Evaluation of Urban Traffic Congestion Externalities Induced by Chiang Mai Public Transit Systems

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Abstract

Traffic congestion in urban areas is one of the most pressing problems for urban transport policymakers in the nation. The urban traffic congestion not only inconveniences the users on roadways, but also affects the entire urban areas. The significances of congestion that have been considered are the increase of travel time, fuel consumption, traffic accidents, and environmental pollution. Public transport has been an alternative transport solution that helps manage the travel demand and reduce traffic congestion in urban areas. This study aims to propose the analytical framework to evaluate congestion externalities induced by road transport under different public transit scenarios being planned in 2017 Chiang Mai Public Transit Master Plan (CMP-MAP). Three public transit systems were compared: conventional transit vehicles (Song-taew), diesel buses, and electric buses. The study applied microscopic traffic simulation and emission models to evaluate the mobility performance, operating speed, air pollution, and energy consumption. The results showed that congestion externalities are affected by public transit modes. The proposed public buses either diesel-based or electric-based would reduce congestion externalities within a certain extent due to the reduction in private vehicles along the corridor. However, its cost-effectiveness and potentials should be further analyzed in detail.

Keywords: traffic congestion,public transport, energy,emission, traffic simulation

1. Introduction and its significance

The automobile marks one of the most significant engineering achievements in the human history. While the automobile has brought about tremendous changes and benefits to the society, the highly use of private vehicles creates traffic congestion problem and its externalities. In Chiang Mai, traffic congestion is steadily getting worse each year. Travel demand continues to outpace the capacity of existing transportation infrastructure, while their capacity is unlikely to increase due to land use development and economic crisis. Figure 1 shows the predicted traffic saturation conditions on Chiang Mai road network (OTP, 2017)

One of the alternative solutions to solve congestion problem and reduce congestion externalities is to manage travel demand by automobiles, and to promote the use of urban public transport system. Public transport has been successfully an alternative transport solution that helps manage the travel demand in many cities worldwide (OECD, 2007).

In Chiang Mai, the conventional public transit vehicles (called Song-taew) as shown in Figure 2 have been dominated for decades.

Figure 1. Current and forecasted traffic conditions on Chiang Mai road network (Source: OTP (2017))

Figure 2. Public transit vehicles in Chiang Mai

They have played an important role to serve commuters between Chiang Mai municipality and neighboring cities. However, the public transport system in Chiang Mai has still been inefficient. The policy makers face numerous pressures from local stakeholders about the need of better public transport systems that effectively serve the increased travel demand.

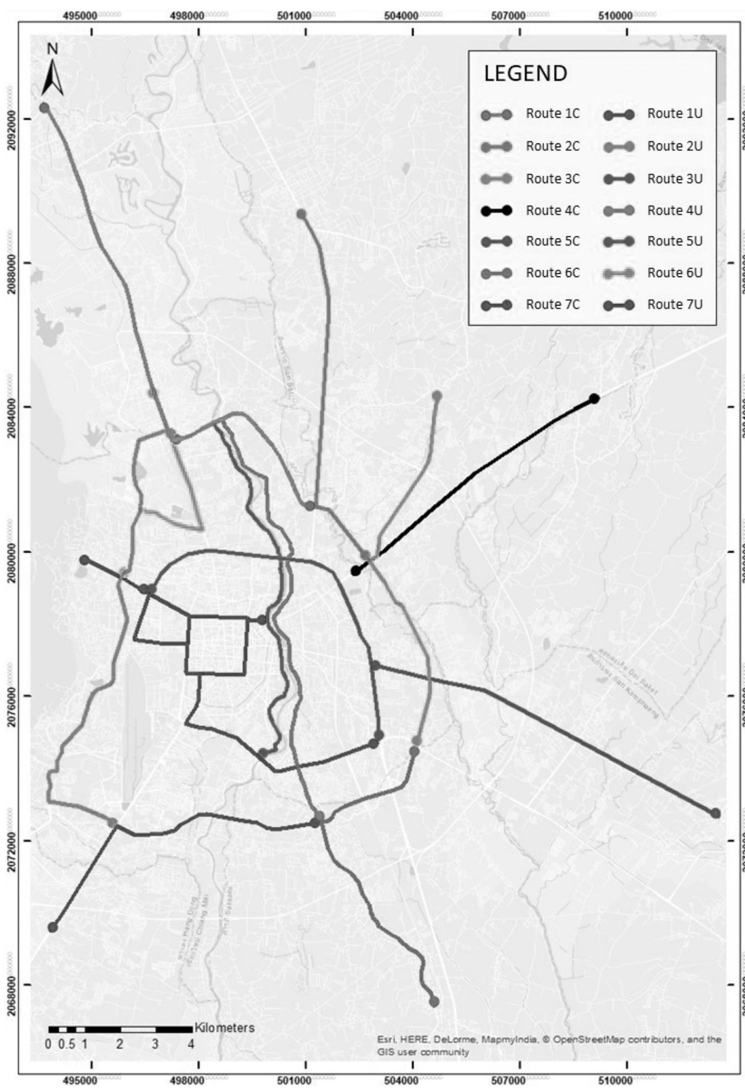


Figure 3. Planned transit routes in Chiang Mai (Source: OTP (2017))

According to 2017 Chiang Mai Public Transit Master Plan (CMP-MAP) study, the new public transport systems including the light-rail system (trunk services), the secondary bus system (intercity services) and feeder bus system are proposed as shown in Figure 3.

The challenging question is how the proposed alternatives can solve traffic congestion problem and at the same time reduce its externalities that pursue the improvement of life quality, energy and environment impacts, and social benefits. The objectives of this study are to propose the analytical procedure that can evaluate traffic congestion conditions and their externalities for public transit systems using microscopic traffic simulation models, and to compare the congestion externalities of different public transit systems for Chiang Mai City.

2.Literature Review

2.1 Congestion externalities

In general, externalities occur when the action of one group of people cause costs or benefits to other groups. They occur when a large amount of people shares the same public goods or services. Externalities of road traffic congestion are impacts accrued when a large amount of road users create traffic congestion on the roadway. Such impacts can be either positive or negative to other road users and neighboring communities. Congestion has a wide range of externalities both direct and indirect impacts. The externalities of traffic congestion usually discussed can be divided into 3 aspects. (OECD, 2007)

• Impact on travel time. Increased traffic congestion results in increased travel time, which causes travel delay, which is the direct impact to road users. It is the most concern when measuring performance of transport services. The impact of travel delay is generally estimated as hours of delay and the value of time per hour, which is the direct economic loss to road users.

• Impact on fuel consumption. Fuel consumption is a function of idling and travel times for all vehicles on the road. Increased traffic congestion would increase time spent in the traffic along with an associated increase of the fuel consumption of the vehicles.

• Impact on environment problem. There are a wide range of environmental and ecological problems due to traffic congestion, such as air pollution, global warming, and noise pollution. The environment is deteriorated as the traffic volume increases. Each vehicle spends longer time on roadways, creates more heats and air pollutants, and produces noise pollution.

2.2 Evaluation of congestion externalities

A number of research efforts proposed the approaches to quantify congestion externalities including travel delay, fuel consumption, and emission. Two approaches were found in the literature. One is the use of macro-model, and the other is the use of micro-model. The former uses the predicted mathematical models that determine the relationship between performances and parameters. The latter uses traffic flow theory and the relationship between performances and traffic parameters, e.g. instantaneous speed and acceleration.

For last decade, various microscopic traffic simulation models and microscopic emission models have been developed in urban transportation planning and engineering applications. Specifically, they have been used to evaluate operational performance, energy and environmental impacts induced by transportation alternatives. For instance, the study by Fukutomi (2004) studied the simulation approach to examine driving behavior, fuel consumption, and emissions. The study combined both microscopic traffic simulation model (e.g. CORSIM and VISSIM) and emission model (Comprehensive Modal Emissions Model, CMEM) to estimate fuel consumption and emissions. Stevanovic et al. (2006) applied microscopic models to signal control optimization problem. The signal timings were designed based on minimum fuel consumption and CO2 emission.

Later, Anh et al.(2009) developed a microscopic emission models to assess the environmental impacts of transportation projects. The model accounts for time lags between vehicle operational variables and measured vehicle emissions. They further applied their microscopic model together with microscopic traffic simulation to quantify the energy and environmental impacts for different highway designs, such as roundabouts, intersections. The study by Bao & Li (2014) applied the microscopic traffic simulation (VISSIM) and the micro-energy consumption model (PERE) to evaluate the bus station locations in terms of energy consumption and pollution emission under different traffic conditions. Moreover, the study by Abou-Senna & Radwan (2013) found the speed effect to emission in acceleration and deceleration situation. The study integrated VISSIM and US EPA mobile source emission model (MOVES) to estimate pollution emission. Elkafoury et al. (2015) developed the prediction model for pollution emission. The mathematical model was presented to predict the emission based on the time headway obtained from the microscopic traffic simulation model.

Moreover, the study by Quaassdorff et al.(2016) applied both microscopic traffic simulation model (i.e. VISSIM) and microscopic emission model (i.e. VERSIT through ENVIVER) to determine the relationship between pollution emission and traffic parameters. The traffic model was used to calculate speed profile and time-space diagram, and microscopic emission model was used to calculate vehicle pollution emission.

In summary, based on literature review, various microscopic traffic simulation models have been developed since last decade to model traffic conditions and evaluate traffic performances of a road network. Microscopic mathematical models have also been developed using the relationship of instantaneous speed and acceleration of vehicles and energy and emission outcomes. Many studies integrated these two models to predict energy consumption and environmental impacts. However, such developments in Thailand are still in an infant stage due to the lack of calibrated traffic simulation and vehicle emission models.

3. Methodology

The methodology of this study is divided into 7 steps: defining the scope, collecting data, developing base model, establishing alternatives, evaluating performances, and making conclusions. The schematic procedure is shown in Figure 4. The details are described below.

3.1 Scope Definition

Public transport routes in the Chiang Mai city and intercity were selected from the Chiang Mai Public Transport Master Plan (CMP-MAP) studied by OTP (2017). The master plan proposed public transport system and its networks in Chiang Mai City. They consist of three public transit systems, which are the main system, secondary

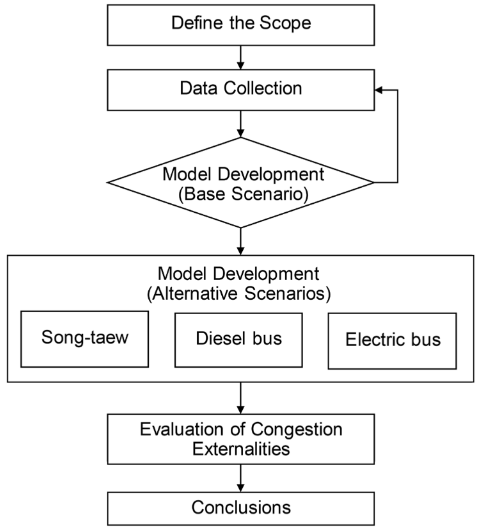
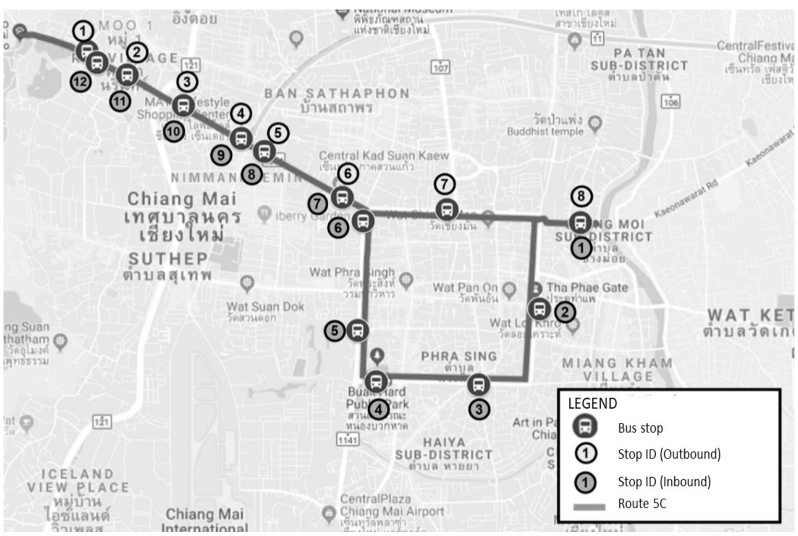
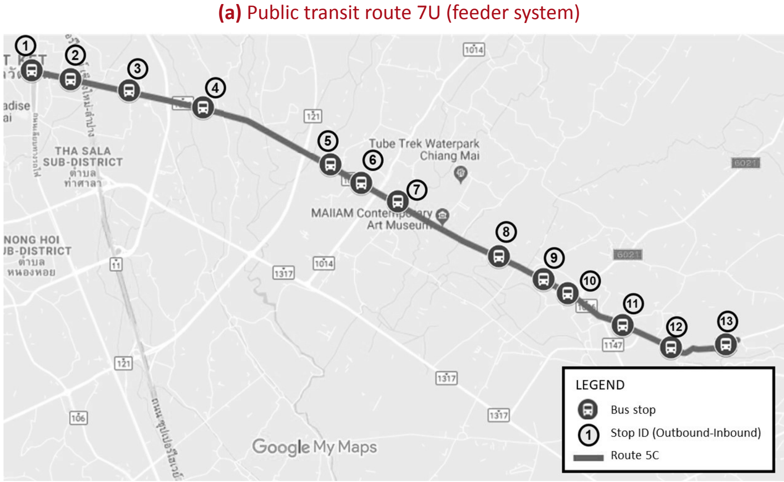


Figure 4. Steps of analysis



(a) Public transit route 7U (feeder system)



(b) Public transit route 5C (inter-city system)

Figure 5. Selected public transit routes

(inter-city) systems and supplementary (feeder) systems. In this paper, the secondary and supplementary systems were selected as case studies.

- The feeder system (Route 7U) between Chiang Mai Zoo and Chiang Mai Municipality Area as shown in Figure 5(a)
- The inter-city system (Route 5C) between Chiang Mai Muang District and Sankhampang District as shown in Figure 5(b).

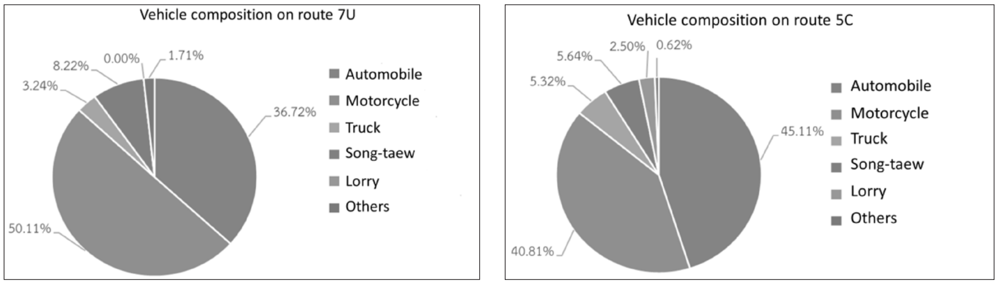
3.2 Data Collection

Data were gathered from field observation. They are road geometry and control, traffic flow and its composition, and transit services.

- Road geometry and control. The survey of the physical characteristics of the study area was conducted by site visiting and checking the information from the street view map. Relevant data include the width, number of lanes, and the main landmarks on the study route. Such data are used to build the network in the base models.
- Traffic flow and its composition. Traffic volume data were collected at various points on the road network in the study area. The surveys were carried out during morning peak period (06: 00-10: 00) and evening peak period (16: 00-20: 00). In addition, vehicle composition data were collected. Various types of vehicles were observed, such as automobiles, motorcycles, and trucks. The results are as shown in Figure 6.

3.3 Model Development (Base Scenario)

The study created the base traffic network of transit Route 7U and Route 5C in the microscopic traffic simulation model using PTV VISSIM package. (PTV Group, 2019) The steps in model development are as follows. First, road links in the study area were created. The road geometry, intersection layout, and signal timing and control along each transit route were set. Then, the vehicle inputs (vehicle types and vehicle composition) and their turning movements were then defined. Later, the vehicle transit characteristics were set,



(a) Route 7U

(b) Route 5C

Figure 6. Vehicle composition along transit routes

followed by the possible vehicle transit stops, its stopping regime, and its operations were designated based on the field observation. Finally, the base simulation model was evaluated in terms of vehicle throughputs, vehicle travel time, and vehicle operating speed in order to calibrate the base model.

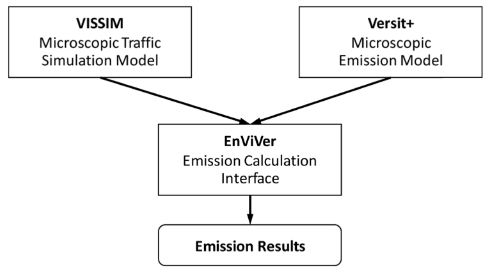


Figure 7. Emission calculation procedure (Source: Mattias & Puala, 2019)

For the evaluation of fuel consumption and emission, the add-on EnViVer module in the simulation package, which is based on the VERSIT+ exhaust emissions model, was used. The module can determine the pollutant emissions based on vehicle trajectories and other information from microscopic traffic simulation models. (Mattias & Puala, 2019; Blomgren, & Jungbjer. 2019) The traffic simulation can generate the trajectory of individual vehicle, and export to vehicle record files, which can be imported into EnViVer for further analysis. Vehicle types are used to assign additional properties; such as fuel type or pollutant class to each vehicle. The proposed microscopic emission model calculates CO2 and NOx emissions based on the speed profile for vehicle types. The emission calculation procedure is shown in Figure 7.

(a) Song-taew

(b) Diesel bus

(c) Electric bus

Figure 8. Vehicle models for three public transit vehicles

3.4 Establishment of Alternatives

The study aims to evaluate the performance among three public transit systems, which are Song-taew, Diesel bus, and Electric bus system. Thus, vehicle characteristics and service characteristics of each transit alternative were setup. Figure 8 illustrates the vehicle models of Song-taews, Diesel buses, and Electric buses, and Table 1 presents the service characteristics of each transit mode.

Table 1: The service characteristics of public transit alternatives

Characteristics	Alternatives		
	Song-taew	Diesel bus	Electric bus
Vehicle capacity	11 persons	16-31 persons	31-34 persons
Transit stop	7U (in-bound): 10 7U (out-bound): 7 5C (in-bound): 5 5C (out-bound): 7	7U (in-bound): 12 7U (out-bound): 8 5C (in-bound): 13 5C (out-bound): 13	
Transit stop type	On-curb	Bus bay	Bus bay
Service headway	7U: 15 minutes 5C: 5 minutes	7U: 10 minutes 5C: 15 minutes	7U: 10 minutes 5C: 15 minutes

3.5 Model Evaluation

The study applied the microscopic traffic simulation model and microscopic traffic emission model to evaluate congestion externalities of different transit alternatives. The simulation models analyzed the instantaneous speed and acceleration of all vehicles. They also calculated vehicle travel delay, vehicle operating speed, air pollution emission (CO and NOx), and energy consumption (fuel and electricity) based on speed profile data obtained from the models.

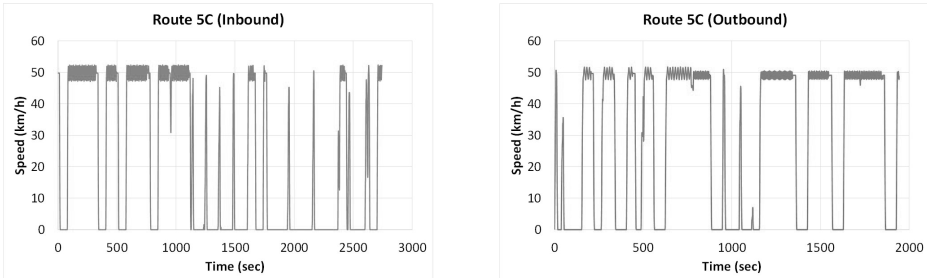
4. Results and Discussion

The study applied microscopic traffic simulation to model traffic scenarios for different public transit systems. The results are shown in Table 2. It compares the congestion externalities induced by 3 alternate transit modes: Song-taew system, diesel bus system, and electric bus system for Route 7U (inter-city route) and Route 5C (feeder route). Some of the significant findings are as follows.

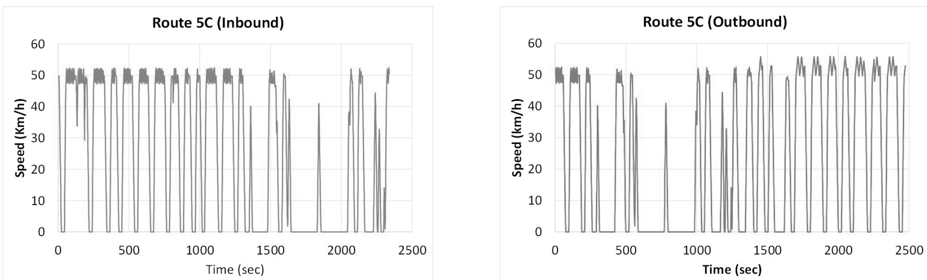
- The traffic simulation models showed that the electric bus system can attract the highest travel demand, followed by diesel bus system and conventional Song-taew system for both inter-city route and feeder route. As a result, the estimated vehicle traffic volumes along the roadway for electric bus system are the lowest. For Route 7U (inter-city route) the estimated total traffic volumes on both directions are 8,923 veh/hr for Song-taew system, 8,022 veh/hr for diesel bus system, and 7,179 veh/hr for electric bus system.
- Among three transit alternatives, electric bus system performed the best in terms of service efficiency and traffic impacts, followed by diesel bus system and Song-taew system.
- The electric bus system has the shortest average vehicle travel time, total travel delays, and highest average vehicle traveling speed among all alternatives, especially in the heavily congested direction. The transit system will make the traffic more agile.
- The bus system consumes less fuel than conventional system, because the bus system increases service efficiency, reduces travel delay, and lowers number of vehicles on the roadway.

Table 2. Comparison of congestion externalities among three public transit systems

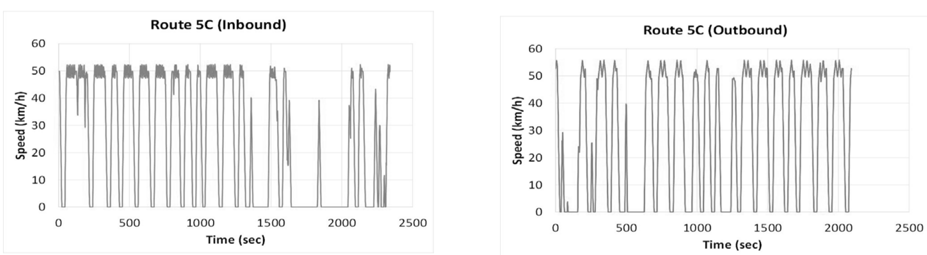
Alternative	Traffic volume (veh/h)	Direction	Distance (km)	Average travel time (min)	Average speed (km/h)	Total delay (hours)	Emission		Energy consumption	
							CO (g/s)	NOx (g/s)	Fuel (liter/s)	Electricity (kWh/km)
Route 7U (Intercity route between Muang and Sankamphang Districts)										
Song-taew	8,923	Inbound	5.7	23.5	14.5	6.91	35.2	6.85	0.504	-
		Outbound	8.8	44.8	11.8					
Diesel bus	8,022	Inbound	5.7	20.3	16.8	5.98	28.7	5.58	0.410	-
		Outbound	8.8	29.7	17.8					
Electric bus	7,179	Inbound	5.7	18.5	18.5	5.82	24.6	4.78	0.352	0.82
		Outbound	8.8	27.0	19.5					
Route 5C (Feeder route between Chiang Mai Zoo and Municipality Area)										
Song-taew	3,697	Inbound	16.0	30.5	31.5	7.86	69.07	13.44	0.988	-
		Outbound	16.0	39.5	24.3					
Diesel bus	3,551	Inbound	16.0	27.7	34.6	7.23	63.22	12.3	0.904	-
		Outbound	16.0	39.3	24.4					
Electric bus	3,398	Inbound	16.0	25.5	37.6	7.07	59.57	11.59	0.852	1.09
		Outbound	16.0	37.0	25.9					



(a) Song-taew



(b) Diesel bus



(c) Electric bus

Figure 9. Speed profiles of Song-taew, diesel bus, and electric bus on Route 5C

• The electric bus system creates lowest air pollution (CO and NOx) and least environmental impacts due to the use of electricity power.

Figure 9 presents the examples of speed profile associated with diesel bus and electric bus on Route 5C Inbound (feeder system). The speed profiles show instantaneous speed caused by intermittent stops of each bus type.

5. Conclusions

This research project presents the analytical procedure to evaluate congestion externalities (operational performance, energy depletion and environmental impacts) induced by public transit modes being proposed in Chiang Mai Public Transport Master Plan (CMP-MAP). The study uses microscopic traffic simulation and emission models to compare three alternate transit modes, which are the conventional public transit vehicles (Song-taew), diesel buses, and electric buses. Among three alternatives, electric buses performed the best operational performances and energy and environmental impacts. However, its cost-effectiveness and potentials should be further analyzed in detail.

To manage the problem of traffic congestion and its externalities, relevant agencies should apply a systematic or holistic approach to transportation system development. Providing alternative clean transportation systems with high travel efficiency and minimal impact tends to reduce the use of personal vehicles.

For further study, to improve the service efficiency of alternative public transportation system, the improvement of transit and service facilities should be performed, such as the design of stop facilities (bus bay), transit priority (exclusive lane, signal priority at intersections), and transit services and user information (service frequency, intermodal transit facilities).
In addition, the limitation of this research is the relative comparison of service performance among transit system alternatives. For further research, the integrated model and a decision tool that can calculate the congestion externalities as a single indicator will be very powerful for urban transportation policy makers to justify and make decision on future urban transportation systems.

6. Acknowledgement

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