A Potential Study of Bus Rapid Transit (BRT) Supporting Low Carbon Asian Developing City

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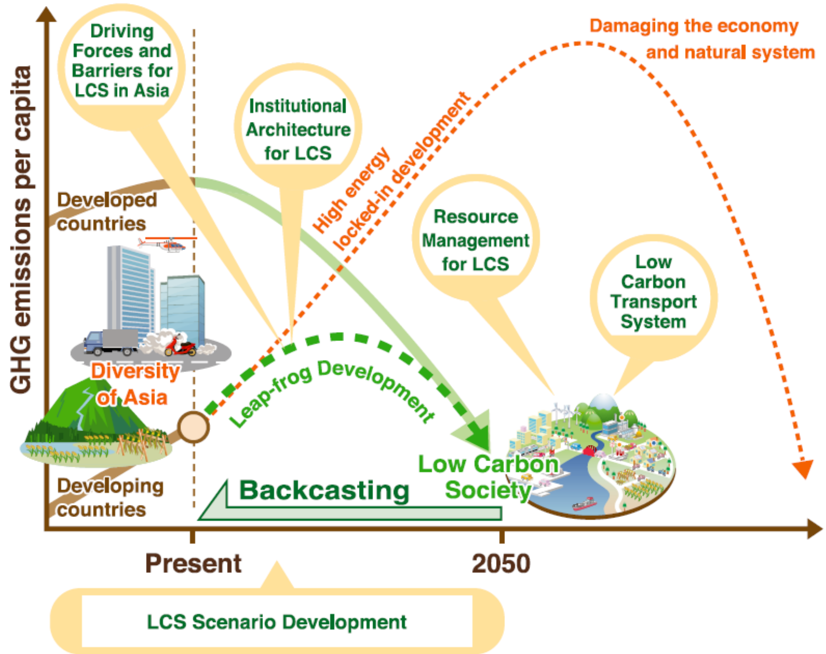
Abstract: The objective of this study is to explore a potential of Bus Rapid Transit (BRT) systems supporting Asian developing city being a low carbon city. The study evaluated 3-proposed types of BRT in term of CO2 reduction from the transport sector in Khon Kaen city, Thailand. Approach of Bottom-Up2 by Road Network and Demand Forecasting Model applied with Emission Factors were used to calculate CO2 emission for each road link. The proposed scenarios, consist of Minibus(Scenario1), BRT without Park&Ride and local feeder (Scenario2) and BRT with Park&Ride and local feeder (Scenario3), were compared to the baseline case of do-nothing in year 2022. Estimation results reveal that the proposed policy responses to CO2 emissions reduction. For the do-nothing scenario, the CO2 emission would be increased about 4.42% in the year 2022. Scenario1, 2 and 3 could reduce CO2 emission from the transport sector with 5.56%, 13.16% and 26.32% from this Baseline case, respectively.

Keywords: Bus Rapid Transit, Low Carbon City, Demand Forecasting Model, CO2 emission, and Asian Developing City

1. INTRODUCTION

Nowadays, the global climate (Global Warming) has been turned to bad conditions. It affects the rise in the average temperature of Earth's atmosphere and oceans. CO2 has increased about 36% from 1973 to 2009 (IPCC, 2006). Among the human activities, the transport sector emits a large proportion of CO2 emission. The amount of CO2 emissions has increased rapidly due to the high level of motorization resulted by an economic growth, particularly, in Asian developing countries.

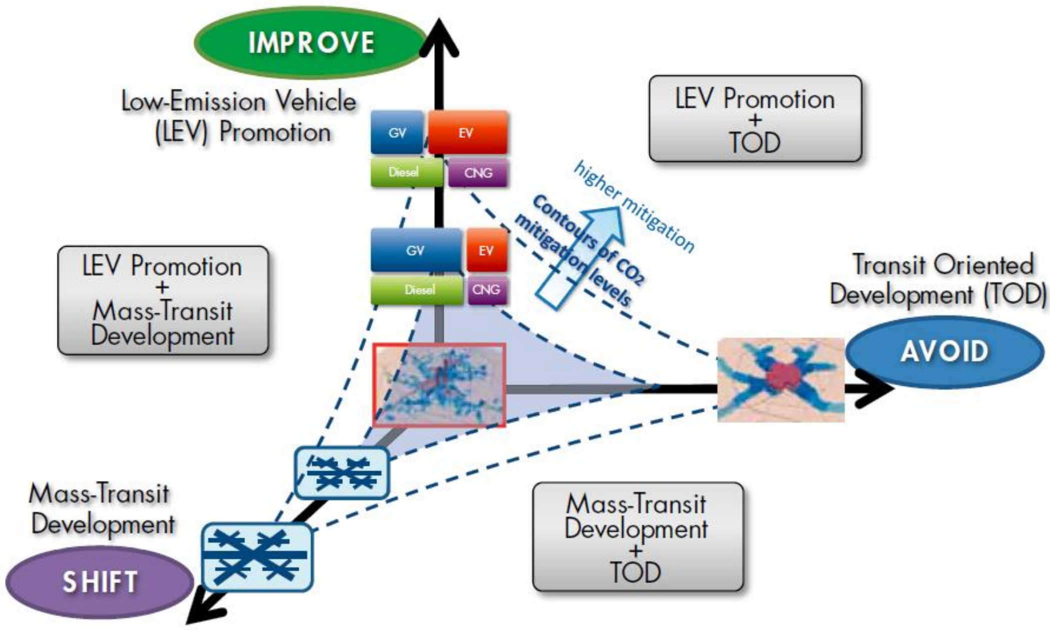
The international community has recognized the need to reduce greenhouse gas (GHG) emissions by 50% by 2050 in order to keep global mean temperature change within 2 degree centigrade compared to preindustrial times(NIES, 2011). In order to achieve the target, it is very important to develop the Low Carbon Societies (LCS) in Asia. This is due to Asian developing countries account for more than half the global population and GHG emissions. The CO2 emissions from transport sector will significantly increase due to rapid economic growth and urban sprawl in developing countries of Asia. It is thus necessary to identify leapfrog development pathways to enable a shift to low carbon emissions and low-resource consumption while simultaneously improves daily life through economic growth as displayed in Figure 1 (NIES, 2011).



Source: NIES, 2011

Figure 1. Leapfrog development pathway for Asian developing countries

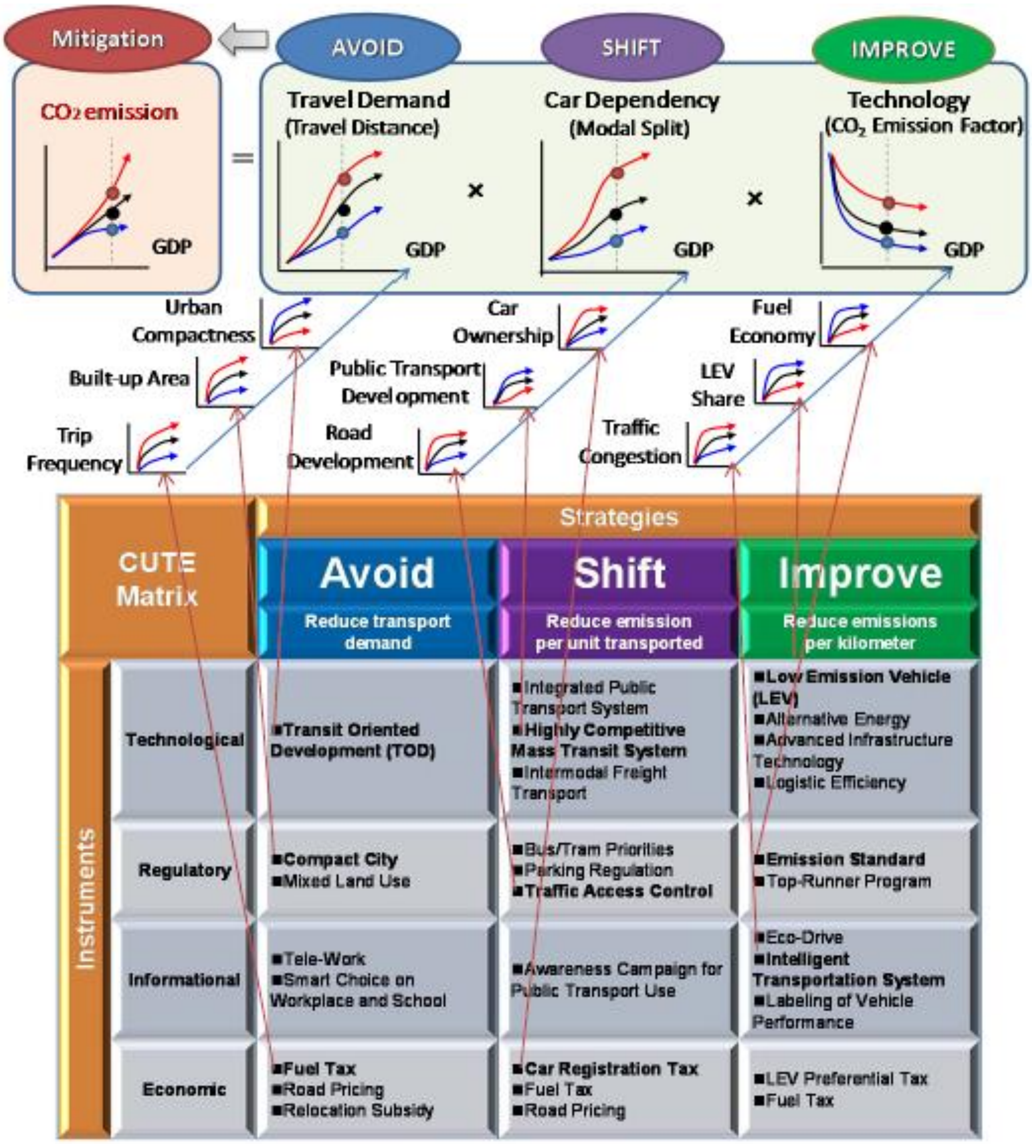
To achieve the leapfrog development, the research project of Asia LCS has been carried on to propose the measures to establish a low carbon transport system in Asia [S-6-5] (NIES, 2011). The low carbon transport systems for Asian developing cities can be designed with AVOID, SHIFT and IMPROVE strategies as displayed in Figure 2.



Source: NIES, 2011

Figure 2. Approach to designing a low carbon transport system (NIES, 2011)

Measures to achieve each strategy are further classified by instrument, including technological, regulatory, informational and economic ones, represented as the CUTE matrix proposed by the WCTRS as presented in Figure 3 (WCTRS, 2012). The ones suitable for Asian developing countries and cities can be identified, such as introducing Transit Oriented Development (TOD), Bus Rapid Transit (BRT) systems, and promoting Low Emission Vehicles (LEV).



Source: WCTRS, 2012

Figure 3. CUTE matrix

Thailand is one of Asian developing counties where its economic and motorization are growing rapidly. The registered number private vehicles increase every year not only in Bangkok but also other major provincial cities. This high demand of private vehicle usage increases the fuel consumption and causes directly to a huge amount of air pollution emission. Recently, there are several studies about the guideline to reduce CO2 from transport sector in Thailand (OTP, 2007; OTP, 2009; TGO, 2011).

Therefore, this study has an objective to explore a potential of BRT systems supporting Asian developing city being a low carbon city. The BRT is interesting and achievable measure since its low investment cost. Its flexible and accessible service route is suitable for Asian developing city.

The content of this paper is separated into following parts. The second part presents the methodology. The third part displays the results and discussions. And, the final part gives the conclusions and recommendations.

2. RESEARCH METHODOLOGY

The flow chart of methodology of this study is displayed in Figure 4. Each step of research methodology is described in detail as follows.

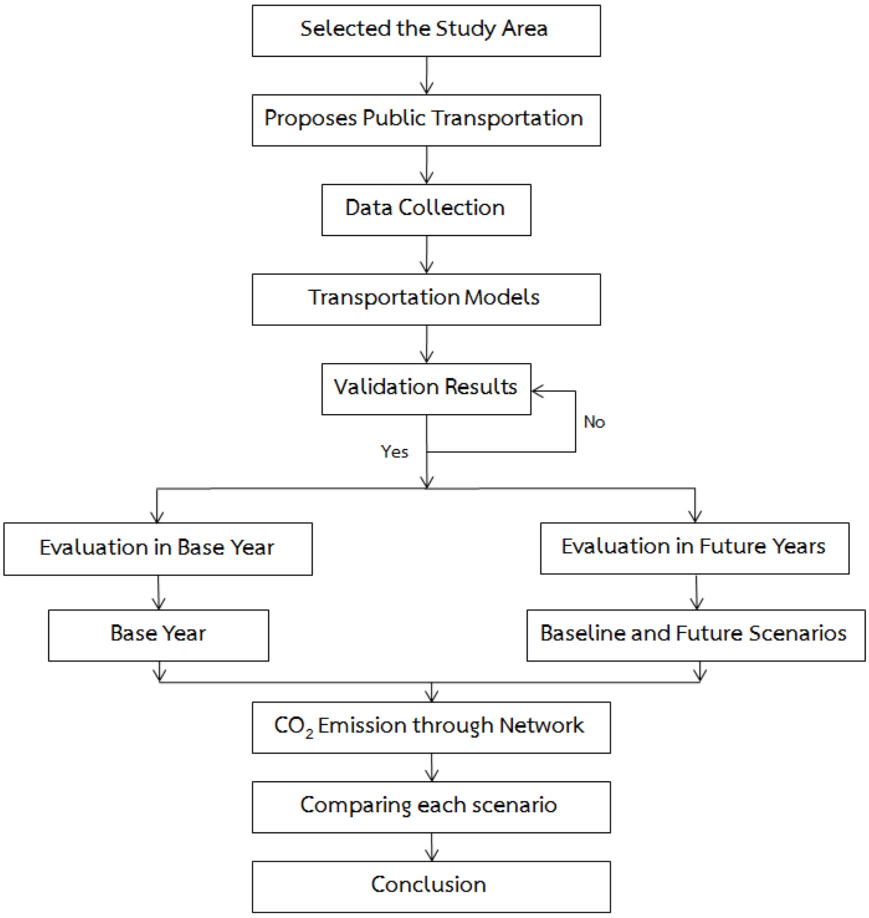


Figure 4. Flow chart of methodology

2.1 A Case Study

This study selects Khon Kaen city as a representative study city of Asian developing cities. Khon Kean city is located in the Northeast part of Thailand, covering area about 228 km^2. The population is approximately 116,157 persons with 2,525 person/km^2 density. The road network of Khon Kaen city consists of 5 important main roads, including Mittraphap Hwy., Maliwan Rd., Srichan Rd., Prachasamosoan Rd. and Rualnade Rd. This study selected the section of Mittraphap Rd. between Sam-Ran district and Ta-Pha district, a total 33 kilometers as shown in Figure 5, to implement the BRT corridor of Khon Kaen city (SIRDC, 2007).

Currently, Khon Kaen City encounters a high number of registered vehicles, as displayed in Figure 6, and its tendency has increased dramatically as similar to other Asian developing cities. Results from a household interview reveal that 68 % of Khon Kaen city people travel by private vehicle. Only 15 % of them travel by public vehicle (SIRDC, 2007).

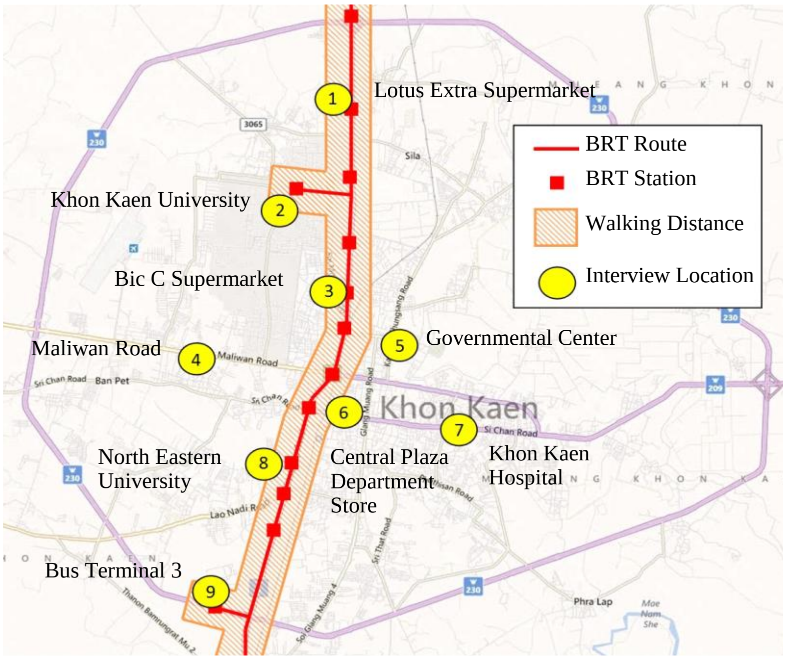
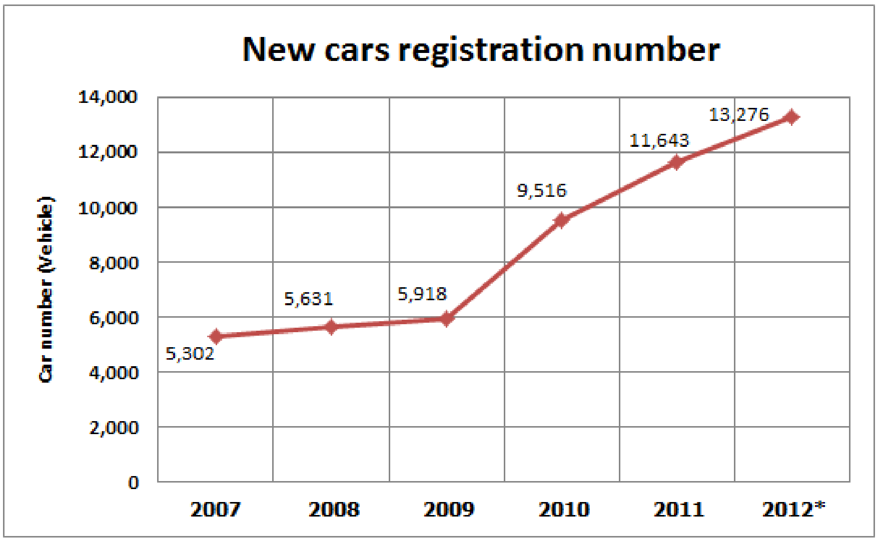


Figure 5. BRT Corridor along Mittraphap Highway in Khon Kaen City



*The data of 2012 is new car registration number from January to September.

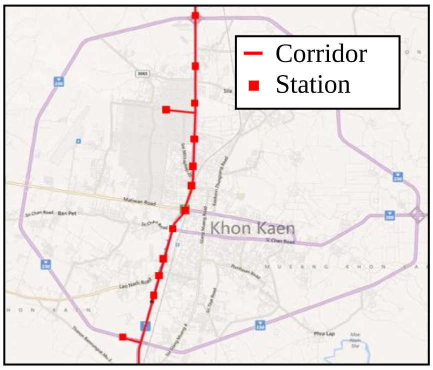
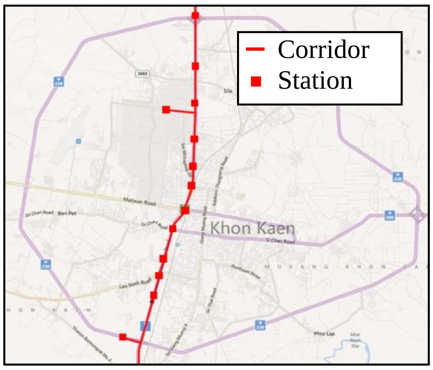
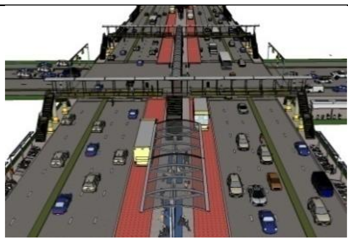
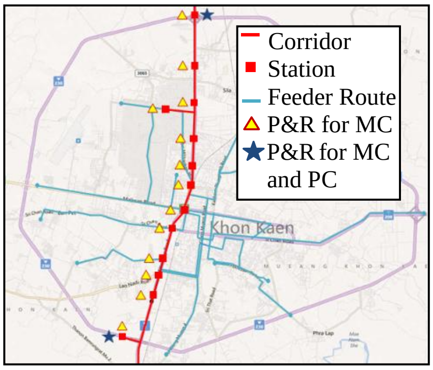
Figure 6. New car registration number in Khon Kaen city

2.2 Low Carbon Bus Rapid Transits for Asian Developing Cities

This study proposed the BRT projects to reduce the CO2 emission inside the Khon Kaen city. The proposed projects are 1) Minibus (MNB), 2) BRT without Park&Ride and local feeder, i.e. an existing public service, a pickup truck called "Songthaew" in Thai (BRT), and 3) BRT with Park&Ride and local feeder (BRTF). The systems and service routes of proposed BRT projects are summarized in Table 1. The CO2 emission reduction of each proposed BRT project in year 2022 is evaluated by comparing with do nothing condition in year 2022. The baseline case and three scenarios are established as follows.

1) **Baseline Case**: Do nothing condition in year 2022
2) **Scenario 1**: Implementing Minibus along the Mittraphap Hwy. in year 2022
3) **Scenario 2**: Implementing BRT without Park&Ride and local feeder along Mittraphap Hwy. in year 2022
4) **Scenario 3**: Implementing BRT with Park&Ride and local feeder along Mittraphap Hwy. in year 2022

Table 1. Summary of proposed BRT projects

<table>
<tr><th>Project</th><th>Vehicle Type</th><th>Busway, Station & Priority</th><th>Service Route</th></tr>
<tr><td>MNB</td><td>
- Capacity 21-40 per.
- Speed 25 kph
- NGV</td><td>
- Mixed traffic lane
- Bus stops</td><td>
</td></tr>
<tr><td>BRT</td><td>
- Capacity 60-80 per.
- Speed 40 kph
- NGV</td><td>
- Exclusive bus lane
- Stations with elevated platforms
- Bus priority system at signalized intersections</td><td>
</td></tr>
<tr><td>BRTF</td><td>
- Capacity 60-80 per.
- Speed 40 kph
- NGV</td><td>
- Exclusive bus lane
- Stations with elevated platform
- Bus priority system at signalized intersections
- P&R for MC at stations
- P&R for MC and PC at end-of-line stations
- Song Thaew feeder routes</td><td>
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2.3 Data Collection

This study collected the primary data and secondary data from several sources for using in transportation model and CO_2 emission estimation.

2.3.1 Primary Data

This study applied the Stated Preference technique to explore the change of travel behavior after introducing the BRT projects to Khon Kaen people. The three different types of BRT projects were assumed to operate along Mittraphap Highway. The questionnaire interview was conducted to the passenger car users and the motorcycle users. For each proposed BRT project, the 200 samplers were interviewed, divided into 100 passenger car users and 100 motorcycle users. In summary, 600 samplers were interviewed for 3 different systems of BRT.

2.3.2 Secondary Data

The study has been given the data from several sources. The general data (such as number of population and employment), road network and transportation demand volumes of Khon Kaen are given by SIRDC (2007). The project surveyed the existing traffic volume on main road by Mid-Block counting technique. For the CO_2 emission estimation, the emission data of various speeds by each vehicle type is given by PCD (2011).

2.4 Demand Forecasting Model

This part describes the methodology for calculating Carbon Dioxide (CO_2) emitted from transportation inside the study area. This study divided the study area into 96 zones (91 internal zones and 5 external zones) as shown in Figure 7. The authors summarize all steps to calculate CO_2 emission in flow chart for comprehensive understand as shown in Figure 4. This flow chart consists of the first step of data collection, including collecting primary and secondary data. The next step is the estimation of traffic volume by 4-step urban transportation planning model using JICA STRADA program, then validating the results (traffic volume and average speed by link). The last steps are calculating CO_2 emission by link and by whole network. The same sequence will be repeat calculated for CO_2 emission in the future.

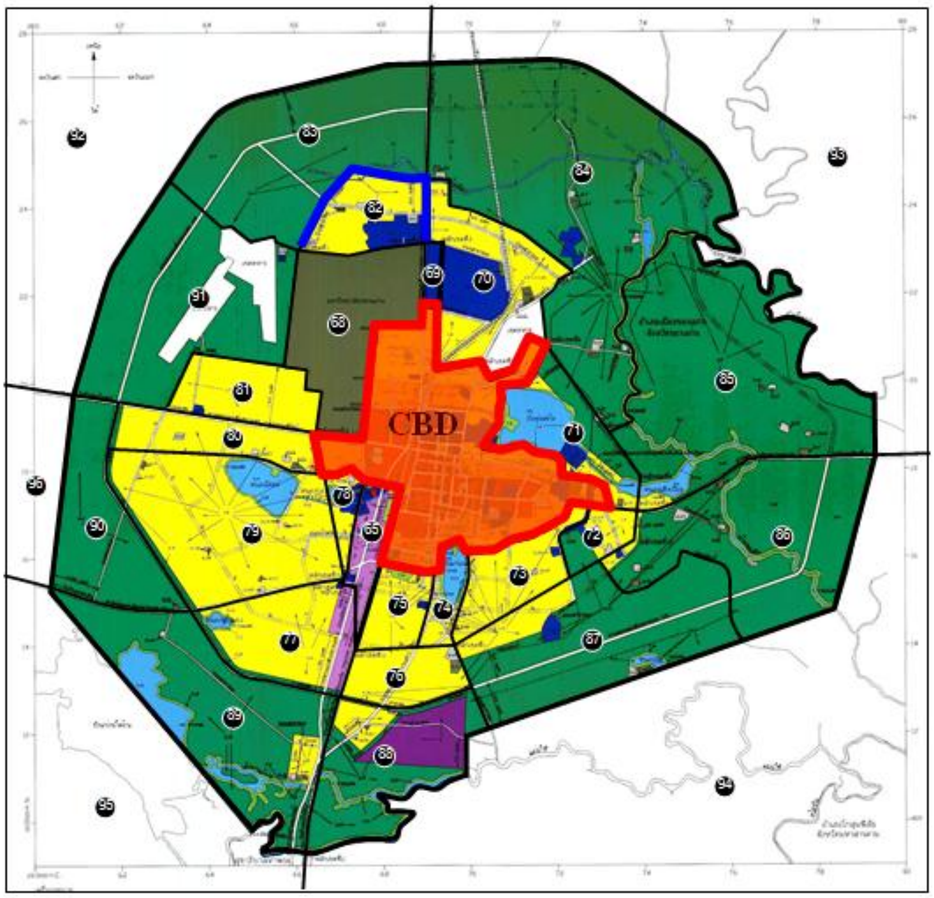

Figure 7. Divided zones in the study area

2.5 Estimation of CO2

After the estimated link traffic volumes were accepted, the results from traffic assignments model, including traffic volume and average speed, would be further used to estimate the CO2 emission as presented in the Equation 1. The Emission factors in the equation are given by PCD (2011). An example of emission factor data is as shown in Figure 8. This project researched the emission rates of each vehicle type in Bangkok that is similar to the vehicle type used in Khon Kaen.

$$\text{Link Emission} = \sum_{k}\sum_{i} D_k \times T_{ki} \times Ef_{ki} \tag{1}$$

Where as

Link Emission	=	Amount of CO2 Emission on link (gCO2/time)
k	=	Link number
i	=	Vehicle type
D_k	=	Link length (km)
T_{ki}	=	Traffic volume in link k of vehicle type i (Vehicles/time)
Ef_{ki}	=	Emission factor of vehicle type i (g/km)

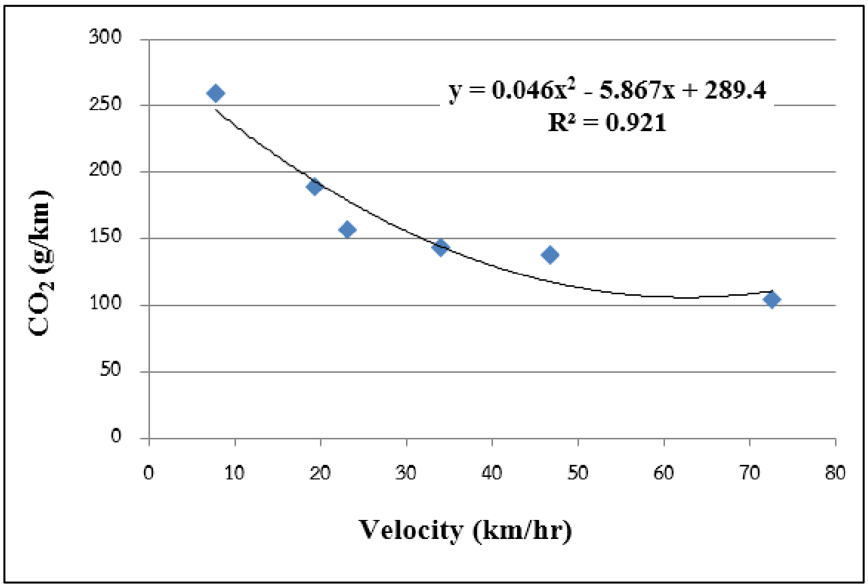

Figure 8. Emission Factor data of CNG passenger car

3. RESULTS AND DISCUSSIONS

This study applied the 4-step urban transportation planning model using JICA STRADA program to estimate the present traffic volume (in the year 2012) and future traffic volume (in the year 2022) along Khon Kaen road network. These 4 steps consist of following steps.

3.1 Trip Generation Model

As the demand model developed by SIRDC (2007), the linear model has been applied to estimate the trip generation of each zone by trip purposes. Trip purposes have 4 purposes that include Home Base Work (HBW), Home Base School (HBS), Home Base Other (HBO), and Non Home Base (NHB). HBW is a trip that related with home and office that is to say trip from home or office to office or home. HBS is a trip that relate with home and school. HBO is a trip that relate with home and other place. NHB is a trip that over there above trip. Authors chose a level of confident at 95% with statistics analysis. The results of trip generation model are displayed by trip purposes as shown in Table 2 and 3.

Table 2. Trip Production Models

Trip Purpose	Models	Standard Error	T-value	R^2
HBW	$P = 0.131POP + 15.6$	0.00572	22.82	0.92
HBS	$P = 0.423STD_1 + 82.4$	0.01819	23.24	0.93
HBO	$P = 0.025POP + 71.1$	0.00592	4.19	0.41
NHB	$P = 0.062EMP + 14.8$	0.00724	8.50	0.67

Remark: POP = Number of population in each zone, STD_1 = Number of student in each zone, EMP = Number of employer in each zone

Table 3. Trip Attraction Models

Trip Purpose	Models	Standard Error	T-value	R^2
HBW	A= 0.343EMP+96.9	0.01529	22.41	0.92
HBS	A = 0.413STD_2+57.8	0.02098	19.67	0.90
HBO	A = 0.040EMP+109.1	0.01555	2.55	0.30
NHB	A = 0.075EMP+2.9	0.00413	18.16	0.89

Remark: POP = Number of population in each zone, STD_2 = Number of student in the school in each zone, EMP = Number of employer in each zone

3.2 Trip Distribution Model

The Gravity model has been applied to forecast the trip distribution from zone to zone by trip purposes. The result of trip distribution is presented as shown in Table 4 and Equation 2.

Table 4. Trip Distribution Models

Variable Name	Coefficient	Standard Error	T-value
G_i	0.326	0.01889	17.27
A_j	0.346	0.01535	22.57
d_{ij}	-0.248	0.02359	-10.51
Impedance Name	Minimum Travel Time		
Constant	0.142		
R^2	0.54		

$$T_{ij} = 0.142 \frac{G_i^{0.326} A_j^{0.346}}{d_{ij}^{-0.248}} \quad (2)$$

3.3 Modal Split Model

Step of model split is displayed in Figure 9. The Multinomial Logit (MNL) model was applied to split between private modes (Passenger Car (PC) and Motorcycle (MC)) and public mode (Songthaew (ST)). This study applied the generalized cost variable to develop the utility function. The result of mode split is presented as shown in Table 5 and Equation 3. The Binary Logit (BL) was applied to shift the PC and MC users to BRT. The utility functions were developed by Stated Preference (SP) survey, presented in Table 6. The interview locations are displayed in Figure 5.

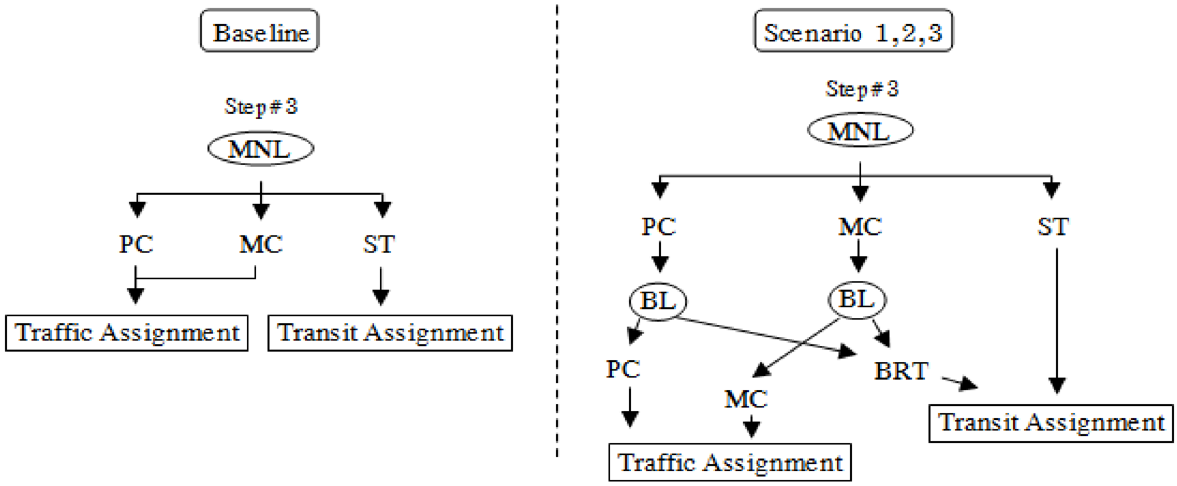

Figure 9. Step of Modal Split

Table 5. Multinomial Logit Models

Mode	Coefficient	Standard Error	T-value
Passenger (PC)	-0.301	0.09671	-3.11
Motorcycle (MC)	-0.603	0.23904	-2.52
Songthaew (ST)	-0.218	0.04505	-4.84
Impedance Name	Generalized Cost		

$$P_m = \frac{e^{U_m}}{\sum_{m=1}^{N} e^{U_m}} \tag{3}$$

Where as

$$U_{PC} = -0.301 \times GC_{PC}$$
$$U_{MC} = -0.603 \times GC_{MC}$$
$$U_{ST} = -0.218 \times GC_{ST}$$

3.4 Traffic Assignment

The User Equilibrium was applied to assign private trip into the road link through Highway Assignment. Minimum Generalized Cost was applied to assign public trip into transit route by Transit Assignment. The results of validation of assignment are presented in Table 7.

Data in Table 7 passed standard of checking for accuracy with the root mean square error (RMSE) less than 30%. Therefore, assignment models can be used to forecast and analyze the travel demand in the future.

Table 6. Utility function of Binary Logit Model Choosing between BRT and Private Vehicles

Mode	Utility Function	ρ^2	%Correct
MC&MNB	UMNB = 3.62 - 0.2TTMNB - 0.22CMNB UMC = - 0.33TTMC - 0.1CMC	0.391	80.00%
MC&BRT	UBRT = 4.57 - 0.26TTBRT - 0.22CBRT UMC = - 0.22TTMC - 0.18CMC	0.352	76.67%
MC&BRTF	UBRTF = 2.33 - 0.25TTBRTF - 0.22CBRTF UMC = - 0.67CMC	0.360	73.33%
PC&MNB	UMNB = 3.47 - 0.26TTMNB - 0.15CMNB UPC = - 0.30CPC	0.497	86.67%
PC&BRT	UBRT = 6.26 - 0.38TTBRT - 0.22CBRT UPC = - 0.33CPC	0.451	83.33%
PC&BRTF	UBRTF = 4.77 - 0.26TTBRTF - 0.14CBRTF UPC = - 0.17CPC	0.184	65.00%

Remark: MNB = Mini Bus, BRT = BRT without P&R and local feeder, BRTF = BRT with P&R and local feeder, MC = Motorcycle, PC = Passenger car, TT = Total travel time (min.) and C = Cost of travel (Baht)

Table 7. Checking for accuracy of assignment models

Name	Highway Assignment		Transit Assignment	
	2004 (Year)	2012 (Year)	2004 (Year)	2012 (Year)
Slope	0.97	0.97	0.98	0.88
%RMSE	29.61	28.43	27.18	28.99

3.5 Evaluation of Traffic Flow

The results of demand forecasting model are shown in Table 8. Mode share during morning peak hour (7:30-8:30 AM) of passenger car, motorcycle, and Songthaew are 39%, 45%, and 16%, respectively.

Table 8. Travel volume by each mode in Current Year and Baseline Case

Vehicle Type	Mode Share	Travel volume in morning peak hour (Trip/hour)	
		Current Year (2012)	Baseline Case (2022)
Passenger Car	39%	47,643	52,020 (+9.2%)
Motorcycle	45%	54,806	59,698 (+8.9%)
Songthaew	16%	18,871	20,345 (+7.8%)
Total	100%	121,320	132,063 (+8.9%)

If three different types of BRT (Scenario1, 2 and 3) are operated in the future, the private mode users would shift to BRT as shown in Table 9. The travel volume by mode in the future is displayed in Table 10.

Table 9. Percent of shift to BRT in the future (2022)

Private Vehicle	Percent of shift to BRT mode		
	Scenario		
	1	2	3
Passenger Car	7.97%	13.47%	56.00%
Motorcycle	7.09%	9.93%	30.69%

Table 10. Volume of travel by each mode in the future with BRT

Private Vehicle	Volume of travel (Trip/hour)		
	Scenario		
	1	2	3
Passenger Car	47,875	45,015	22,888
Motorcycle	55,466	53,770	41,379
BRT and Songthaew	28,722	33,278	67,796

The result of traffic flow is displayed in Table 11. The road network with BRT operation could increase average speed and decrease total travel distance, total travel time and V/C.

Table 11. Result of Traffic Flow

Traffic Flow Parameter	Current Year (2012)	Year 2022			
		Baseline Case	Scenario		
			1	2	3
Total travel distance ($x10^4$ Vehicle-kilometer)	41.99	45.75	42.55 (-7.0%)	39.02 (-14.7%)	29.32 (-35.9%)
Total travel time (Vehicle-hour)	7,109	7,987	7,317 (-8.4%)	6,723 (-15.8%)	4,916 (-38.5%)
Average speed (Kilometer/hour)	35.98	35.60	35.76 (0.5%)	35.93 (0.9%)	37.31 (4.8%)
Volume per capacity (V/C)	0.27	0.30	0.28 (-6.7%)	0.27 (-10.0%)	0.16 (-46.7%)

3.6 Evaluation of CO2 emission

The result of evaluation of CO2 emission is presented in Table 12. The road network with do-nothing in year 2022 would increase CO2 emission about 4.42% from current year (2012). However, the road network with BRT operations (Scenario 1, 2, and 3) would decrease CO2 emission about 6%, 13% and 26%, respectively. The scenario 3 (BRT with P&R and local feeder) could reduce the highest amount of CO2 because it achieved highest amount of private mode users switching to travel by BRT. Thus, it decreased highest number of private vehicles traveling along road network.

Table 12. CO_2 Emission in Current Year and Future

Year	CO2 Emission ($x10^4$ ton/year)				
	Current Year (2012)	Baseline (2022)	Scenario (2022)		
			1	2	3
2012	22.91	-	-	-	-
2022	-	23.93 (+4.42%)	22.59 (-5.56%)	20.78 (-13.16%)	17.63 (-26.32%)

4. CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations of this study are listed as below.

1) This study proposed and evaluated the Shift policy for low carbon city by implementing various types of BRT. They would shift the existing private vehicle users to use public transit.
2) The results show that for the do-nothing condition, in year 2022 the transport sector in the study area would increase 4.42% of CO_2 emission.
3) Vice versa, implementing different types of BRT in year 2022, including Minibus, BRT without P&R and local feeder and BRT with P&R and local feeder would decrease 5.56%, 13.16% and 26.32% of CO_2 emission from the do nothing condition, respectively.
4) Implementing BRT with Park&Ride and local feeder achieved the highest amount of CO_2 emission reduction. It could achieve transport sector in Asian developing city achieving low carbon city.
5) The future study should consider not only the Shift policy, but also other Avoid policy and Improve policy (such as hybrid urban truck and electric motorcycle) to achieve highest amount of CO_2 emission reduction for sustainable low carbon Asian developing city.

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REFERENCES

Asian Development Bank (ADB) (2009) *Rethinking Transport and Climate Change*, James Leather and the Clean Air Initiative for Asian Cities Center Team. No. 10, December 2009

GTZ. (2007) *Transport and Climate Change, Module 5 Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities*. <http://www.gtz.de/de/dokumente/en-transport-and-climate-change-2007>

Intergovernmental Panel on Climate Change (IPCC) (2006) *IPCC Guidelines for National Greenhouse Gas Inventory,* Volume 2 Energy.

Intergovernmental Panel on Climate Change (IPCC) (1996) *Reporting Instructions.* Revise 1996 IPCC Guidelines for National Greenhouse Gas Inventory. Volume 1

May, D. (2003) *A Decision Maker's Guidebook*, Transport and Travel research, Institute for Transport Studies, University of Leeds, UK

Ministry of Land Infrastructure and Transport Japan (MLIT), (2004), *Study to Promote CDM Projects in Transport Sector in order to Resolve Global Environmental Problem (Bangkok Metropolitan Area Case).*

National Institute for Environmental Studies (NIES) (2011) *Asian Low Carbon Society Research Project*, Report, National Institute for Environmental Studies, Japan.

OTP (2007) *The Feasibility Study of Clean Development Mechanism (CDM) Project in Transportation sector*, Final Report, Office of Transport and Traffic Policy and Planning, (OTP), Ministry of Transport and Sustainable Infrastructure Research and Development Center, Khon Kaen University.

OTP (2009) *The Feasibility Study of Clean Development Mechanism (CDM2) Project in Transportation sector (Phase 2)*, Final Report, Office of Transport and Traffic Policy and Planning, (OTP), Ministry of Transport and Sustainable Infrastructure Research and Development Center, Khon Kaen University.

Pollution Control Department (PCD) (2011) An estimation of the gas emission amount from transportation sector was classified into fuel type, vehicle type, (Bangkok Metropolitan Area Case).

Satiennam, T., Fukuda, A. and Kaneko, Y. (2007) Demand Supply Policy for Bus Rapid Transit Development in Asian Developing Cites -Accumulating Demands from Urban Sprawls to BRT Corridor by Paratransit Feeder-, *11th World Conference on Transport Research*, Berkeley, USA.

Satiennam, T., Tankaseam, P., Sathitkunarat, S., and Kowtanapanich, W. (2010) A Feasibility Study on Clean Development Mechanism Project for Transport Sector in Khon Kaen University, Thailand: Case Study of Campus Shuttle Bus, Paper ID 0316, *Selected Proceedings of the 12th World Conference on Transport Research Society*, ISBN 978-989-96986-1-1.

SIRDC (2007) *A Master Plan of Khon Kaen Transit System*, A Final Report, Khon Kaen Municipality and Sustainable Infrastructure Research and Development Center, Khon Kaen University.

Thailand Greenhouse Gas Management Organization (TGO) (2011) *A Study on the Development of Greenhouse Gas Emission Baseline Model in Transportation Sector of a Regional City Prototype and Evaluating the Possibility of Reducing Greenhouse Gas Emission in Transportation Sector of Thailand*, A Final Report, Sustainable Infrastructure Research and Development Center, Khon Kaen University.

United Nations Framework Convention on Climate Change (UNFCCC). Approved Consolidated Baseline and Monitoring Methodology: ACM0016 Baseline Methodology for Mass Rapid Transit Projects

World Conference on Transport Research Society (WCTRS), (2012) *Putting Transport into Climate Policy Agenda -Recommendations from WCTRS to COP18-*, Report.