM_{m,j} - \Delta DUM_{m,i}$$

$$PrL(i,j) = \frac{exp\,(-\theta_3 \cdot (wrd \cdot dDUM_{road,j,i} + wrl \cdot dDUM_{rail,j,i} + MV + CT))}{\sum_l exp\,(-\theta_3 \cdot (wrd \cdot dDUM_{road,l,i} + wrl \cdot dDUM_{rail,l,i} + MV + CT))}$$

, where
$DUM_{m,i}$: travel disutility from origin *i* by transport mode *m*;
$\Delta DUM_{m,i}$: change in travel disutility from 2005 to 2050;
θ_3: decay parameter;
$dDUM_{m,i,j}$: relative change in travel disutility in location *j* compared to location *i*;
PrL(*i,j*): probability to choose residential location *j* from location *i*;
MV: fixed disutility to move residential location;
CT: dummy to implement development control;
wrd: .parameters of preference for road accessibility to road accessibility;
wrl: .parameters of preference for rail accessibility to road accessibility.

The parameters of the land-use model are calibrated by development scenario to represent habits of travel and location behaviours by matching an estimated urbanised area with one estimated in the macroscopic urban model. To model the impact of railways on drawing more people nearby as a magnet and calm urban sprawl, this study introduces parameter *wrl* to account for preference for rail accessibility compared to road accessibility in residential location. In this study, the calibration is made for road-oriented development as BAU and railway-oriented development as an alternative scenario. In BAU, fixed disutility to move MV is calibrated by setting the decay parameter θ_3 equal to be θ_1 and the preference parameters (*wrd* and *wrl*) to be 1. These parameters are recalibrated to represent more compact urbanised area in the scenario of railway-development scenario by making the decay parameter and the preference parameter for rail accessibility more significant. Fixed disutility *CT* is also added to be set depending on the level of additional density increase from development control. Distribution of employees is set according to changes in population distribution in a way that allocates more employees in cells with more population.
In modal split, motorisation increases car use, which could be calmed by railway development. Higher car ownership could make it easier to access car use. The model considers the impact of car ownership on car use by introducing vehicle purchasing cost per travel distance into travel cost for people not owning cars, which is reduced by increase in

car ownership. On the other hand, railway development could reduce travel cost of rail use by reducing distance for access to stations and expanding the coverage of a railway network. In network assignment, road development reduces on-road travel time by increasing road capacity. The road network is virtually set to link all adjoining cells with population and employees and to allocate the total road length to them as their capacities. The capacity of total road development is allocated depending on traffic demand. The parameters of QV relation are set to match the average traffic speed in Bangkok.

Assessments

CO_2 emissions are estimated based on the estimated transport demand and vehicle technologies. The estimation is made by multiplying travel distance (km) by fuel economy (l, kWh /km) and emission intensity (g-CO_2/l, kWh). LEV spread can improve fuel economy by shifting GVs to HVs, and emission intensity by shifting GVs to EVs.

Table 1 – QOL factors considered in this study

Components	Factors	Indicators	Weight (US$ per unit)
Accessibility	Commuting	Log-sum of travel disutilities	6.4
	Travel to school		7.4
	Travel to hospital		6.9
	Travel to shopping		8.2
Amenity	Floorspace	Floorspace per capita (m^2)	7.6
	Greenspace	Greenspace per capita standardised by the maximum level in 2005	139.6

This study also assesses liveability of each cell with the output of the urban transport model. Although there are various liveability indicators, this study uses a way of measuring QOL by summing up physical indicators of built-environments weighted by subjective values of people on them (Kachi et al., 2005). This QOL represents the utility of residential location, which consists of several components, including accessibility and amenity, each of which has some factors. Among a range of factors for the QOL measurement, this study focuses on ones listed in Table 1. The accessibility $AC_{p,i}$ estimated from the model is used as the indicators of accessibility factors.

For amenity factors, the cell-level data of floorspace and greenspace, which is often unavailable in developing countries, was constructed from the property-level data and the district-level data. Their future changes are estimated from changes in population density. There are negative relationships between floorspace/greenspace and population density. Based on the relationships, the sensitivities of floorspace and greenspace to population density are identified, which are added to or subtracted from the current levels of floorspace and greenspace to estimate their future changes.

The liveability measurement QOL_i is measured as willingness to pay for monthly rent per property. The weights *wac* and *wam* of preferences are identified from conjoint analysis using the results of questionnaires. The QOL measurement is based on the average housing rent as the standard value R_0 which is US$65 per household in Bangkok in 2005. While the average rent changes over time, this study fixes R_0 in measuring future QOL to make it comparable with the level of 2005. The spatial variation of QOL is measured with the difference of accessibility/amenity factor k from their averages in 2005, AC_{k0} and AM_{k0}.

$$QOL_i = R_0 + \sum_k \mathrm{wac_k}(AC_{k,i} - AC_{k0}) + \sum_k wam_k(AM_{k,i} - AM_{k0})$$

, where

QOL_i: liveability measurement of location *i* measured as willingness to pay for monthly rent per property;

R_0: average housing rent of the study area;

$AC_{k,i}$: accessibility indicator *k* of location *i*;

AC_{k0}: average accessibility indicator *k* of location *i*;

$AM_{k,i}$: amenity indicator *k* of location *i*;

AM_{k0}: average amenity indicator *k* of location *i*;

wac_k: weight of preference for accessibility indicator k;

wam_k; weight of preference for amenity indicator k.

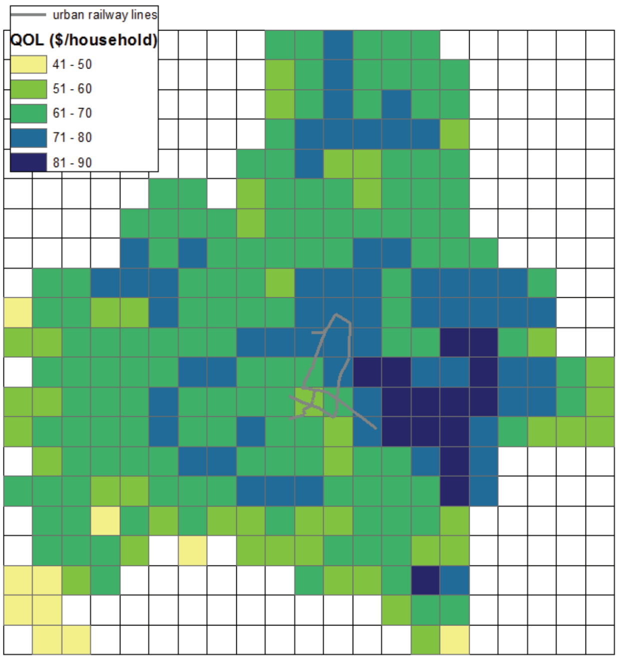

Figure 3 – Spatial distribution of QOL in 2005

Although the values for accessibility and amenity may change over time in economic growth, it is difficult to empirically capture such changes in values. Assuming that future values in Asian developing countries would become similar to the current values in Japan, this study uses the weights of accessibility and amenity factors for QOL identified in the previous study in Japan, as in Table 1 (Togawa et al., 2011). Using the weights, the spatial distribution of QOL in 2005 is measured in Fig.3. Areas with high QOL are not in city-centre areas with high accessibility, but in suburban areas with high amenity. This result shows QOL based on the hypothetical future values on the existing land-use transport system in Bangkok, which may not show the current demand. Moreover, QOL represents potential housing demand without constraints of economic cost and regulation, which may show the different pattern of actual population distribution. Further analysis is required about dynamic changes in values in QOL and the relationship between QOL and residential location.

FUTURE SCENARIOS

In this study, given a future socio-economic scenario, 2 scenarios of transport development are set for analysis.

Socio-economic scenario

In the socio-economic scenario, while economic growth will increase the number of trips per capita, population growth is limited (Table 2). GDP will grow by 3 times in Thailand from 2010 to 2050, which is equivalent to the growth in Japan from 1970 to 2000 (Fujimori et al., 2011). Although the level of growth could change depending on macroeconomic scenarios, it may not be far beyond the current economic level of Japan. The amount of investment in road development and railway development is set as 1.2% of GDP, which amounts to 26,332 million US$ from 2005 to 2050.

Table 2 – Socio-economic characteristics

	Income	Population	Trips
	US$/year	1000 persons	trips/person/day
2005	5,030	10,477	1.79
2050	15,318	12,174	2.47

In Bangkok, the total number of personal trips is expected to grow according to economic growth (the World Bank, 2007). While the current number of trips is 1.79/person/day (OTP, 2007), the forecasted number of trips in 2050 is similar to the level of Tokyo in 1980, 2.87. The number of trips per capita for passenger trips by purpose is set based on the data of 2005, assuming that only non-commuting trips would increase according to economic growth. The number of freight trips per worker is set based on the data of Japanese cities and is adjusted to match the total number of freight trips in Bangkok (Takahashi and Sirikupanichkul, 2001).

On the other hand, population growth in Thailand is not significant due to the trend of ageing. According to the UN forecast (2010), population in Thailand will start to decline from 2035. The percentage of more than 65 aged people will increase from 10% in 2005 to 30% in 2050. In Bangkok, the total population will increase by 16% for the period.

This study assumes that, as time value would become higher in economic growth, elasticity of transport cost to trip distribution would become higher in 2050. Accordingly, the parameter of trip distribution in 2050 is set by referring to the current one for Nagoya city as an example of a developed city. Nagoya is a central city of the third largest metropolitan region in Japan, in which road development is relatively high in Japan, although it has the city-wide scale of an underground network.

Development Scenarios

This study compares scenarios of road-oriented development and railway-oriented development in combination with urban compaction. Table 3 shows characteristics of each scenario. Population and railway networks in 2005 are distributed into cells (Fig.4), based on the current data of Bangkok.

Table 3 – Land-use transport characteristics in the scenarios

	Road	Railway	Urbanised area	Average population density	Car ownership
	km	km	km^2	$persons/km^2$	cars/1000persons
2005	3,541	46	1,540	7,574	189
Road 2050	16,739	81	1,920	5,552	407
Railway 2050	13,564	524	1,565	6,380	337

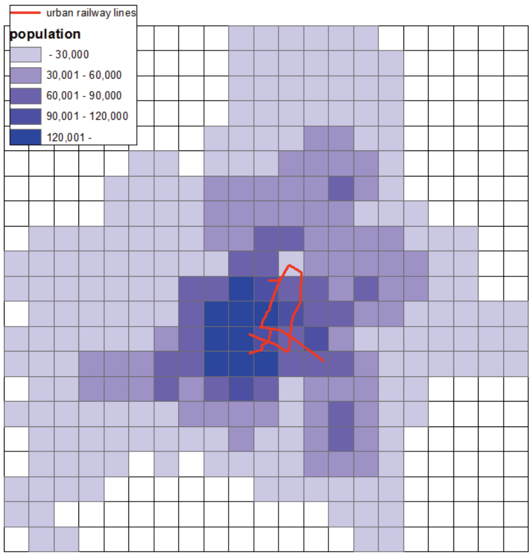

Figure 4 – Population distribution and urban railway network in 2005

The same level of technology advancement is given to both scenarios. The current levels of fuel economy and emission intensity in Bangkok are estimated by referring to the previous studies (Narupiti, 2007; the World Bank, 2009). 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 (Yamamoto et al., 2010). 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 in 2050. 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%, although 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 (Fujimori et al., 2011). In this forecast, the power source will be shifted from petrol and coal to biomass. This shift could reduce the emission factor of power generation by 37% in Thailand from 2005 to 2050.

Car-oriented development scenario

The road-oriented development scenario assumes that the current trend of rapid motorisation will continue, and car use will be overwhelming. Most of transport infrastructure investment will be made in road development, assuming that no railway development will take place beyond the level of 2010. Road-oriented development will decrease urbanised density and increase car ownership. Distribution of population and employees is dispersed according to accessibility improvement from extensive road development (Fig.5). Assuming that preference for car use would stay high, the parameters of modal split is kept from one for 2005 in Bangkok.

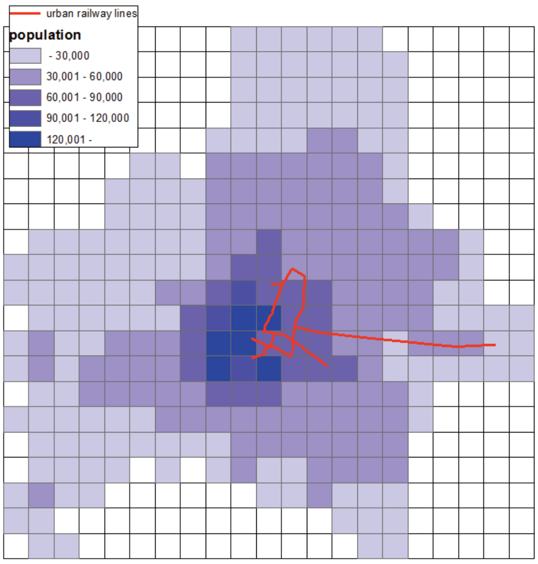

Figure 5 – Population distribution and urban railway network in the road-oriented scenario in 2050

Railway-oriented development scenario

The railway-oriented development scenario assumes that the large-scale development of urban railway networks will take place, and rail use will become popular. Urban railway networks will be developed up to the level of the existing plan for 2030. The rest of the investment will be made in road development. Railway development will calm urban sprawl and slow the pace of growth in car ownership. In the urban form, although urban sprawl will take place to some extent, people and employment would move to accessible areas to stations (Fig.6). As a result, the urban form will become polycentric with more secondary-ranked centres in suburbs. As rail use will become popular, the model increases the fixed attractiveness of rail use in the parameter of modal split to the level of Nagoya.

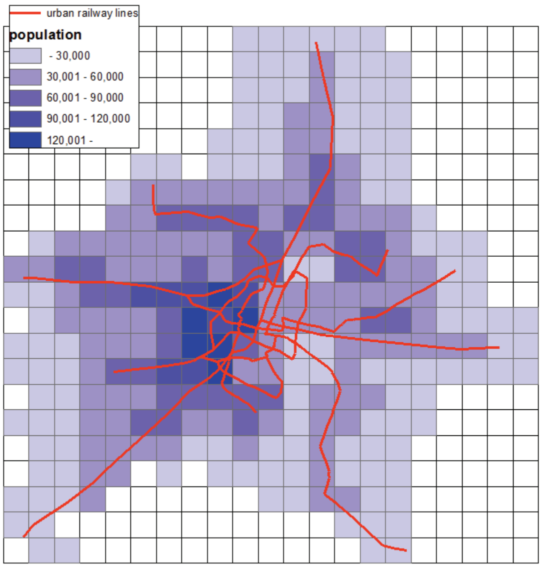

Figure 6 – Population distribution and urban railway network in the railway-oriented scenario in 2050

Compact development scenario

Another railway-oriented development scenario is set as a compact development scenario to introduce land-use control to concentrate more population around the railway network. Land-use control is not an easily-feasible option in Asian developing countries, as organisation coordination is poor and market-oriented development is overwhelming. However, such an approach can be an effective scheme to realise a low-carbon and attractive land-use transport system. While this scenario assumes the same railway network and the same travel behaviours as the railway-oriented development scenario, attractiveness to locate in areas without stations will be reduced (Fig.7). In this study, 2 different high-density scenarios are tested; one to increase population density from the level of 2005 by 30% (Compact 2050a) and another to increase it double (Compact 2050b).

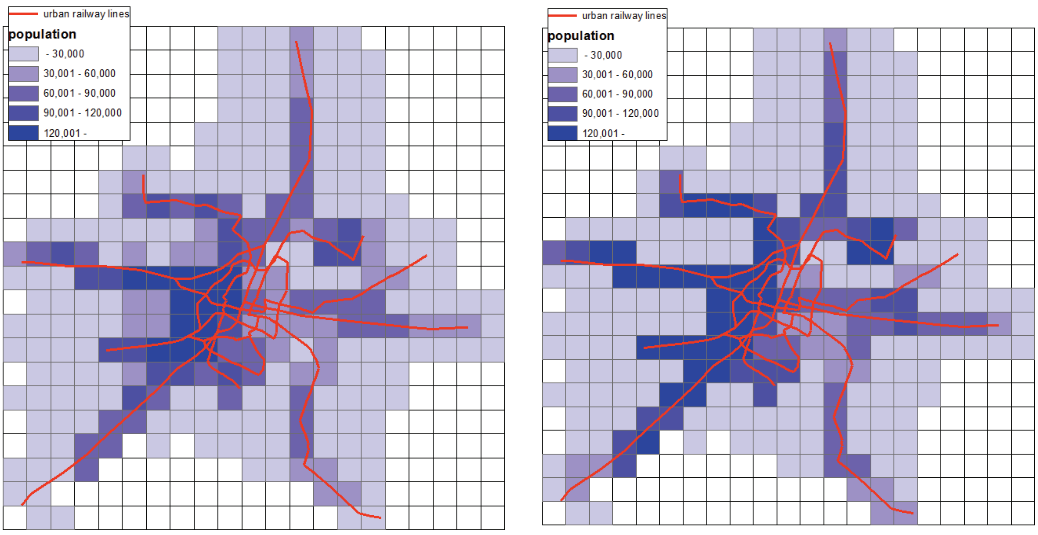

Figure 7 – Population distribution and urban railway network in the compact development scenario in 2050
left: density 30% increase scenario (a), right: density double scenario (b)

EFFECTS OF RAILWAY DEVELOPMENT AND URBAN COMPACTION

For each development scenario, travel demand for urban transport is estimated with the urban transport model, and the effects of development on CO_2 emissions and QOL are examined. The key difference of travel demand between the scenarios is shown in modal split. While road-oriented development increases the modal share of car use from 59% to 97% from 2005 to 2050, railway-oriented development increases the share of rail use from 2% to 67%. Both scenarios reduce car travel time by expanding the capacities of transport from road development. Although road-oriented development provide more roads than railway-oriented development, the saving of average car-trip time from 2005 to 2050 is more significant in railway-oriented development with the 58% saving than road-oriented development with 22%. This result suggests that the impact of modal shift on decreasing congestion to reduce on-road traffic demand is more significant than the impact of road capacity expansion to improve traffic efficiency. Moreover, railway-oriented development decreases average railway-trip time by 62% for the period by improving access to stations and expanding network coverage.
Table 4 shows the average time saving of all trips and the total amount of CO_2 mitigation from them in each scenario compared to the level of 2005. Road-oriented development could not reduce CO_2 emissions from the level of 2005. Moreover, both benefits are more significant in railway-oriented development. Railway-oriented development could save travel time per trip by 16% more than road-oriented development.

Table 4 – The effects of transport development on time saving and CO_2 mitigation

	Average travel time saving in 2050 compared to 2005	CO_2 mitigation in 2050 compared to 2005	Cost of CO_2 mitigation
	mins/trip (% of change)	kt-CO_2/year (% of change)	US$/ tCO_2
Road 2050	-7 (-22%)	4,528 (+10%)	125
Railway 2050	-12 (-39%)	22,666 (-49%)	32

The cost of CO_2 mitigation from urban transport is calculated by dividing the total amount of mitigation by the amount of investment in transport development. The total amount of mitigation is calculated with the differences of CO_2 emissions in each scenario from the level of a Do-Nothing case in which no investment in transport development would be made. It assumes that the level of mitigation would linearly grow from 2005 to 2050. The result shows that the mitigation cost of railway-oriented development is much lower than the cost of road-oriented development. Although these prices are higher than the current CO_2 price, around 15 US$/ tCO_2, they are expected to rise as increasing pressure on the mitigation is made. It is suggested that to mitigate CO_2 emissions from all sectors to half of the current level in Asia, it will cost around 750 US$/$tCO_2$ (Fujimori et al., 2011). Accordingly, transport development has large potential of CO_2 mitigation, which could be a reasonable incentive to support railway development in Asian developing cities.

Thanks to the extensive infrastructure development, liveability can also be improved in both scenarios, but the improvement is more significant in the railway-oriented development scenario. Table 5 shows the levels of QOL improvement in each scenario, including their details of changes in accessibility and amenity parts. The difference in QOL improvement is attributed to the difference in accessibility improvement. Although road-oriented development has higher amenity, the difference between the scenarios is marginal. This means that the spatial variation of floorspace and greenspace depending on population density is not significant enough to affect the comparable level of benefits to accessibility improvement.

Table 5 – The effects of transport development on QOL

	Accessibility improvement in QOL in 2050 compared to 2005	Amenity improvement in QOL in 2050 compared to 2005	QOL improvement in 2050 compared to 2005
	US$/person/year (% of change)	US$/person/year (% of change)	US$/person/year (% of change)
Road 2050	658 (+ 73%)	8 (+1.2%)	666 (+82%)
Railway 2050	950 (+105%)	2 (+0.2%)	952 (+118%)

Table 6 compares the impacts of railway-oriented development with the different levels of urban compaction (Compact 2050a: density 30% increase, 2050b: density double) on CO_2 emissions and QOL. CO_2 emissions can be reduced by drawing more population around stations and reducing their travel distances. However, higher-density development does not continuously improve QOL, as the level of amenity is worsened from less floorspace and greenspace. The result shows that if population density is slightly increased from the current level, urban compaction can secure both benefits of CO_2 mitigation and QOL improvement. This does not necessarily mean that further urban compaction is not effective, but implies that more careful urban design is needed to improve QOL in such high-density development.

Table 6 – The effects of urban compaction on CO_2 mitigation and QOL improvement

	Average population density	CO_2 mitigation in 2050 compared to 2005	QOL improvement in 2050 compared to 2005
	people/ km2	kt-CO_2/year (% of change)	US$/person/year (% of change)
Railway 2050	6,380	22,666 (-49.3%)	952 (+117.6%)
Compact 2050a	8,411	23,313 (-50.7%)	956 (+118.2%)
Compact 2050b	13,042	25,519 (-55.5%)	927 (+114.5%)

COONCLUSIONS

This paper has presented how effective railway development in combination with urban compaction is, compared to road development, in Asian developing cities. One of the largest obstacles to developing a low-carbon transport system is preoccupation of their transport planning that road development is inevitable to tackle serious traffic congestion. Although this could be true for a short-term measure, the level of development needs to be balanced with railway development in a long term. Even though technologies are considerably advanced to improve fuel economy and reduce emission intensity, road-oriented development can hardly decouple economic growth with growth in CO_2 emissions. On the other hand, railway-oriented development is more effective not only for CO_2 mitigation but also for accessibility improvement. The benefit of accessibility improvement from railway-oriented development is significant enough to improve liveability more, even if the negative impact on amenity improvement is taken into account. Additional urban compaction to keep the current level of population density with land-use planning against urban sprawl can enhance the benefit of liveability improvement. It may take some time to change land-use transport systems in Asian developing cities, and, therefore, it is important to implement the development earlier by assessing the long-term effects.

This implies the large potential of investment in railway development in international financial support for Asian developing countries. Traditionally, ODA for them, to which Japanese government has greatly contributed, has been used more for road development. As Asian developing countries economically grow, the paradigm of financial support will be changed for green development. Although Clean Development Mechanism (CDM) is one example to internationally invest in CO_2 mitigation, their application to transport is relatively low due to lack of ways to measure benefits from it. Accordingly, it is important to develop a simplified method to measure transport-related benefits, such as CO_2 mitigation, with limited data, which is a new challenge to researchers in transport planning and modelling.

Domestic systems of development also need to be changed to promote low-carbon land-use transport systems in a bottom-up approach from cities. Conventional ways of cost-benefit assessment for transport development no longer works. To make a low-carbon land-use transport system attractive, the assessment needs to be focused not on traffic efficiency, but on liveability based on people's values. It is particularly important to develop an adaptable system for rapid socio-economic changes to aged society in Asian developing countries.

It is recognised that there are other obstacles to the development of a low-carbon transport system in Asian developing countries. Nevertheless, Asian developing megacities have changed a lot for the past 20 years, in which rail use has received much more attention than the past. Research on the development of a low-carbon transport system could contribute to encouraging further changes of their transport systems in a leap-frog manner.

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