Evaluation for Low-carbon Land-use Transport Development with QOL Indexes in Asian Developing Megacities: a Case Study of Bangkok

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Abstract: To decouple global economic growth with emission growth, a necessary local challenge is to develop attractive low-carbon transport systems in developing cities. Whether mass-transit development can be low-carbon against conventional road development in Asian developing megacities depends on how attractive they can be for local residents. This paper is aimed at evaluating the estimated long-term effects of rail-oriented development on transport-related CO2 mitigation and Quality of Life (QOL) improvement in Bangkok. It develops a land-use transport model integrated with QOL indexes to estimate changes in travel demand up to 2050, considering the quality of transport modes and residential locations. Then, the model is applied to evaluating future scenarios of land-use transport development with different types of transport modes and station areas. The result showed that rail-oriented development can be more low-carbon than road-oriented development and can improve QOL, if planning is introduced to quality station-area development.

Keywords: Low-Carbon Transport, Rail Development, Station-Area Development, Land-use Transport Model, QOL, Bangkok

1. INTRODUCTION

Approaches to low-carbon development need to be taken both on global and local scales, which introduces an important global role into local planning for cities in developing countries. Rapid economic growth in developing countries has caused serious environmental problems by increasing the emissions, particularly from the transport sector, so as to affect the global emissions. It is thus a globally urgent issue to decouple their economic growth from growth in CO2 emissions. The measures of low-carbon transport 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 of vehicles (IMPROVE). These strategies have increasingly received attention in Asian developing countries (UNCRD, 2010). While IMPROVE depends more on global technology development and technology transfer, AVOID and SHIFT are conducted more by local planning of land-use transport systems. To realise the global target of CO2 mitigation, which is 50% of the current level, the measures for developing countries should be designed in a leap-frog manner by strongly implementing land-use transport planning as well as extensively
introducing advanced technologies.

However, the measures of low-carbon transport development for developing countries have not been sufficiently implemented into practice. The international society proposed the mechanisms of financial support for it, as in the Clean Development Mechanism (CDM), but their application to the transport sector is limited due to the restrict measurement requirements of emission mitigation. Recently, the priority of the international mechanism has been shifted to locally demanded systems that can contribute to CO\textsubscript{2} mitigation without the restrict measurement requirements, as in the Nationally Appropriate Mitigation Action (NAMA). As a result, increasing attention has been paid to developing attractive low-carbon land-use transport systems for AVOID and SHFIT in developing cities.

Low-carbon transport systems for Asian developing cities need to be developed to calm motorisation as a main cause of transport-related CO\textsubscript{2} emissions, but 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 rail development there. Despite such road-oriented development, their road capacities could not meet the growth of road traffic demand, but road development would rather induce more car traffic and consequently more CO\textsubscript{2} emissions. Moreover, a 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, causing serious economic and environmental damages.

Development of Mass Rapid Transit (MRT), such as urban rail transit and Bus Rapid Transit (BRT), is therefore identified as one of the primary measures for SHIFT for developing cities because it is more effective to expand their transport capacities to meet growing travel demand (Nakamura and Hayashi, 2013). Since the late 20th century, megacities in Asian developing countries started to develop urban rail networks. Bangkok opened Skytrain in 1999, Blue Line Metro in 2004 and Airport Rail Link 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 land-use transport planning to promote MRT development there. To change their ways of planning, it is necessary to identify co-benefits of rail development, as CO\textsubscript{2} mitigation is not their priority.

Quality of Life (QOL) improvement is one of the important co-benefits, but it has not been incorporated into evaluation for low-carbon land-use transport development. A low-carbon land-use transport system needs to be attractive for people in order to adapt themselves to it without enforced efforts. Banister (2008) suggested that the conventional approach of transport planning to minimise transport cost for traffic efficiency should be shifted to an approach to improve social accessibility based on people’s value. Moreover, a land-use transport system may affect not only accessibility but also amenity and safety of living environments, both of which are key components of QOL. Recent transport studies have developed the theoretical framework and empirical indexes of QOL evaluation for land-use transport systems (Hayashi et al. 2004; Kachi et al., 2005; Doi et al., 2008).

This study aims to evaluate the estimated long-term effects of low-carbon land-use transport development on CO\textsubscript{2} mitigation and QOL improvement in the context of Asian developing megacities, comparing types of land-use transport development. First, it summarises a theoretical framework of evaluation for land-use transport systems in Asian developing cities. Then, an urban model integrated with QOL indexes is developed to estimate the long-term effects of land-use transport development in Bangkok. Finally, the evaluation is made for future scenarios in 2050 to represent road-oriented development and rail-oriented development with different types of station-area development.
2. EVALUATION FRAMEWORK OF TRANSPORT DEVELOPMENT

2.1 Comparative Effects of Road and Rail

The theoretical effects of road development and rail development on CO$_2$ mitigation and QOL improvement are compared, taking account of the generic contexts of Asian developing megacities. In developing megacities, investment in transport development 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 demand of car use (Hayashi et al., 2011). 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 (Figure 1).

![Figure 1. Theoretical effectiveness of rail development](image)

Given the same total amount of investment, road and rail investments to enlarge the transport capacities can reduce travel time ($\Delta T_{ro}$ and $\Delta T_{ra}$) and increase passenger travel volume ($\Delta V_{ro}$ and $\Delta V_{ra}$) by shifting their supply curves from $S_0$ to $S_{ro1}$ and $S_{ra1}$ to the demand curve D. While marginal cost of road construction per distance is lower than that of rail construction, rail development can carry more passengers because of a larger capacity of a rail carriage. On the other hand, in the ranges of larger passenger volumes, road development carry less passengers as induced traffic causes more traffic congestion. As a result, a supply curve for road ($S_{ro1}$) is steeper than one for rail ($S_{ra1}$). Moreover, rail 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 rail development...
\(\Delta T_{ra}\) can be more significant than the benefit of road development \(\Delta T_{ro}\).

This theory is applicable to the effects on CO\(_2\) mitigation. Road development can reduce traffic congestion and CO\(_2\) emissions by \(\Delta B_{ro}\) by improving traffic efficiency (IMPROVE). Rail development can reduce congestion and the emissions by \(\Delta B_{ra}\) by shifting car users to rail users (SHIFT). As per-capita emissions are lower in rail use than in car use, the total emissions can be lower in rail development than road development if there is the sufficient amount of rail passengers.

On the other hand, the comparative effects of road development and rail development on QOL improvement are more uncertain. The difference of the effects by development type is attributed mainly to the trade-off relationship between accessibility improvement and amenity improvement. More time saving from rail development can lead to higher access improvement. Lower-density development from road development might improve amenity more by providing larger houses in greener areas in suburbs. In Asian developing megacities, this type of development takes place not only in suburban areas but also in city-centre areas, as in quality private residential development around stations. As a result, living costs in station areas become expensive, so that low-income people cannot afford to live there. This causes a problem of social exclusion in QOL improvement that contributes little to promoting MRT use, in which high-income people, who rely more on cars, live in most accessible areas to stations, excluding low-income people, who need access to transit most.

### 2.2 QOL Evaluation

QOL evaluation is required to identify the uncertain effects of development. The effects of rail development depend on the level of demand shift from car use to rail use. QOL is a primary factor affecting the demand of rail development, as it represents value of local residents for the quality of rail systems. The demand shift varies by city according to value of local residents and it is therefore important to capture QOL in a quantitative manner that can be incorporated into urban models to estimate travel demand.

QOL measurement is made both with objective status of life domains and individual’s subjective value of them (Felce and Perry, 1995). Life domains have been classified as QOL elements, such as job, finances, house, health, leisure, and environment, and residents’ value of them has been compared (Van Praag et al., 2003; Poortinga et al., 2004; Doi et al., 2008; Senlier, 2009). The value may be consistent with Maslow’s hierarchy of needs (1954), in which, once more basic demand becomes satisfactory, higher-class demand becomes more important. Doi et al. (2008) suggested that, in the value mechanism of QOL, safety is the most basic demand, followed by economic opportunity, service cultural opportunity, spatial amenity and environmental benignity.

QOL evaluation for land-use transport planning pays more attention to easy access from residential locations to the opportunities of activities (Lotfi and Kooohsari, 2009). Conventional transport studies have been focused on physical access to employment activities as residential attractiveness. However, they lack people’s value of access to various opportunities according to preferences by socioeconomic group, which is called social accessibility (Kenyon et al., 2002). QOL indexes have been thus developed to capture the contributions of access to them (Doi et al., 2008) and compare it with the contributions of the other elements of residential quality, such as amenity and safety (Kachi et al., 2005).
3. LAND-USE TRANSPORT MODEL WITH QOL INDEXES

3.1 QOL Model

This study conducted QOL analysis to quantify value of quality indicators of transport modes and residential location of local residents in Asian developing megacities (Nakamura et al., 2014). A QOL index is modelled as a linear function of value parameters and quality indicators of land-use transport systems, as below. In this model, the value parameters are set for each quality indicator and for each socioeconomic type of local residents, such as income and age. In addition, the levels of quality indicators are subtracted by the existing averages of the study area, in which the QOL index represents the levels of satisfaction. The QOL index for transport mode is included in the quality indicators of access in the QOL index for residential location, details of which are explained later in the equation (5) and (6).

\[
QOLT_{s,m,i,d} = \sum_k \alpha_{s,k} \cdot X_{k,m,i,d}
\]

\[
QOLL_{s,i} = \sum_j \beta_{1s,j} \cdot (\bar{AC}_{s,j,i} - \bar{\alpha \bar{C}_{s,j}}) + \sum_o \beta_{2s,o} \cdot (\bar{Y}_{o,i} - \bar{\alpha \bar{Y}_{o}})
\]

where,

- \(QOLT_{s,m,i,d}\) : QOL index of socioeconomic group \(s\) for transport mode \(m\) in a trip from origin \(i\) to destination \(d\),
- \(QOLL_{s,i}\) : QOL index of socioeconomic group \(s\) for residential location \(i\),
- \(X_{k,m,i,d}\) : quality indicator \(k\) of mode \(m\) from origin \(i\) to destination \(d\),
- \(AC_{s,j,i}\) : access quality indicator \(l\) of group \(s\) of location \(i\),
- \(Y_{o,i}\) : non-access quality indicator \(o\) of location \(i\),
- \(\bar{AC}_{s,j,i}, \bar{\alpha \bar{C}_{s,j}}\) : the existing average of quality indicators in the study area, and
- \(\alpha_{s,k}, \beta_{1s,j}, \beta_{2s,o}\) : value parameters for quality indicators.

3.1.1 QOL value parameters

The quality indicators are classified into convenience, amenity and safety, in which access is included in convenience in QOL for residential location. Among a range of the indicators for the QOL measurement, this study focuses on ones listed in Table 1. The indicators without units uses dummy variables which are qualitatively represented by good or bad.

The value parameters of the indicators were estimated with conjoint analysis. For the estimation, an interview survey was designed to collect data of Stated Preference (SP) for the quality indicators of transport modes and residential locations. Respondents were asked to choose one of 2 options of transport modes and residential locations respectively with different combinations among the high and low levels of quality indicators to test a range of the trade-off relationship between the indicators. The survey was conducted during November and December in 2012 and collected data from approximately 1,000 respondents. Respondents were divided by household income into more than 100,000 baht/month for high-income ones, less than 20,000 baht/month for low-income ones and the remaining for middle-income ones. They were also divided by age, depending on whether they are working age younger than age 60 (under 60) or older (over 60).

Figure 2 shows the relative value of the quality indicators, which compares the % contributions of the range between the high and low levels of the indicators to QOL. The
result showed that the levels of value of quality indicators vary by socioeconomic type. In terms of the value for transport mode, while time-saving is important more for high-income people and middle-income under-60 people, cost-saving is important more for low-income people, due to their different budget of time and cost. Moreover, high-income people and middle-income over-60 people prefer the comfort and convenience indicators, but low-income people care more about safety. These may reflect the hierarchy of travel needs from safety as a basic-level need to comfort as a higher-level need, depending on the mobility development stage. High-income people and middle-income over-60 people, who are likely to be in higher-level mobility stages, prefer car use as a more comfortable mode. On the other hand, middle-income under-60 and low-income people prefer rail use as a reliable and safe mode. However, in many Asian developing cities, the rail network covers only a small area and feeder transport services, such as minibuses and motor-cycle taxis, are not safe. Thus, while car use is advantageous for comfort, there is potential of quality improvement in rail use.

Table 1. The quality indicators of QOL (units of numerical indicators in brackets)

<table>
<thead>
<tr>
<th>Element</th>
<th>Indicators for Residential Location</th>
<th>Indicators for Transport Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convenience</td>
<td>Access to work (min)</td>
<td>Arrival delay</td>
</tr>
<tr>
<td>Access to shop (min)</td>
<td>Flexible departure</td>
<td></td>
</tr>
<tr>
<td>Access to school (min)</td>
<td>Feeder access (min)</td>
<td></td>
</tr>
<tr>
<td>Access to hospital (min)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amenity</td>
<td>House size (m²)</td>
<td>Passenger space (m²)</td>
</tr>
<tr>
<td>Streetscape</td>
<td>Protection</td>
<td></td>
</tr>
<tr>
<td>Green area</td>
<td>Transfer (times)</td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td>Accident</td>
<td>Accident</td>
</tr>
<tr>
<td>Crime</td>
<td>Crime</td>
<td></td>
</tr>
<tr>
<td>Flood</td>
<td>Privacy</td>
<td></td>
</tr>
<tr>
<td>Pollution</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. The relative levels of value for the quality indicators of QOL
In terms of value for residential location, while low-income people care more about cost and convenience, middle-income people and high-income people prefer safety. Particularly, flooding is cared about most, which may be affected by the serious flooding Bangkok experienced in 2011. Moreover, comfort is more important for high-income people and middle-income over-60 people. This may suggest that the hierarchy of living needs consists of convenience as the basic need, followed by safety and comfort. These results reflect that high-income people prefer car-oriented lifestyle living in large and safe houses, as in quality gated development. In Asian developing megacities, a problem is that such quality gated development has taken place around MRT stations more for car-oriented higher-income people. This may result in preventing lower-income people from afford to live there and accessing MRT despite their higher demand for MRT use. Therefore, it may be necessary to introduce planning into quality station-area development by improving access to station in surrounding areas and controlling car use in areas close to stations.

3.1.2 QOL measurement

Whether the quality indicators are numerical or not, measurement of QOL is made with a single unit by standardising the value parameters. In this study, the QOL indexes for transport mode and residential location are measured as perceived time saving of travel and willingness to pay for monthly rent respectively. In evaluation for QOL changes from future land-use transport development, this study fixed the starting-point average level of quality indicators to be comparable with the level of 2005.

In terms of the numerical quality indicators, the spatial data of floorspace and green area were constructed based on population density. There are negative relationship between floorspace/green area and population density. Based on the relationship, the sensitivities of floorspace and green area to population density are identified, which are added to or subtracted from their current levels in future estimation.

3.2 Land-use Transport Model

This study developed a land-use transport model to estimate urban transport demand in a long-term future and evaluate the impacts of land-use transport development on CO2 emissions and QOL in Asian developing megacities (Figure 3). Difficulties in developing urban models in developing cities are mainly attributed to limited data availability and uncertain future behavioural changes. This model tackles the challenge by integrating macroscopic models and the QOL indexes to a spatial urban model.

Simpler macroscopic models are more feasible for Asian developing countries, as data is more available. This study uses some outputs of macroscopic models to provide inputs of a spatial urban model. Various models are applicable to such multi-scale modelling depending on data availability. This model thus captures the generic mechanism of motorisation in Asian developing cities by integrating models on a macro scale.

Moreover, although it is difficult to observe behavioural changes of travel and location over a long term in economic growth, some signs of future behavioural changes can be observed from the diversity of value among a range of socioeconomic groups in current developing cities. QOL analysis can capture such value for land-use transport systems as potential demand without constraints of economic cost and regulation. The value may be changed by socioeconomic changes, such economic growth and ageing. This model uses value parameters of QOL as utility parameters of travel choice and location choice and
represents future changes in value with changes in shares of socioeconomic groups, assuming that future value by socioeconomic group is same as the current value.

The structure of a land-use model developed in this study is based on a spatial interaction model integrated with a component of an econometric input-output model and a 4-step transport model (Nakamura et al., 1983). The model is applied to Bangkok Metropolitan Region (BMR). The spatial unit of the model is a 3km by 3km cell. The estimation is made by 5-year period from 2005 to 2050.

![Figure 3. The framework of a land-use transport model](image)

**3.2.1 Macroscopic model**

This model uses the macroscopic inputs of socioeconomic 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, GDP, income and employment by industry is set from the output of the macroeconomic model. Urban freight volumes between primary, secondary and tertiary sectors are estimated based on their trade of production outputs in an approach of an input-output model of CGE. This study also introduces a budget constraint of road and rail development based on GDP.

Prospective urban sprawl and motorisation in economic growth in Asian developing cities are modelled with a macroscopic urban model, using city-wide panel data of Asian megacities in the motorisation period (Ito et al., 2013). In this model, income and population growth would decrease population density as urban sprawl, which leads to an increase in car ownership as motorisation. On the other hand, rail development would slow the pace of decreasing urban density and consequently calms growth in car ownership.
3.2.2 Transport model

These macroscopic data is input into an intra-city transport model to estimate a) trip generation (trip counts), b) trip distribution (trip distance), c) modal split and d) trip allocation (trip 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 (OTP, 2007; the World Bank, 2007). The number of freight-vehicle trips per production unit is set to match a total freight-vehicle volume in Bangkok (Takahashi and Sirikupanichkul, 2001), which is applied to estimating future growth of a freight-vehicle volume according to production growth. These transport volumes are spatially distributed depending on spatial locations of population and employment, which determine trip distance. The spatial locations are estimated by a land-use model that is explained in the next section.

Modal split is estimated for passenger transport by a modal-choice model using an aggregate logit model, as below. Transport modes to be analysed are car, conventional bus and MRT (Mass Rapid Transit), such as Skytrain and Metro, with feeder transport. The utility of mode choice is determined by generalised cost, the QOL indexes for transport mode and car ownership. While the QOL indexes represent potential demand to use modes, car ownership is used to account for captive demand of car use. The residual attractiveness of QOL and car ownership are standardised to make the residual attractiveness of car zero. The decay parameter is taken from the QOL questionnaire survey and the parameter of car ownership is taken from the prevision study (Sanit et al., 2014).

$$PT_{m,s,i,d} = \frac{\exp(\theta_1 \cdot (gc_{m,i,d} - (QOLT_{s,m,i,d} - QOLT_{s,car,i,d}) + \lambda_1 \cdot CarOwn_s))}{\sum_q \exp(\theta_1 \cdot (gc_{q,i,d} - (QOLT_{s,q,i,d} - QOLT_{s,car,i,d}) + \lambda_1 \cdot CarOwn_s))} \quad (3)$$

where,

- $PT_{m,s,i,d}$: probability of socioeconomic group $s$ to choose transport mode $m$ in a trip from origin $i$ to destination $d$,
- $gc_{m,i,d}$: generalised cost of mode $m$ from origin $i$ to destination $d$,
- $CarOwn_s$: car ownership rate of socioeconomic group $s$, and
- $\theta_1, \lambda_1$: parameters.

The generalised cost of travel, which consists of time and cost, is estimated by a network model for trip allocation. The model also estimates some of the numerical quality indicators, such as feeder access time to MRT and the number of transfers of bus and MRT. The other quality indicators of each mode are set as in Table 2. Car travel is generally more convenient and comfortable than public transport travel. In public transport, while bus is advantageous for cost-saving, the advantages of MRT are time-saving and reliability. In this model, feeder transport modes of MRT includes walk, motorcycle taxi, bus and car. The model sets their feeder mode shares and population density by distance range from a station. Thus, average time and cost of feeder transport are estimated with population in the distance range and the service levels of feeder transport, such as speed, fare and waiting time. Riding space depends on vehicle occupancy. This study set it highest for car, which does not have passenger congestion, and lowest for bus, which has the lower vehicle capacity than MRT.

The model estimates changes in car ownership by socioeconomic group proportional to the city-wide average level. The city-wide average level of car ownership is estimated in the
macroscopic urban model. The questionnaire survey in Bangkok also identifies car ownership by socioeconomic group, which showed the increase in car ownership by income. The model can account for motorisation from economic growth with more car use from more high-income people. On the other hand, rail development could reduce travel cost of rail use by reducing distance of 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 that contain population and employees and to allocate the total road length to them as their capacities, depending on traffic demand. The parameters of the QV (Quantity-Velocity) relation are taken from the previous study of Asian developing cities (ADB, 2010).

Table 2. The quality indicators of transport modes (best option in bold Italic)

<table>
<thead>
<tr>
<th></th>
<th>Car</th>
<th>Bus</th>
<th>MRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>1 (Likely)</td>
<td>1 (Likely)</td>
<td>0 (None)</td>
</tr>
<tr>
<td>Flexibility</td>
<td>1 (Flexible)</td>
<td>0 (Scheduled)</td>
<td>0 (Scheduled)</td>
</tr>
<tr>
<td>Access</td>
<td>0 min</td>
<td>30min (walk)</td>
<td>(Estimated)</td>
</tr>
<tr>
<td>Space</td>
<td>1 (Large)</td>
<td>0.375</td>
<td>0.5</td>
</tr>
<tr>
<td>Protection</td>
<td>1 (Protected)</td>
<td>0.5 (Partly Air-Conditioned)</td>
<td>0.75 (Not for feeder)</td>
</tr>
<tr>
<td>Transfer</td>
<td>0</td>
<td>(Once every 10km)</td>
<td>(Once every 30km)</td>
</tr>
<tr>
<td>Accident</td>
<td>1</td>
<td>0.5</td>
<td>0.25 (Safer)</td>
</tr>
<tr>
<td>Crime</td>
<td>0 (Safe)</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Privacy</td>
<td>1 (With)</td>
<td>0 (Without)</td>
<td>0 (Without)</td>
</tr>
</tbody>
</table>

3.2.3 Land-use model

A land-use model estimates spatial locations of population and employment based on the input-output relationship between the sectors and households consistent with the CGE model. In the model, employment consumes workers, generating commuting trips, and people consume services of the tertiary sector, generating non-commuting trips. The spatial distribution of consumption determines the locations and trip distances of people and employment altogether, which are estimated with a spatial interaction model using an aggregate logit model. The model estimates the spatial distribution with the expected minimum cost of transport modes estimated by the transport model and the decay parameter identified from the QOL questionnaire survey. The residential location is estimated not with the commuting cost but with the QOL index for residential location along with population and rent. The rent is also estimated by location as the expected average bid for rent by socioeconomic group that are measured from their QOL indexes. Parameters to estimate rent are calibrated to match estimated population distribution with the actual data.

\[
PL_{s,i,d} = \frac{\exp(\theta_2 \cdot QOLL_{s,i} (AC_{s,i,d} + \ln(pop_{s,i}) - rent_i))}{\sum_j \exp(\theta_2 \cdot QOLL_{s,j} (AC_{s,j,d} + \ln(pop_{s,j}) - rent_j))}
\]  

\[
AC_{s,i,d} = \sum_d \frac{\text{trip}_{s,i,d}}{\text{Trip}_{s,i,i}} \cdot ge_{s,i,d}^r
\]
\[ g_{c,s,i,d} = \frac{1}{\theta_1} \cdot \ln \sum_m \exp (\theta_1 \cdot (g_{c,m,i,d} - (QOLT_{s,m,i,d} - QOLT_{s,car,i,d}) + \lambda_i \cdot CarOwn_i) ) \]  

\[ rent_i = \frac{1}{\theta_3} \cdot \ln \sum_s \exp (\theta_3 \cdot (QOLL_{s,i} + \ln (pop_{s,i}) + \chi_s) ) \]

where,

- \( PL_{s,i,d} \) : probability of socioeconomic group \( s \) working at \( d \) to choose residential location \( i \),
- \( trip_{s,i,d} \) : trips of socioeconomic group \( s \) for purpose \( l \) from location \( i \) to location \( d \),
- \( Ttrip_{s,i,d} \) : total trips of socioeconomic group \( s \) for purpose \( l \) from location \( i \),
- \( gc'_{s,i,d} \) : expected minimum generalised cost of socioeconomic group \( s \) among transport modes of a trip from location \( i \) to location \( d \),
- \( pop_{s,i} \) : population of group \( s \) in location \( i \),
- \( rent_i \) : rent of location \( i \), and
- \( \theta_2, \theta_3, \chi_s \) : parameters.

In the QOL index for residential location, this analysis takes account of the quality indicators of access to various activities, house size and green area. To represent quality development in station areas in the model, the dummy of the quality indicator of streetscape is set 1 for the certain amount of residents in station areas and set 0 for the other areas. Motorisation promotes urban sprawl by improving access in suburban areas and attracts car users to live there in larger houses and green areas, increasing trip distance. On the other hand, rail development promotes high-rise residential development in station areas, providing larger floorspace and better urban streetscape. This quality development can draw higher-income residents in station areas, but whether they choose rail use despite their preferences for car use depends on their levels of QOL for the modes.

3.2.4 Model validation

Due to low data availability in developing cities, the model validation is limited. This study made the model validation with several macroscopic city-wide indicators, such as modal split, vehicle distance and CO\(_2\) emissions. The city-wide level of estimated modal split in passenger transport is equivalent to the level of the actual data in 2005 (OTP, 2007). This is also the case of passenger-vehicle distance.

Moreover, the city-wide total amounts of estimated CO\(_2\) emissions are at the similar levels of data in 2005 and 2010. CO\(_2\) emissions are estimated based on the estimated transport demand and vehicle technologies. The estimation is made by multiplying vehicle-km by fuel economy (kWh /km), affected by traffic congestion, and emission intensity (g-CO\(_2\)/l, kWh). LEV (Low-Emission Vehicle) spread can improve fuel economy by shifting GVs to HVs and emission intensity by shifting GVs to EVs.

4. EFFECTS OF LAND-USE TRANSPORT DEVELOPMENT

In this study, given a future socio-economic scenario and a technology scenario, scenarios of land-use transport development are tested with the simulation analysis using the urban model.
4.1 Socioeconomic Scenario

In a socioeconomic scenario, economic growth would increase the number of trips per capita. GDP would 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 and rail development is set as 1.2% of GDP, which amounts to 31,955 million US$ from 2005 to 2050.

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 by purpose for passenger trips 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 to match the total number of freight trips with the data of Bangkok (Takahashi and Sirikupanichkul, 2001).

On the other hand, population growth in Thailand would not be significant due to the trend of ageing. According to the UN forecast (2010), population in Thailand would start to decline from 2035. This model sets the total population of Bangkok increasing by 16% from 10,477 thousand people in 2005 to 12,174 thousand people in 2050. The socioeconomic mix of population would change more than the population change, which would significantly affect travel demand due to the different value by socioeconomic group. In terms of the income mix, the shares of low-income, middle-income and high-income people are 51%, 45% and 4% respectively in 2005 in Bangkok. According to the recent trend of the change in the income mix, this scenario represents economic growth by assuming that the shares would change to 19%, 54% and 27% respectively in 2050. In addition, ageing is considered in this scenario, in which the share of aged people over 60 in Bangkok would grow from 10% in 2005 to 25% in 2050 in this scenario based on the existing forecast in Thailand.

4.2 Technology Scenario

This study sets a single scenario of technology advancement. The current levels of fuel economy and emission intensity in Bangkok were estimated by referring to the previous studies (Narupiti, 2007; the World Bank, 2009). The future levels of technology advancement, such as Tank to Wheel (TtW) and vehicle weight and LEV spread, are assumed based on the forecasting study for Japan (Yamamoto et al., 2010). To represent a leap-frog approach of technology advancement, this study assumes that the same level of technology advancement as Japan would be available in Asian developing countries in 2050. This technology 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 in Thailand. 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 would 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.

4.3 Development Scenarios

Development scenarios are set for land-use transport development up to 2050. This study first
compares scenarios of A) road-oriented development and B) rail-oriented development. The scenarios are designed with the different inputs of investment balance between road development and rail development, in which the total investment is fixed.

A) The road-oriented development scenario assumes that the current trend of rapid motorisation would continue and car use would be overwhelming. Most of transport infrastructure investment would be made in road development, assuming that no railway development would take place beyond the level of 2010, which is 81km of the total rail length. As a result, the total road length grows from 3,541km in 2005 to 5,520km in 2050. Road-oriented development would decrease urbanised density and increase car ownership from 260 cars/1,000people in 2005 to 526 cars/1,000people in 2050.

B) The rail-oriented development scenario assumes that the large-scale development of an urban rail network would take place and rail use would become popular. The urban rail network would be developed up to the level of the existing plan for 2030, 509km (OTP, 2010). The rest of the investment would be made in road development, which amounts to 4,508km. Rail development would therefore calm urban sprawl and slow the pace of growth in car ownership to the level of 390 cars/1,000people in 2050.

Moreover, the effects of rail development may significantly be affected by station-area development. This study set 3 scenarios of station-area development. B1) a scenario of car-oriented station-area development allows car-oriented lifestyle more for high-income residents in station areas as a BAU scenario in rail development. B2) a scenario of feeder improvement reduces the fare of feeder public transport to 0 to provide better access more for middle-income and low-income people. B3) a scenario of car-free scenario excludes car use in station areas as planned quality station-area development to encourage station-area residents to use MRT, in addition to the feeder improvement.

4.4 Evaluation

For each development scenario, travel demand for urban transport is estimated with the land-use transport model and the effects of development on CO₂ emissions and QOL are examined. Table 3 summarises the outputs of the modal split of the study area, the average trip time to the city centre by car and rail and CO₂ emissions from urban transport in each development scenario. The key difference of travel demand between the scenarios is shown in the modal split. Road-oriented development (A) increases the modal share of car use from 48% to 76% from 2005 to 2050. Rail-oriented development with car-oriented station-area development (B1) and feeder improvement (B2) can have the lower shares of car use, 63% and 60% respectively in 2050. Rail-oriented development with car-free station (B3) development can keep the share of car use from 2005 to 2050, increasing the share of rail use most from 2% to 23%.

The result of modal split is reflected by the result of time saving. As a result, whether rail-oriented development saves more time than road-oriented development (A) depends on the types of station-area development. Despite road development from 2005 to 2050, all the scenarios increase the average car-trip time to the city centre because of more travel-demand increase. Moreover, rail-oriented development with car-oriented station-area development (B1) and feeder improvement (B2) cannot save the car-trip time from road-oriented development (A) due to the overwhelming impacts of lower road capacities. Only car-free station-area development (B3) can do so by 7%. This result suggests that quality station-area development needs to be designed in a planned manner to make sure the impact of modal shift on congestion mitigation. Furthermore in rail-oriented development with car-free station-area development (B3), the rail-trip time can be saved most by 40% from road-oriented
development (A), which is shorter than the level of 2005.

On the other hand, while road-oriented development (A) can reduce CO₂ emissions by 9% from the level of 2005, the mitigation is more significant in all the scenarios of rail-oriented development. Rail-oriented development with car-free station-area development (B3) reduces CO₂ emissions most by 36%. The CO₂ mitigation varies by station-area development, in which car-oriented station-area development (B1) and feeder improvement (B2) reduce CO₂ emissions by 22% and 25% respectively from the level of 2005.

Table 3. Modal split, travel time and CO₂ emissions from 2005 to 2050

<table>
<thead>
<tr>
<th>Development Scenarios</th>
<th>2005</th>
<th>A</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of car use</td>
<td>48</td>
<td>76</td>
<td>63</td>
<td>60</td>
<td>48</td>
</tr>
<tr>
<td>% of rail use</td>
<td>2</td>
<td>2</td>
<td>10</td>
<td>12</td>
<td>23</td>
</tr>
<tr>
<td>Average car-trip time (hrs)</td>
<td>1.22</td>
<td>2.07</td>
<td>2.28</td>
<td>2.27</td>
<td>1.93</td>
</tr>
<tr>
<td>Average rail-trip time (hrs)</td>
<td>1.21</td>
<td>1.89</td>
<td>1.39</td>
<td>1.35</td>
<td>1.14</td>
</tr>
<tr>
<td>CO₂ emissions (kt-CO₂/year)</td>
<td>50,808</td>
<td>46,089</td>
<td>39,397</td>
<td>38,312</td>
<td>32,732</td>
</tr>
</tbody>
</table>

The levels of QOL improvement by development scenario in station areas are shown in Table 4. Thanks to the quality station-area development, QOL in station areas can be improved for all the socioeconomic groups from the level of 2005 in all the scenarios of rail-oriented development. Car-oriented station-area development (B1) highly improves it for high-income people and middle-income over-60 people, who enjoy the benefit of quality station-area development. This results in excluding low-income people to access to rail use due to rent increases in station areas. On the other hand, rail-oriented development with feeder improvement (B2) and car-free development (B3) can improve QOL for middle-income under-60 people and low-income people from car-oriented station-area development (B1) and road-oriented development (A), thanks to the higher time-saving benefit. Although rail-oriented development with car-free development (B3) reduces the effects of QOL improvement on high-income people and middle-income over-60 people, relying more on car use, it still secures the positive improvement with the higher level of QOL from 2005 to 2050.

Table 4. The QOL improvement % in station areas from 2005 to 2050

<table>
<thead>
<tr>
<th>Development Scenarios</th>
<th>A</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-income</td>
<td>4%</td>
<td>7%</td>
<td>12%</td>
<td>15%</td>
</tr>
<tr>
<td>Middle-income Under 60</td>
<td>-4%</td>
<td>5%</td>
<td>8%</td>
<td>8%</td>
</tr>
<tr>
<td>Middle-income Over 60</td>
<td>23%</td>
<td>20%</td>
<td>20%</td>
<td>12%</td>
</tr>
<tr>
<td>High-income</td>
<td>24%</td>
<td>12%</td>
<td>13%</td>
<td>8%</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

This paper has presented how effective rail-oriented development coupled with quality station-area development is in Asian developing megacities. 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. As road development induces more car use, the level of development needs to be balanced with rail development in a long term. The result of this study showed that, even though technologies are considerably
advanced to improve fuel economy and reduce emission intensity, road-oriented development can hardly be more low-carbon than rail-oriented development in developing megacities.

However, it is interesting to see the result that rail-oriented development is not always more effective for congestion mitigation and QOL improvement. The fact that quality station-area development takes place more for car-oriented lifestyle is another obstacle to developing an attractive low-carbon transport system in Asian developing cities. Such car-oriented station-area development causes more traffic congestion than road-oriented development and limit QOL improvement for lower-income people who afford less in the station area despite their higher demand for rail use. Car-free station-area development can not only reduce CO₂ emissions most, but also improve QOL for the lower-income people. Therefore, planning intervention to station-area development is necessary to make sure the effectiveness of rail development.

This implies the large potential of investment in rail development coupled with planned station-area development. Traditionally in international financial support for Asian developing countries, ODA (Official Development Assistance), 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 needs to be changed for green development. As the application of CDM (Clean Development Mechanism) to transport is low due to a lack of ways to measure benefits from it, it is important to develop a simplified method to measure transport-related benefits of CO₂ mitigation with limited data, which is a new challenge to researchers in transport planning and modelling.

Moreover, local planning systems for station-area development need to be incorporated in the rail investment to promote low-carbon land-use transport systems in a bottom-up approach from cities. Conventional ways of cost-benefit evaluation for transport development may no longer be sufficient as the value of people becomes diverse. To make a low-carbon land-use transport system attractive, the evaluation needs to be focused not only on traffic efficiency but also on QOL based on the value of local residents. It is particularly important to develop an adaptable system for rapid socioeconomic changes to aged society in Asian developing countries. This may help to propose a new lifestyle for the local residents, supported by a low-carbon land-use transport system

The findings of this study are expected to contribute to these international policies and local planning, providing an evaluation tool for low-carbon land-use transport development. Although it is not easy to develop a low-carbon transport system in Asian developing countries, there is a sign of changes in their megacities, in which rail use has received much more attention than the past. Further research is needed to apply the evaluation tool to Asian cities at different development stages to identify what are attractive low-carbon transport systems for them.

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REFERENCES


behavior and urban railway commuting of Bangkok households, *Urban and Regional Planning Review*, 1, 1-17.


