MEASURING THE CARBON DIOXIDE IMPACTS OF URBAN TRANSPORTATION PROJECTS IN VIENTIANE, LAO PDR

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ABSTRACT

This paper presents a study on the impact regarding the reduction of CO2 emissions by implementing the comprehensive package of transportation improvement measures in Vientiane, Lao PDR. The macro traffic demand forecasting model and the micro traffic simulation model were developed to estimate CO2 emission reduction by different scale of countermeasures such as introduction of BRT lines, an area wide signal control system and parking management for illegal on-street parking which were included in this package. Results show that such packages potentially reduce urban areas´ CO2 emissions in a more effective way comparing to individual public transportation improvement measures.

Keywords: BRT, Parking Management, Public Transport, VISUM, VISSIM, Vientiane Package analysis

1. INTRODUCTION

Recently, motorization has been increasing continually in Vientiane, the capital city of Laos, due to rapid growth of economy and population. According to JICA (2008), since 1998, the number of registered cars in Vientiane has been increasing at an annual rate of 20%, while registered motorcycles have been increasing at an annual rate of 10.7%. In 2006, the total number of registered vehicles was around 232,000 and increasing at a global growth rate of about 11% per year.

During morning and evening peak hours, severe traffic congestion is observed. As the congestion increases along with motorization, it is expected that roadside environmental conditions deteriorates due to higher pollution emissions. In an attempt to change such condition, the implementation of a BRT system was proposed. However, previous studies to evaluate the impact of the BRT implementation focused exclusively on the demand estimation from the macroscopic point of view, ignoring additional benefits obtained by improved traffic control and parking management. Previous studies have been carried out for urban transportation policy development in Vientiane. In August 2010, as a result of the Fifth Regional Environmentally Sustainable Transport Forum, held in Bangkok, Thailand, a document entitled Bangkok Declaration for 2020 – Sustainable Transport Goals for 2010-2010 summarized the intent of the participating countries to voluntarily develop and realize integrated and sustainable transport policies options, programmes and projects in order to realize goals and objectives by the year 2020 in the Asian region. The document, known as EST20, summarizes 20 goals that are to be realized by the Asian countries. The proposed policies and measures were classified in three categories: Avoid, Shift and Improve (shown in Table 1). Each category represents the main objective of such measures. The "Avoid" category refers to measures that aim at avoiding traffic in the city by changes in land use and promotion of public transport. The "Shift" category refers to measures that aim at shifting private car and motorcycle trips to public transportation. The "Improve" category refers to measures aiming at the improvement of traffic facilities.

ADB (2010) provides an overview of the ADB effort in supporting the international development community for environment sustainable transport through funding of studies and development. ADB has identified three components as the aid framework for Vientiane: Potential institutional, funding, capacity building; Public transport investments and pilot route development; and Traffic Management.

JICA (2008) describes a study on "Comprehensive Urban Transportation for Vientiane" which was proposed to serve as a Master Plan for the transportation development in Vientiane. The objectives of this study were the formulation of a comprehensive urban transport development plan, the preparation of a implementation plan, the conduction of pre-feasibility studies for selected projects and the transfer of technology between the JICA experts and the local personnel.

Vientiane was selected as one of the targeted city under "Asian Mayors' Policy Dialogue for the Promotion of Environmentally Sustainable Transport in Cities".(MoE, 2010)

Based on careful evaluation of the policies considered in the previous studies, the promotion of a shift from individual transportation modes to public transportation were selected as most appropriate for Vientiane. Hence, in addition to Parking Management, which is expected to reduce the attractivity of the area for cars and motorcycles, the construction of a medium capacity public transportation system was evaluated.

Table 1 presents a comparative view on the policies considered by previous studies in Vientiane. The policies are divided into the three mentioned strategies (avoid, shift and improve) shown in the first column. Second and third columns present the policies. In the columns labelled "Comparison", it is possible to understand the use of each policy in the three previous studies in Vientiane.

Table 1 - Policies in previous studies on Vientiane

Strategy	Policy	Outline	Comparison		
			EST	ADB	JICA
Avoid	Compact City	Sprowling area put together.	○		
	Transit Oriented Development (TOD)	Land use designed to maximize access to public transport	○		
	Information Communications Technolgies (ICT)	Cut down commute time by using the Internet.	○		
Shift	Non-Motorized Transport (NMT)	Accelerate the use of NMT.	○		
	Bus Improvement	Introduce of Loop bus or Articulating bus. etc		○	○
	Bus Rapid Transit (BRT)	Public transportation systems using buses to provide faster, more efficient service than an ordinary bus line.	○		
	Light Rail Transit (LRT)	Higher capacity and higher speed than traditional street-running tram systems.			○
	Road Pricing	An economic concept regarding the various direct charges applied for the use of roads.	○		
	Provision with Parking Space	Maintenance appropriate parking.		○	
	Parking Management	Introduce of Park and Ride. etc	○	○	○
Improve	Road Improvement	Improvement of the intersection and development bypass.			○
	Cleaner Fuels and Technogies	Eco-car to recommend.	○		
	Road Taffic Law	Implement the Road Taffic Law.	○	○	
	Intellingent Transportation Systems (ITS)	Improvement of the signal control.	○		
	Freight Transport	Efficiency of freight vehicles.	○		

Source: Ministry of the Environment, Government of Japan (MoE) (2010) Bangkok Declatration for 2020, The Fifth Meeting of the Regional EST Forum in Asia Held, News Headline, Available online: http://www.env.go.jp/en/headline/headline.php?serial=1419, (Issued on September 2, 2010)
Asian Development Bank (ADB) (2010) TA 7243: Implementation of Asian City Transport Vientiane Sustainable Urban Transport Project
Japan International Cooperation Agency (JICA)(2008) THE STUDY OF MASTER PLAN ON COMPREHENSIVE URBAN TRANSPORT IN VIENTIANE LAO PDR

According to FTA New Starts Report (Table 2), BRT systems can be built at much lower costs show. Moreover, the bus operation is far more flexible than its rail counterpart, hence, changes in operational characteristics such as increasing and decreasing headways are easy and quick to implement. Additionally, system capacity can be changed by the use of different vehicles (standard buses, articulated or bi-articulated).

Table 2 - Capacity and construction costs of mass transportation systems

System	Passenger Capacity per car	Number of cars	Composition Capacity	Headway (min)	System Capacity (pass/h)	Construction cost (million US$/km)
LRT	100	3	300	5	3600	25~37
	100	5	500	5	6000	
Monorail	100	4	400	5	4800	35~50
	100	5	500	5	6000	
	100	6	600	5	7200	
Train	400	7	2800	5	33600	50~70
	400	8	3200	5	38400	
	400	9	4000	5	48000	
Conventional Bus (1 lane)	100	1	100	0.5	3000	
Conventional Bus (2lanes)	100	1	100	0.25	6000	
Articulated Bus (exclusive lane)	80	2	160	1	9600	4~5
Articulated Bus (exclusive lane with overtaking)	80	2	160	0.5	19200	
Bi-articulated Bus (exclusive lane)	80	3	240	1	14400	
Bi-articulated Bus (exclusive lane with overtaking)	80	3	240	0.5	28800	

Source: FTA New Starts Report FY 2000/2001

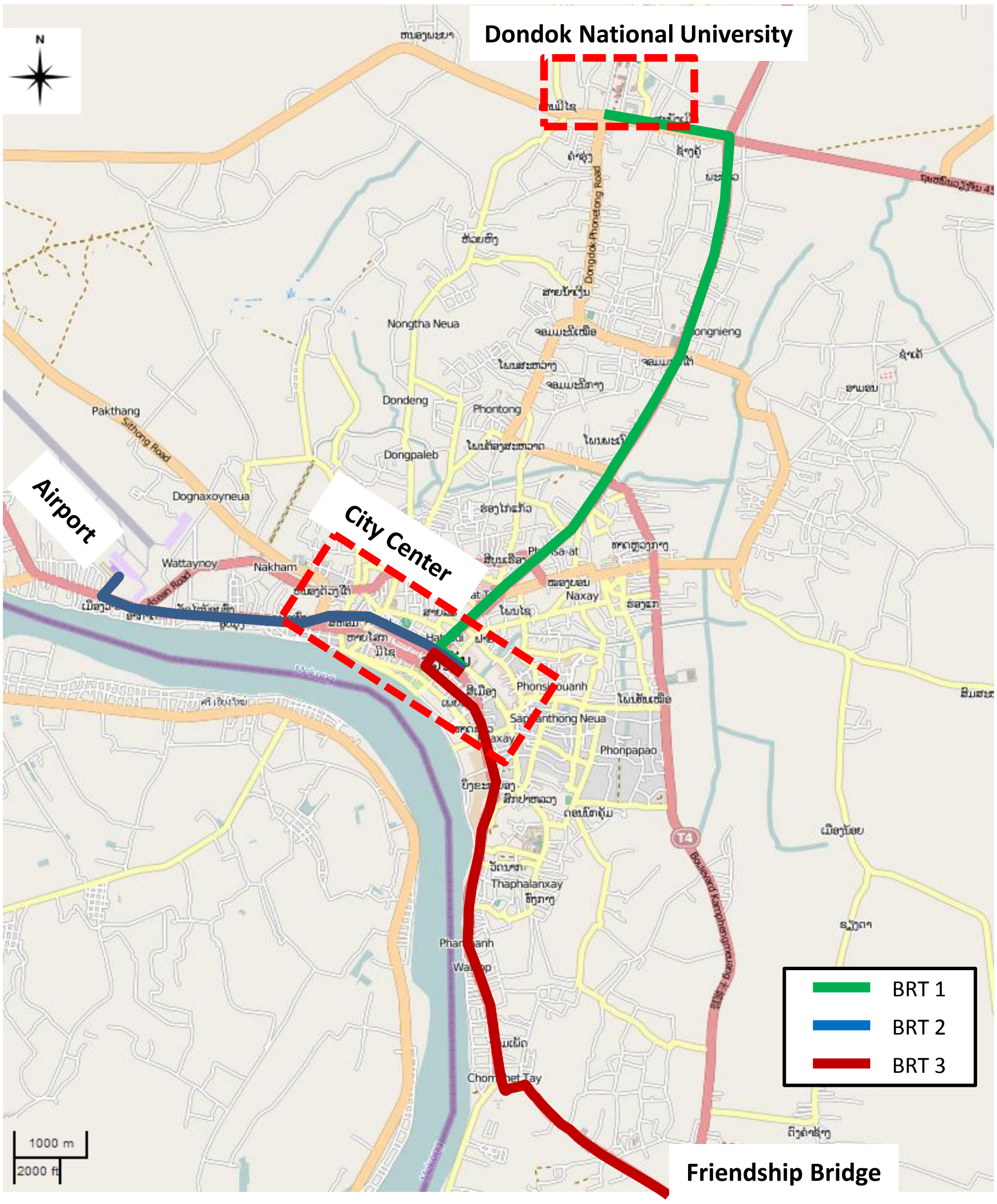

Figure 1 - Map of proposed BRT lines in Vientiane

Three BRT lines have been proposed for Vientiane as shown in Figure 1 shows. BRT Line 1 will connect the city center and the Dongdok National University, along National Route No.13. The traffic of motorcycles along this route is very high due to the commuting traffic between the city center and university.

The traffic signal control in the central area of Vientiane operates under the Australian SCAT system. This system uses on-line real-time traffic data gathered by vehicle detectors installed under the road surface. Using such data, this Area Traffic Control (ATC) automatically computes and applies various signal control parameters, such as signal cycle, split and offset at each intersection.

The SCAT system operates in a four-stage cycle which provides lower than necessary signal capacity during peak hours. Figure 3 shows the SCAT plan for Intersection No. 3 (JICA, 2008). In this study, a two-stage signal plan was used to obtain higher capacities in the signalized network, with a cycle length of 180s, increasing green time in 29% to one movement and 34% to the conflicting movement in each cycle, as shown in Figure 4.

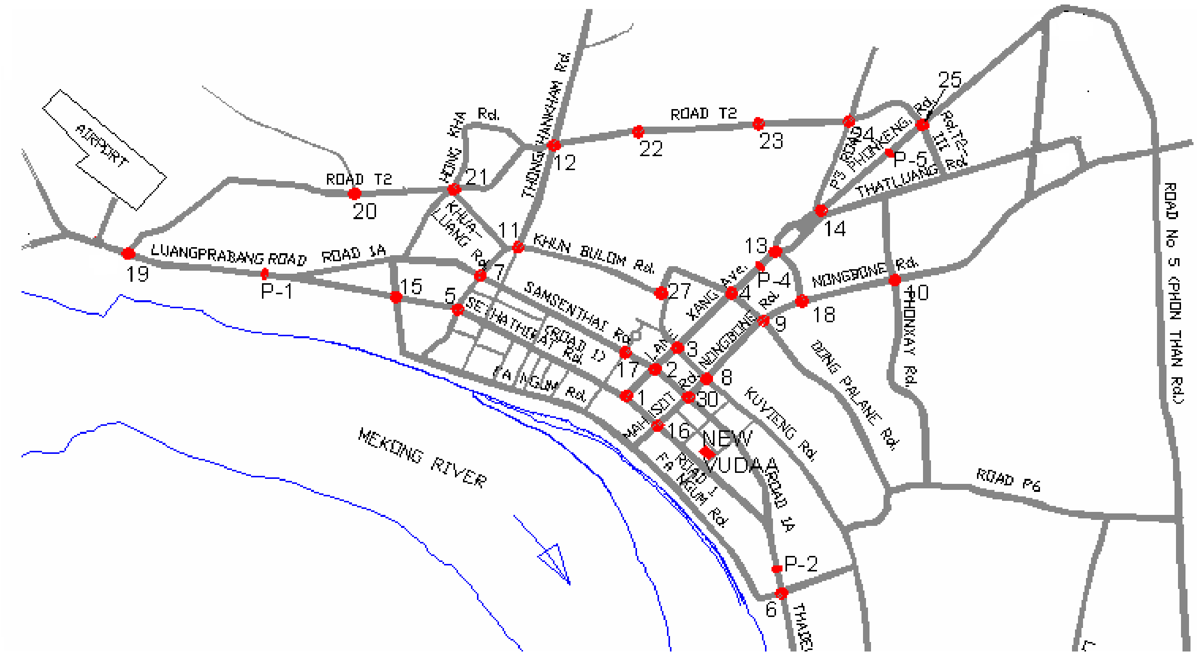

Figure 2 - Intersections currently controlled by Traffic Management Center
Source: Japan International Cooperation Agency (JICA) (2008) THE STUDY OF MASTER PLAN ON COMPREHENSIVE URBAN TRANSPORT IN VIENTIANE LAO PDR.

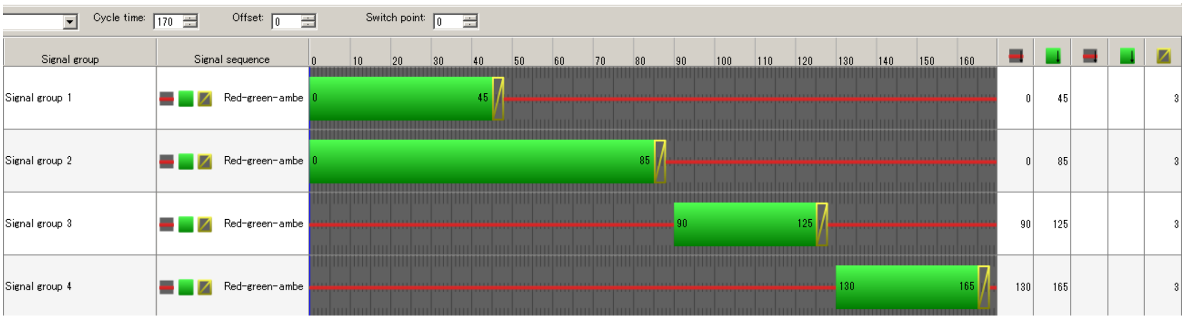

Figure 3 – Calculated Signal cycle sample at No.3 intersection by SCAT

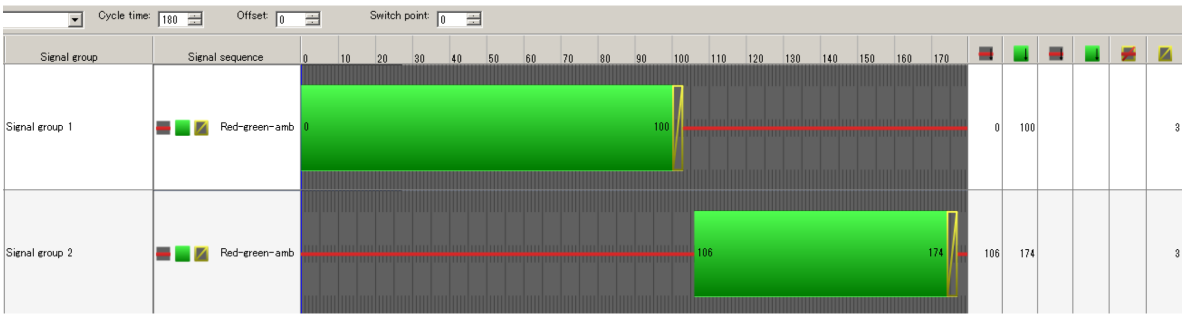

Figure 4 –Two-stage signal sample at No.3 intersection suggested by our study

As the traffic increased, illegal parking has escalated as a result of insufficient parking facilities. Travel speed is immediately affected by on-street illegal parking leading to congestion. In this study, the concept of parking management proposed by the Asian Development Bank is included in the package of measures that were evaluated.

According to Shiftan (2007), parking policy is one of the most powerful means urban planners and policy makers can use to manage travel demand and traffic in city centers.

Moreover, Feeney (1989) identified that there is some support for the view that parking policy measures are a relatively important influence on modal choice.

According to ADB, parking management is a set of measures that include intensive actions against illegal parking, improving information on the directions to existing parking facilities and building new parking facilities.

Figure 5 - Illegal on-street parking scene in Vientiane

2. OBJECTIVE

The objective of this study is to evaluate the benefit of combined measures over individual measures in a transportation improvement plan aiming at the reduction of traffic congestion directly resulting in lower CO2 emissions.

The measures considered in this study include the implementation of BRT lines, the improvement of signal control systems and the implementation of parking management. Various scenarios are evaluated and compared.

Moreover, the benefit of using an integrated macro/micro simulation model is addressed in the proposed methodology.

3. METHODOLOGY

In order to assess the different scale of policies and measures mentioned in Table 1, a microsimulation model was used for the evaluation of signal control and parking management, while a macroscopic traffic demand forecasting model was used in the evaluation of road network improvement and modifications in public transportation network and services. The software VISUM and VISSIM were chosen in order to permit that a travel demand model works in parallel with a microsimulation model. Both macro and micro models share the same network information and the results of traffic assignments from the travel demand model are transferred to the microsimulation model. The software share the signal plan information which is stored in independent files. The travel demand model access the signal plan files, in case an assignment method that considers the capacity of signalized intersections is selected. The same files are accessed by the microsimulation, resulting in coherent results between the travel demand model and the microsimulation.

Three scenarios were analysed with microsimulation regarding on-street parking: on-street parking for 2010, on-street parking for 2030 and on-street parking with restriction for 2030.

Thus, including the reference situation in 2010 and a “do nothing” perspective for year 2030, a total of five scenarios were studied, as presented in Table 1:

Table 1 - Scenarios of implemented measures

Scenario	Demand	BRT	Parking Management	Signal Management
1	2010	-	-	-
2	2030	-	-	-
3	2030	Implemented	-	-
4	2030	Implemented	Implemented	-
5	2030	Implemented	Implemented	Implemented

Using the microsimulation model, average speed of each lane per link was estimated and used in the calculation of CO2 emissions. Following, a comparative analysis of the CO2 emission in the different scenarios was performed. Figure 6 shows an outline of the methodology.

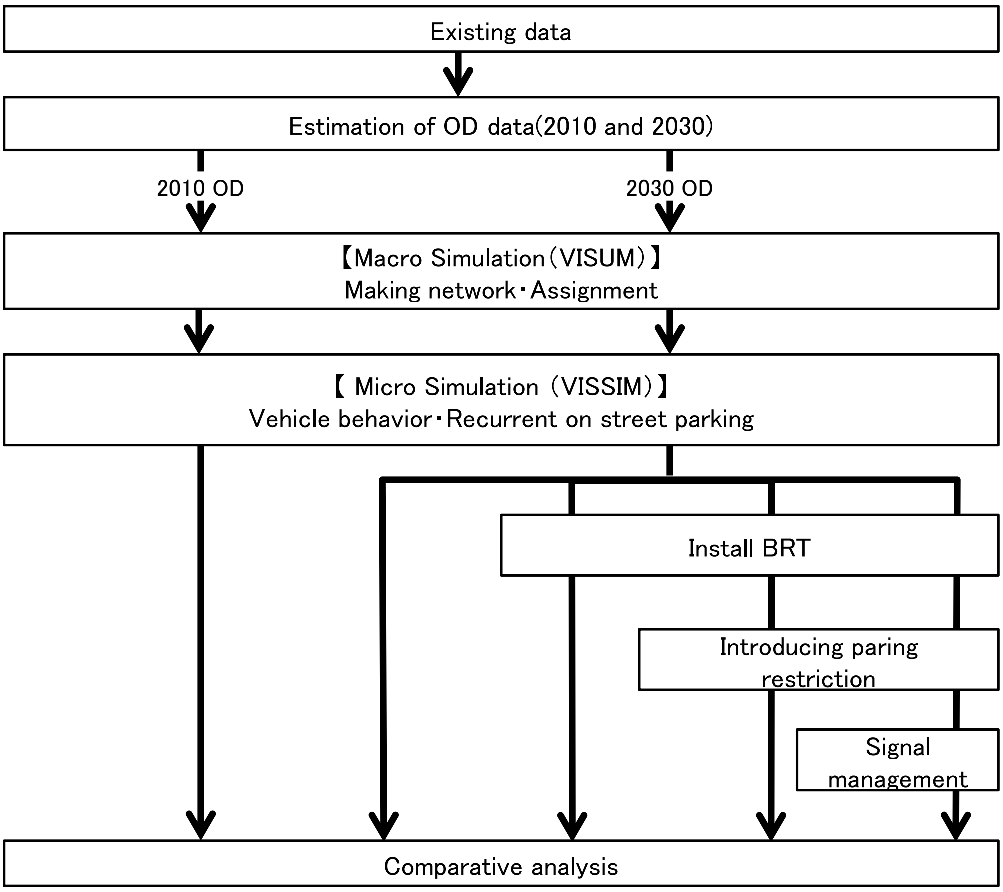

Figure 6 – Flow chart of this study's methodology

3.1. FIELD SURVEY

The data required for the analysis were obtained in three field surveys conducted in Vientiane. Figure 7 details the areas where the surveys took place.

In the first survey, classified traffic volume, signal cycle plans and travel times were collected. It was conducted on October 5th and 6th, 2010. Traffic counts occurred in 5 locations along the proposed BRT route. The measurements happened during the morning peak hours, from 6:30 to 8:30. Signal cycle length was measured on 7 intersections during the same period. Travel time was measured using GPS receivers installed on passenger cars driving along the BRT route.

The second survey identified the situation of irregular on-street parking and off-street parking in downtown area, where on street parking was prohibited. This survey was conducted in July and August 2011. Classified traffic volume and signal cycle length were also measured in this area. The situation of on-street parking was observed by taking continuous photos at the city centre on July 20th. This area offers very few parking places. Talat Sao mall, which is the largest shopping mall with 4,022m^2 of floor space, is the largest trip attraction point in the studied area. The parking places servicing the mall were also surveyed on July 20th. Moreover, the traffic volumes on three additional locations in this area were observed during 30 minutes within the morning peak hours (8:00~8:30) on August, 29th. On the same day, signal cycle length was also observed on three intersections located with the same area.

On the third survey, traffic volume and travel time were collected again on August 2012. Traffic volume was counted on three locations along the BRT route and on another three locations in the city center during morning peak hours (7:00~9:00). The travel time along the BRT route and on the city center was measured using GPS receivers installed on passenger cars during the same period. A total of 6 GPS survey trips were conducted on August 28th 2012.

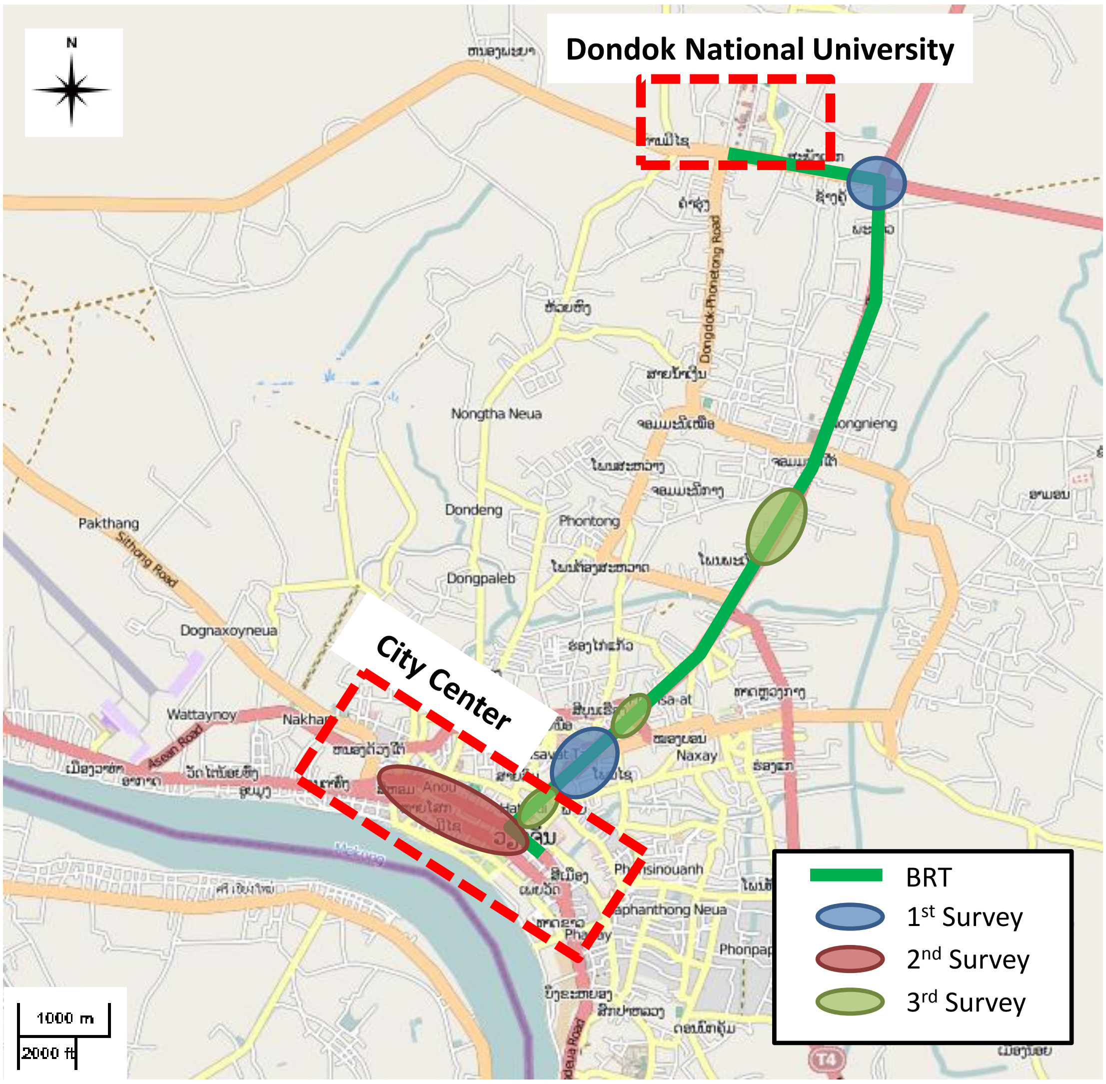

Figure 7 – survey points for this study

3.2. MACROSCOPIC TRAFFIC DEMAND ESTIMATION

The network used in the travel demand included local, collector, and arterial roads. Different volume-delay functions were used according to the road class in order to evaluate the effects of volume over travel time.

The zone distribution followed the zoning used in previous studies, so that the existing OD matrix could be used. The travel demand model uses 52 zones, including internal and external zones, which cover the entire Vientiane.

The travel demand model consists in an assignment model for the individual trips, referring to the passenger cars, and an assignment model for the public transportation trips. As both matrices were generated in a previous ADB study, the travel demand model does not include trip generation, trip distribution and mode choice models. The assignment of the individual trips was performed using a user equilibrium method, calibrated with 999 traffic counts. The public transportation trips were assigned using the so called Headway assignment method in VISUM.

Headway-based assignment is used to analyse areas that employ a headway-based approach rather than a detailed timetable. It allows users to account for fare prices, making it possible to analyse the sensibility of value of time. Moreover, headway-based assignment is used for impact analyses of long-term planning scenarios, such as transport development plans.

The headway assignment method reflects the constraints imposed by line routes and timetables. Specific search algorithms consider transfers between transit lines with their precise transfer time. In contrast to existing schedule-based search methods employing a shortest-path algorithm, the headway based procedure constructs connections using branch & bound techniques. This approach produces better results in cases where slow but cheap or direct connections compete with fast alternatives which are more expensive or require transfers. At the same time it significantly reduces computing time, thus facilitating the assignment for large networks. A key feature of the presented assignment procedure is the extension of the standard choice model by the connections' independence to reflect interaction effects between competing alternatives.

The results of the travel demand model were exported to the microsimulation model. Specifically, the assigned volumes of passenger vehicles and public transportation lines, including itinerary and timetables were transferred to the microsimulation automatically. The selected area for the microsimulation analysis was cut from the travel demand model, generating external zones which represented the bundles of trips in and out of the selected area´s boundaries.

In this study, traffic demand expressed on the OD matrix was estimated in 2010 and 2030 respectively. The demand for 2010 was estimated by interpolation between the OD tables for 2007 and 2013, which were developed by JICA (2008). The demand for 2030 was estimated based on expected growth rates of total number of trips by vehicle types, which presented in Figure 8.

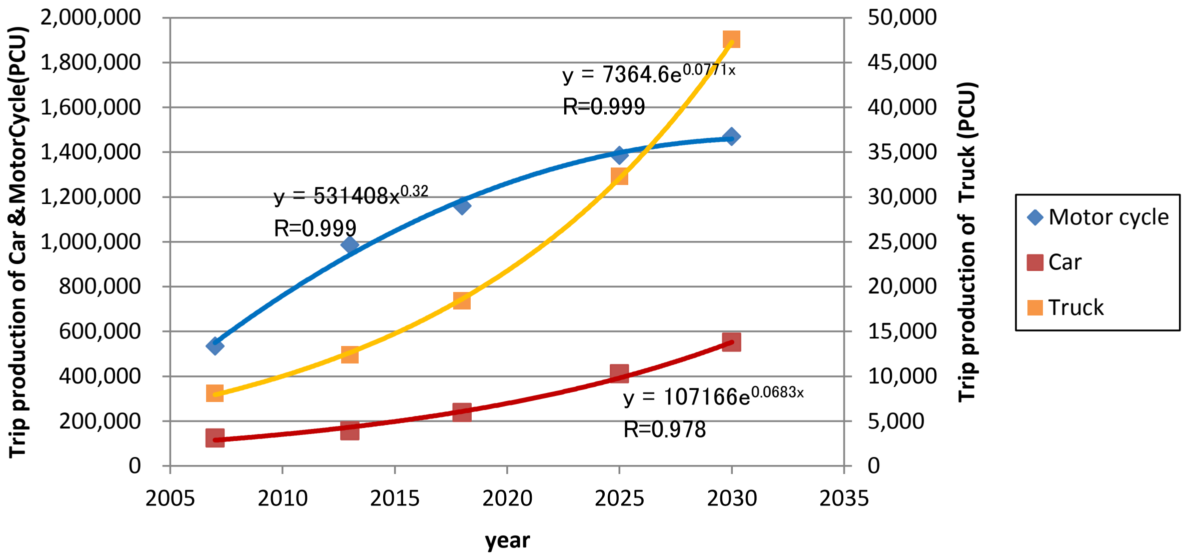

Figure 8 – Approximation expression of total rtip by vehicle types

The traffic volume and the speed on the studied road network as well as the travel speed of the BRT system were estimated using user equilibrium assignment and headway-based assignment, using a 10 min headway for the BRT operation.

3.3. TRAFFIC MICROSIMULATION

The microsimulation model covered the central business district of Vientiane, due to high traffic volumes, and the area along the planned Bus Rapid Transit (BRT) line, where traffic volume is expected to increase. The area covered by the microsimulation model and the restricted on-street parking area are shown in Figure 1. Traffic volume was estimated based on data from a previous study conducted by JICA. The demand data for 2010 was estimated according to existing estimations to 2007 and 2013. A first order interpolation was used to produce the data for 2010.

Moreover, the result of traffic assignment in VISUM was transferred to the microsimulation model in VISSIM, where special attention was given to motorcycles´ overtaking movements, on-street parking behaviour and exclusive lane for BRT.

3.4. PERFORMANCE INDICATORS

The microsimulation model provided the average speed in all links of the studied network considering the impact of on-street parking and capacity of signalized intersections. This speed provides, along with the vehicle type dependent emission coefficients, the emission factor for a vehicle of a given type on the given speed, according to Equation 1.

$$Ef_{ki} = aV^2 + bV + c \tag{1}$$

where:

Ef_{ki}: emission factor
V: average speed of vehicle type i on link k
a,b,c: empiric emission coefficients

The emission factor obtained from Equation 1 is then applied to Equation 2 in order to estimate the total traffic related CO2 emission on a specific link *k*.

$$CO_2 Emissions = \sum\sum D_k \times T_{ki} \times Ef_{ki} \tag{2}$$

where:

k: link number
i: vehicle type
D_k: length of link (km)
T_{ki}: link traffic volume for vehicle type i (vehicles / day)
Ef_{ki}: emission factor

The emission coefficients for Vientiane are not available in the literature therefore, the coefficients obtained for Bangkok, Thailand (JTCA, 2003), are used. The similarities between the characteristics of the vehicle fleet of both cities justified this approach. Table 3 shows the emission factors used for the CO2 estimation.

Table 3 – Emission coefficients for Bangkok, Thailand

	a	B	c
Car	0.0585	-7.4522	336.22
Motor Cycle	0.0308	-3.6385	165.98
Truck	0.0688	-9.0791	457.52

Source: JTCA, 2003

4. ANALYSES

4.1. AVERAGE SPEED ON ALL LINKS

Average speed by vehicle type on all links is shown in Figure 9. Comparing the travel speed in scenarios 1 and 2, it is observed that travel speed dropped as the traffic volume increased.

In scenario 3, it was observed that travel speed increased upon restriction of on-street parking, as expected.

In scenario 2, which represents the estimated traffic for year 2030, traffic conditions deteriorated in such a way that gridlocks were formed in the model and no useful result could be measured. For the evaluation of such condition, a more sophisticated model for the estimation of CO2 emissions would be required.

In the scenario 3, average speed for car, motorcycle and trucks reduced 10% when compared with 2010. In the scenario 4, average speed was 3% higher when compared with the scenario using BRT. Additionally, the implementation of signal plan with higher capacity showed a 14% increase in the average speed when comparing to Scenario 1.

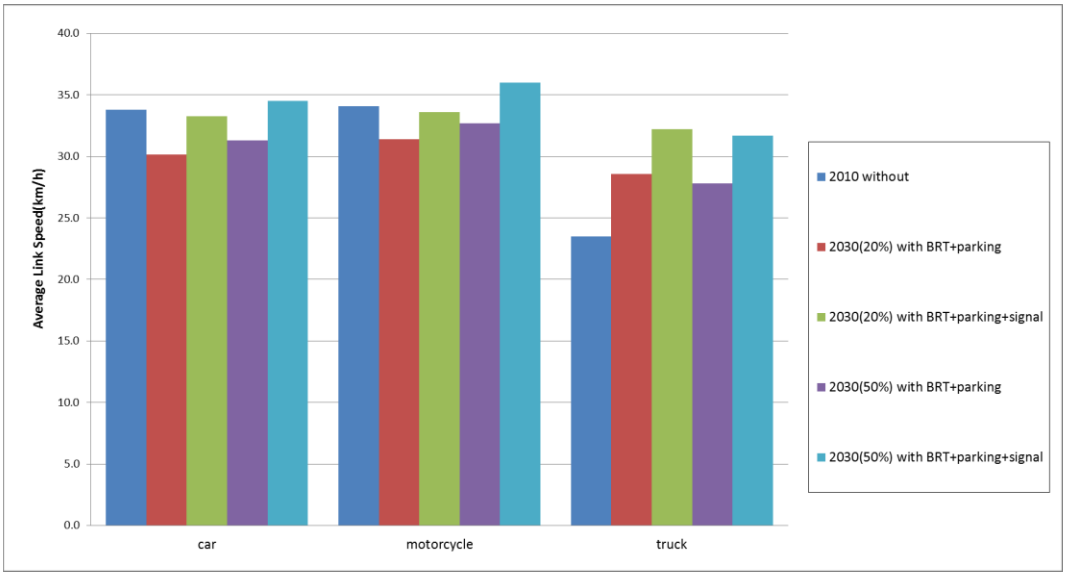

Figure 9 – Average speed per vehicle type in the analysis scenarios

4.2. ESTIMATION OF CO_2 EMISSION

The estimation of CO2 emission was compromised by gridlocks in scenario 2. However, the calculation was successful for the scenarios with parking management and signal control together with BRT.

In order to understand the sensibility of the model to changes in modal split, traffic volume was reduced considering a 50% and 20% modal shift from cars to public transportation in scenario 3.

Scenario 4 showed an additional 2% reduction, while scenario 5 showed additional 8% reduction in CO2 emission.

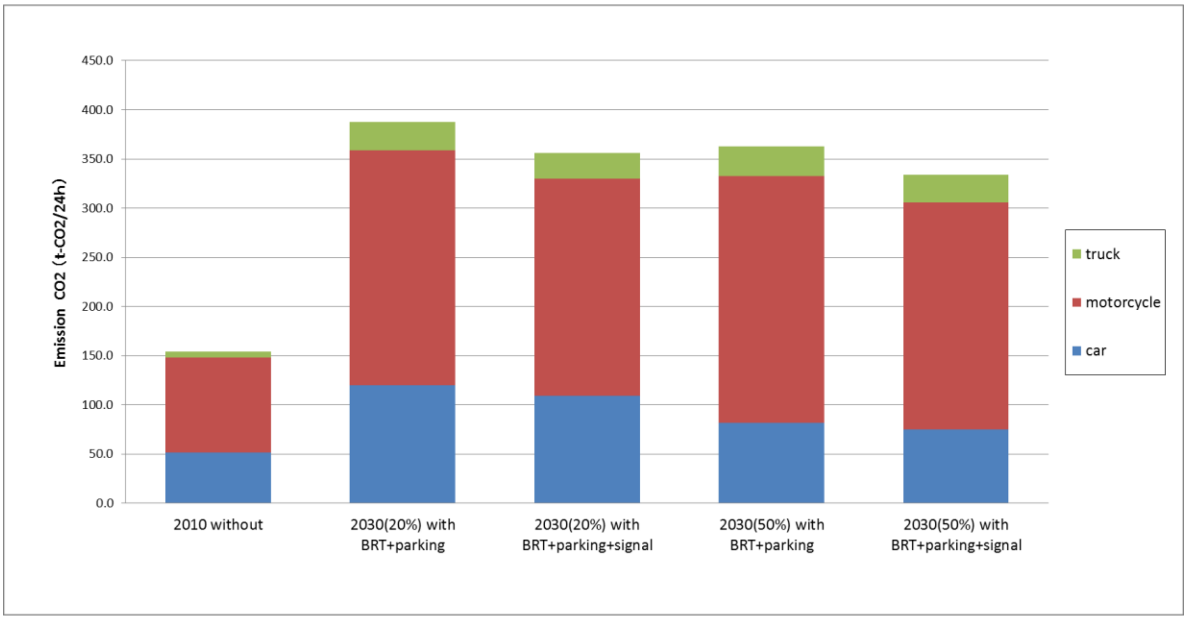

Figure 10 – CO_2 Emissions

5. CONCLUSIONS

In this study of traffic in Vientiane, Lao PDR, a microsimulation model was developed based on results from the multiclass traffic assignment of a travel demand model. Impacts of local traffic control and behaviour such as traffic signal control, movement of motorcycles, and others cannot be described on macroscopic travel demand models. However, such characteristics are significant for the estimation of CO2 emission from vehicles in developing cities. Hence, simulations of local traffic conditions using microsimulation models are proven to be an effective tool to take into consideration the effects of parking and signal control.

In the microsimulation model, the takeover behaviour of motorcycles, illegal on-street parking, traffic signal control and exclusive lanes for BRT were considered in estimation of CO2 emission. Proposed improvements in these areas were shown to positively affect average traffic speed contributing to reduced CO2 emissions on the targeted links.

Comparing the proposed measures, the impact of introducing a BRT system is more effective than restricting on-street parking and improving signal control. The limited influence area associated with parking management measures and signal control solutions is a probable explanation. Therefore, this study shows that implementing a comprehensive transportation improvement solution is expected to be the most effective in reducing CO2 emissions.

Since the modal choice model from vehicle to BRT was not developed, and the modal shift rate from vehicle to BRT was assumed to be 50% and 20% in the year 2030 due to limited data, impacts of implementing a BRT system could not be examined in detail. Thus, developing a modal choice model in Vientiane is strongly recommended to further studies.

A stated preference interview was conducted in order to develop a modal choice model that considers levels of BRT service. Results will be presented in subsequent studies. In addition to proposed solutions presented in this study, an additional reduction to CO2 emissions is expected to be achieved by implementing a transit oriented development (TOD) through introduction of ethanol buses for the BRT system. In combination, these solutions can be evaluated in further studies.

The data transfer from macroscopic travel demand models to traffic microsimulation is a technical challenge in this type of study. In most cities, only a daily OD matrix is available so it is necessary to convert the result of demand analysis to hourly data in order to simulate various traffic scenarios. Therefore, proper approach to generate the hourly data is required. This issue will also be addressed in further studies.

ACKNOWLEDGMENT

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