Proceeding of International Conference

The Future of Ho Chi Minh City Metropolitan Area (HCMC Future 2015)

Editor: [illegible] (Dr.-Ing.)

Vietnamese - German University
Trường Đại Học Việt Đức

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Organizers: Vietnamese-German University in cooperation with UTC and REMON

Main Sponsor: DAAD

Publishing House for Science and Technology

Possibility to Realize Low Carbon City in Khon Kaen, Thailand

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ABSTRACT

Even a Low Carbon Society is strongly required in many developing cities to cope with the global warming problem, this involves an estimation of impacts on CO_2 emission reduction which can be realized by comprehensive policies. This study carried out CO_2 emission reduction estimation based on established scenarios of BRT (Bus Rapid Transit) with Ethanol bus, Transit Oriented Development (TOD), hybrid vehicles (HVs) and Electric Vehicles (EVs) in Khon Kaen

City, Thailand. The results show that by employing scenario of TOD and BRT with shifting the use of conventional vehicles to electric and hybrid vehicles can reduce CO_2 emissions significantly approximately 48% compared to Business As Usual (BAU) scenario. This indicates that a Low Carbon City can be realized by implementation of the comprehensive transport policies.

Keywords: *Low Carbon Society, CO2 emission reduction, BRT, TOD, EV*

1. INTRODUCTION

Sustainability is of challenge which most cities are facing today. Land use and transport are two key elements to reach sustainable target. However, a main difficult task for many cities is prediction of impacts on possible policy instruments. To enable decision makers to identify strategies which can lead to sustainability, modern tools should be utilized.

At present, most of the practical transport models are based on the traditional four-stage sequential algorithm. In terms of demand changes in the medium and long term, these models are static models. Within these models transport demand is derived from exogenous indicators like population, distribution of income, car ownership and etc. This derived demand is then used as input for next stages of the model. No feedbacks from and between infrastructure supply, the transportation system and the land use development do exist.

2. LITERATURE REVIEWS

There are numbers of studies evaluated the effect of CO_2 reduction by introducing transportation policy and/or land use policy. Among those, several policies such as hierarchy and complexity combined with various approaches have never been evaluated under the integrated methodology, even though those policies were tested individually under the different methods in each study.

Many researchers tried to evaluate CO_2 emission reduction by introducing TOD policies. For example, He et al (2007) compared the CO_2 emission reductions by employing TOD and AOD (Automated Oriented Development) for Dongguan city, China. AOD means that non-strict land use policies to aggregate land use along transit corridor were not carried on and the passenger car based transportation mode was assumed to be mainly used in the city. In the study, several scenarios were assumed in which land use policies are set to allocate high density residence around five hundred kilometers from public transit station. The CO_2 emission and energy consumption under both scenarios were estimated. It was concluded that CO_2 emission was reduced more in the case of TOD than the case of AOD and the vehicle kilometer of traveled (VKT) was also decreased.

There are many studies to evaluate the possibility of CO_2 emission reduction using bi-level traffic demand model consisting of upper model and lower model. While upper model is to calculate maximum possible trips subject to the environmental capacities, lower model employs the general equilibrium assignment model integrating modal choice and origin-distribution model to express suitable economic activities and transport under the output of upper model. The lower model is one of the most famous methodologies of bi-level model. In order to develop methodology to evaluate land use policy and public transit simultaneously, several studies employed bi-level traffic demand model. For instance, Gojash (2007) estimated the maximum possible trips subject to emission constant in Chengdu, China. These results depend on road network and public transit in each targeted study area which may not be able to compare with other different cities. Then he estimated the increment of 2% possible trips under the introduction of one subway line to Chengdu. However, by employing bi-level model, it is difficult to verify trend and effect of each policy and its combination because bi-level model provides only one result under the given circumstance.

On the other hand, in the case of the medium-size city of Asian countries generally, traffic demand forecasting model does not include logistic cargo (Truck) OD flow because of lack of actual data of OD table for freight movement. To deal with freight movement, Kaneko (2005) considers the multimode user equilibrium model for evaluating emission in Bangkok. However, the current technological innovations such as HV (hybrid vehicle) and EV (electric vehicle) diffusions were excluded in the study and so do most of existing studies.

There are some studies utilize heuristic policy analysis to clarify effect of each policy. For instance, Rodier (2002) estimated the potential emission reduction of 5-7% by introducing transit policies in the Sacramento, CA (USA). Nevertheless, the study does not include TOD policy and technological innovation.

Thus, this paper focuses on the effect of CO_2 reduction utilizing an integrated policies of TOD, public transit, technological innovation and freight traffic. This study provides some important outcomes applicable for middle-sized cities in Asian countries as well.

3. OVERVIEW OF KHON KAEN

3.1. Current Traffic Situation

Khon Kaen City is a capital of Khon Kaen Province located in northeastern about 450 kilometers away from Bangkok where the number of registered motor vehicles increased at approximately 12% each year since 1990's. As economic growth, the motorization and urban sprawl has posed many problems on traffic congestion and environmental degradation. The modal share of private automobiles is also increasing. Initially, there was a plan to increase intra-city minibuses but failed due possibly to low demand and higher fare compared to other existing modes. The local intra-city minibuses were gradually diminishing and terminating their service afterward. At present, there are 751 songtaews, the ride-sharing pickup trucks run as a main public transportation throughout Khon Kaen city and other modes run on errands.

3.2. Plan of BRT

There is a plan to introduce 5 BRT lines in the city center of Khon Kaen between 2007 and 2022. For the first five years, 3 main BRT lines (i.e., Red Line, Blue Line and Pink Line) will be constructed with 63 buses, and other 2 BRT lines (i.e., Green Line and Yellow Line) will be built with 49 buses in the following years. Nonetheless, there has been a delay in the construction of each BRT line while some pilot programs like a lane restriction are carried out.

3.3. Necessity of introducing TOD in Khon Kaen

There are approximately 3.8 hundred thousand peoples live in Khon Kaen city and approximately 1.2 hundred thousand peoples live in city centre. During 2004 - 2007, the population growth rate of the whole city increased 0.203% but the population growth rate in the city centre (Nai Mueang district) decreased 0.814%. This may due possibly to the suburban sprawl.

In recent years, a high concentration of cars and motorcycles in the city centre causes chronic traffic congestion during rush hours as the workplaces located in the urban area while the housing development located further in suburban area. In this sense, even if BRT would be introduced under the current situation, an expectation of the modal shift from cars and motorcycles to BRT could be low or less without effective land use policy such as TOD policy. Figure 1 shows the future image of population density in the whole Khon Kaen city with introduced TOD policy in 2030.

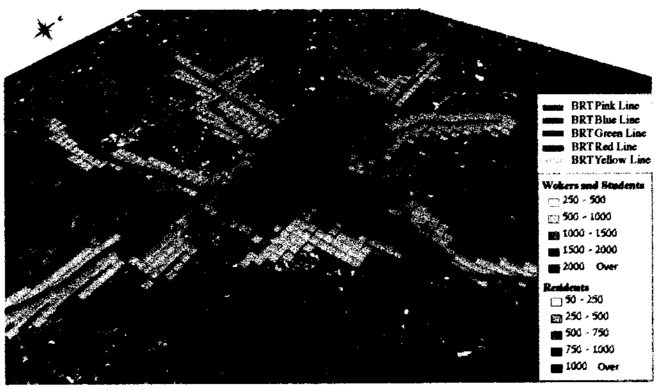

Figure 1: Future image of population density with TOD in 2030

4. METHODOLOGY

4.1. Outline of Methodology

This paper employs method of estimating CO_2 emission reduction by introducing integrated transportation and land use policies as follows;

1) The scenarios were set by selecting the potential policies and countermeasures which would contribute to reduce CO_2 emission from view point of AVOID, SHIFT and IMPROVE concepts.

2) The future transportation networks and the origin and destination matrices were developed based on scenarios including BRT development and TOD along BRT corridor.

3) Future traffic volume and travel speed by each link were estimated by using JICA STRADA which is typical four-step estimation model. In this study, the combined modal split and assignment model were employed in order to estimate CO_2 emission by vehicle types.

4) CO_2 emissions from tail pipe were estimated multiplying emission factor by travel speed to traffic volume by links.

5) Finally, CO_2 emission reductions by each scenario were estimated to compare to BAU emission.

4.2. Introduction of Strategic Policy

Brainstorming on Policies and technologies for achieving a low carbon transport system have been organized systematically by the World Conference on Transport Research Society (WCTRS) deriving a formative matrix so called the "Comparative study on Urban Transport and the Environment" (CUTE) matrix. In association with the project of "Research into concrete measures to establish a low carbon transport system in Asia (S6-5 project), these policies are classified into three main categories: AVOID (avoid unnecessary transport demand), SHIFT (shift to low carbon means of transport), and IMPROVE (improve transport energy consumption efficiency). The classifications of these policies are achieved by technological, regulatory, informational, and economic instruments (see Table.1).

Table 1: CUTE matrix of strategic policy

	AVOID	SHIFT	IMPROVE
Technological	• Transport oriented development (TOD) • Poly-centric development • Efficient freight distribution	• Railways and BRT development • Interchange improvement among railway, BRT, bus and para-transit modes • Facilities for personal mobility and pedestrians	• Development of electric vehicles • Development of biomass fuel • "Smart grid" development
Regulatory	• Land-use control	• Separation of bus/para-transit trunk and feeder routes • Local circulating service • Control on driving and parking	• Emissions standards • "Top-runner" approach
Informational	• Telecommuting • Online shopping • Lifestyle change	• ITS public transport operation	• "Eco-driving" • ITS traffic-flow management • Vehicle performance labeling
Economic	• Subsidies and taxation to location	• Park & ride • Cooperative fare systems among modes	• Fuel tax/carbon tax • Subsidies and taxation to low-emissions vehicles

In this study, three strategic policies were considered: 1) Introduction of TOD (AVOID), 2) Introduction of BRT (SHIFT), and 3) Conversion from fossil fuel powered vehicles to electric vehicles, and hybrid vehicles (IMPROVE).

4.3. Scenario Setting

There are steps and factors for estimation and setting scenario. The future OD matrix for 2030 on Business As Usual (BAU) is estimated based the published data on population and its density in Khon Kaen city. The future OD matrix on BAU was used to estimate all scenarios. Then OD matrix under introduction of TOD is calculated assuming generated trip converted from all zones to the zones along BRT. Given Scenario A, B and C as the ratio of generated trip 10%, 30% and 50% respectively for reproducing the situation of people movement along BRT lines.

It is assumed that all BRT lines are constructed in 2030. The existing songtaew (i.e., a ride-sharing pickup truck) route is discontinued and all passengers of Songtaew are assumed to be shifted to BRT. The technological innovation for engine type of EV/HV would take place and use more in future and hence the conversion rate to EV/HV from each mode is considered constant at: 0%, 30% and 50% respectively. Based on trend of EV/HV in Thailand, Trucks and motorcycles would convert to EV and passenger cars would convert to HV. The conversion rate is set with reference of the advanced vehicle strategies 2010, Ministry of Economy, Trade and Industry of Japan.

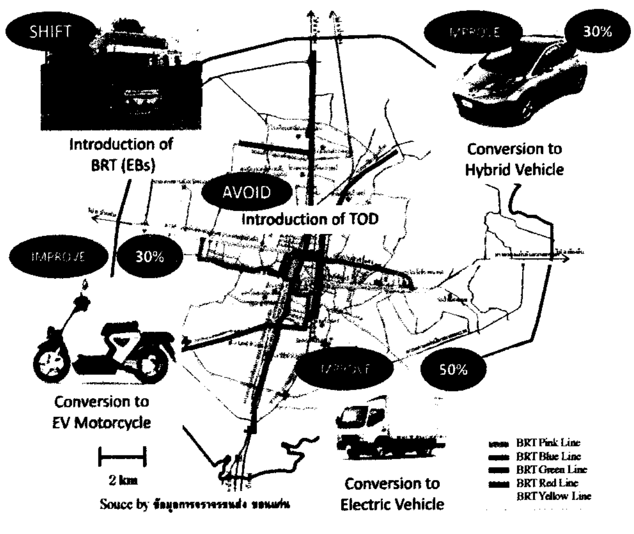

Figure 2: Image of scenario in this study

In relation to the given Scenarios A, B and C, Scenario 1 assumed that the Songtaews are main public transport without introducing BRT and shifting from passenger cars, motorcycles and freight vehicles to electric freight vehicles, hybrid vehicles whereas Scenario 2 assumed only BRT would introduce. Scenario 3 assumed with introducing BRT and shifting from passenger cars, motorcycles to electric vehicles, hybrid vehicles while Scenario 4 assumed with introducing BRT and shifting from freight vehicles to electric freight vehicles. Scenario 5 was introducing BRT and shifting from passenger cars and freight vehicles to electric freight vehicles and hybrid vehicles. Scenario 6 assumed with introduction of BRT and shifting from passenger cars, motorcycles and freight vehicles to electric freight vehicles, hybrid vehicles, see Figure 2.

4.4. Demand Forecasting Model

For estimating the CO_2 emissions, some scenarios related to transportation and land use policies were carried out. In addition to those. the integrated modal choice and assignment model that can estimate the traffic volume of modal choice was utilized for calculating the CO_2 emissions in parallel with traffic assignment.

The combined modal split and assignment model are employed to consider BRT introduction. JICA STRADA. the Japanese software for transport demand forecasting, making OD matrix and the road network was utilized for calibration. The changes in the user of automobile traffic and public traffic are theoretically split by using a nested logit model and the choices over means of travel and paths. The combined model is sloped by satisfying the requirements of network equilibrium expressed by the following mathematical optimization problem.

$$\begin{aligned} \min .Z(x(f),q,O) &= \sum_{m}\sum_{a}\int_0^{x_a^m} t_a^m(\omega)d\omega \\ &+\sum_{rs}\sum_{m}\sum_{p}\sum_{k}\frac{1}{\theta_1^p} f_{m,k}^{rs,p}\ln\left(f_{m,k}^{rs,p}/q_m^{rs,p}\right) \\ &+\sum_{rs}\sum_{m}\sum_{p}\frac{1}{\theta_2^p} q_m^{rs,p}\ln\left(q_m^{rs,p}/q^{rs,p}\right) \\ &+\sum_{rs}\sum_{m}\sum_{p} q_m^{rs,p}C_m^{rs,p} \end{aligned} \tag{1}$$

where,

$f_{m,k}^{rs,p}$: Traffic volume of purpose p and mode m on route k for OD pare between zone r and s

$q_m^{rs,p}$: OD trip of purpose p and mode m for OD pare between zone r and s

$q^{rs,p}$: OD trip of purpose p for OD pare between zone r and s

$C_m^{rs,p}$: Travel cost of purpose p and mode m for OD pare between zone r and s

When the optimization problem is solved, generally simplicial decomposition method or the partial linear approximation method may be applied. The JICA STRADA Model uses the simplicial decomposition method for calibration.

On the other hand, to consider actual traffic situation in Thailand, the parameter estimated by Jaensirisak (2009) in Bangkok was used following this equation.

$$c_a^{auto}(V_a^{auto}) = t_a^0\left(1+0.73\left(\frac{V_a^{auto}}{C_a}\right)^3\right) \tag{2}$$

where,

t_a^0 : Free flow travel time (in minute) of link a.

V_a^{auto} : Hourly volume of autos on the link a,

C_a : capacity of link a in veh/hr.

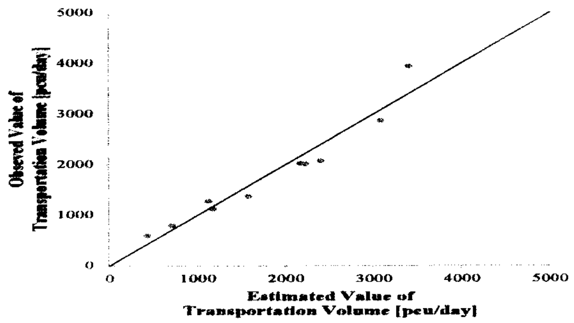

Figure 3: Correlation between observed and estimated value of freight transportation volume

To verify the accuracy of the demand forecast model a correlation analysis has been carried out. The data used for this analysis was taken from results of the traffic assignment. The result, the estimated freight transportation value, was then compared with the observed freight transportation volume of Khon Kaen City. As shown in Fig. 3 the estimated values of the model are very close to the observed once, which supports the accuracy of the model.

4.5. Estimation of CO2 emission and Emission Factor

The CO_2 emission factor is important to verify CO_2 emission reduction. To express reliable CO_2 emission under actual traffic situation, the emission factor as referred to the report "Project of Clean Developing Mechanism for Solution of Global Warming Problems" by MLIT, JAPAN is used. In the report, the emission factor was estimated using the chassis-dynamometer test running on typical running pattern in Bangkok. The emission factor of passenger car and bus has high accuracy. It was noted that ethanol emission factors of bus, EV and HV were not estimated.

Therefore, the emission factor for these vehicles was assumed based on many previous technical papers and the value of NISSAN "LEAF."

The equation to calculate CO_2 emission is formulated as follows:

$$E = \sum_{m \in M} \sum_{r \in R} \sum_{s \in S} q_{rs}^{m} l_{rs}^{m} EF_{rs}^{m} \quad (3)$$

$$EF_{rs}^{m} = \left(a^{m} V_{rs,m}^{2} + b^{m} V_{rs,m} + c^{m}\right) \quad (4)$$

where,

$m \in M$: m is the set M of available mode between OD pare between Zone r and s

$r \in R$: r is the member of the set R of origin

$s \in S$: s is the member of the set S of destination

q_{rs}^{m} : trip distribution by mode between Zone r and s

l_{rs}^{m} : the shortest distance by mode between Zone r and

EF_{rs}^{m} : emission factor of CO_2 by vehicle type

$V_{rs,m}$: average speed by vehicle type between Zone r and s

a^{m}, b^{m}, c^{m} : parameters of emission factor by vehicle type

5. RESULTS

The results of calibration indicated that the C-6 Scenario by introduced TOD and BRT with shifting to electric freight vehicles, hybrid vehicles is the strongest scenario represented 48.2% reduction rate of CO_2 emissions among all Scenarios. Coupling Scenarios 1 and 6 with Scenarios A, B and C, the effect of introducing BRT is about 10%. And if TOD policy was introduced, CO_2 would be reduced 10% in Scenario A; about 20% in Scenario B; and about 30% in Scenario C respectively compared to BAU Scenario.

Regarding the technological innovation on the conversion rate from gasoline vehicle to EV and HV as mentioned in early section, the effect of converted freight truck to EV is about 5% as shown in Scenario 1 and Scenario 4. In Scenario 5 by adding the conversion of passenger cars to HV on the scenario 4, it has an effect about 5% over scenario A, B and C. If motorcycle is converted to EV from gasoline engine, a few reduction rate was shown about 1 or 2 % comparing to scenario 5. Figure 4 shows the CO_2 emissions of each modal type in all scenarios. Consequently, even the TOD policies and the ratio of shifting to hybrid cars and electric vehicles are different, the modal share tends to be not much different in all scenarios.

Table 1: Indicators of khon Kaen City Sustainable Transport Planning

Scenarios	TOD[%]	Introduction of BRT (EB)	Conversion ratio to Freight(EV)[%]	Conversion ratio to PC(HV)[%]	Conversion ratio to MC(EV)[%]	CO_2 Emission [t-CO_2/year]	Amount of change from BAU[t-CO_2/year]	Reduction rate from BAU[%]
BAU	0		0	0	0	96,829	—	—
A-1	10		50	30	30	78,037	-18792.4	-19.4
A-2	10	✓	0	0	0	86,434	-10395.4	-10.7
A-3	10	✓	0	30	30	75,814	-21015.4	-21.7
A-4	10	✓	50	0	0	80334	-16495.4	-17.0
A-5	10	✓	50	30	0	71,035	-25794.4	-26.6
A-6	10	✓	50	30	30	69,713	-27116.4	-28.0
B-1	30		50	30	30	68,450	-28379.4	-29.3
B-2	30	✓	0	0	0	73.964	-22865.4	-23.6
B-3	30	✓	0	30	30	63.554	-33275.4	-34.4
B-4	30	✓	50	0	0	68.936	-27893.4	-28.8
B-5	30	✓	50	30	0	59,799	-37030.4	-38.2
B-6	30	✓	50	30	30	58,525	-38304.4	-39.6
C-1	50		50	30	30	63,467	-33362.4	-34.5
C-2	50	✓	0	0	0	65,464	-31365.4	-32.4
C-3	50	✓	0	30	30	55,140	-41689.4	-43.1
C-4	50	✓	50	0	0	60512	-36317.4	-37.5
C-5	50	✓	50	30	0	51.429	-45400.4	-46.9
C-6	50	✓	50	30	30	50,187	-46642.4	-48.2

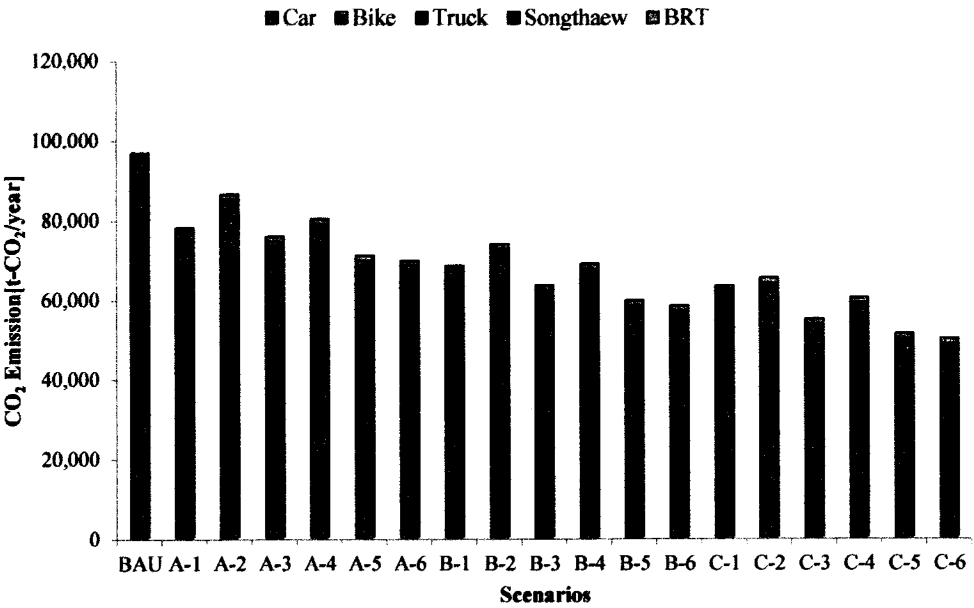

Figure 4:CO_2 Emission of all scenarios

6. CONCLUSIONS

In this study, the results indicated that the C-6 Scenario of introduced TOD and BRT with shifting to electric freight vehicles, hybrid vehicles could reduce the CO_2 emissions by up to

48.2% comparing with BAU scenario. However, the impact of CO_2 reduction will basically be ineffective if only TOD policy or BRT or shifting to electric vehicle was introduced in Khon Kaen city alone. Thus, it is faired to conclude that it is necessary to introduce an integrated land use and transportation policy for realizing a low carbon city in Khon Kaen. At present, there are some limitations of researches done on estimation of the CO_2 emission with TOD and other policies. This study assumed several comparative scenarios toward more reductions of CO_2 emission. In case of Khon Kaen, it is a middle-sized city, its study results may be able to utilize or adopt in many developing cities that have similar characteristics.

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