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A Development of Motorcycle On-road Exhaust Emissions and Fuel Consumption Models for a Traffic Simulation

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CHAPTER 1 INTRODUCTION

This chapter describes the problem background, the objectives, the study area, and the literature review of this research.

1.1 Statement of Problem

Motorcycle has become a popular mode in many Asian cities with its high accessibility when it comparing with other modes (Satiennam et al., 2011). It is a private vehicle for almost low-income households due to its economic cost. Also, because of its small size, it becomes an attractive paratransit with high accessibility for a short travel distance in congested developing cities (Ryosuke et al., 2007). However, the motorcycle comes with it several problems, including high involvement in traffic accidents, high violation of traffic rules and especially high air pollution emissions in Asian congested cities. There are several main research directions to reduce the emissions from the motorcycle, including a development of the innovative engine technology, a development of alternative cleaner energy, and a planning policy of transportation and an energy usage for the motorcycle. To evaluate a innovative engine technology or a cleaner energy in terms of emission reduction, the driving cycle of the vehicle is simulated in the emission measurement laboratory where is available of the emission analyzer and the chassis dynamometer. The driving cycles were developed from the data collected by a test-driving vehicle in traffic-congested urban areas in many cities (Kent et al., 1978; Ergeneman, et al., 1997; Tong et al., 1999; Chen, et. al., 2003; Wang, et al., 2008).

However, the developed driving cycles of motorcycle are different from city to city due to the differences in the driving behavior and the traffic condition of each city (Tsai et al., 2005; Satiennam et al., 2009). Moreover, the driving cycle collected by driving a passenger car does not suitably present the driving cycle of the motorcycle in Asian developing cities since the small-size motorcycle can penetrate highly through the traffic flow, especially in a congested city. Therefore, it is necessary to develop the driving cycle for each city and vehicle type for more accurate estimation of emissions.

On the other hand, to evaluate the planning policy of transportation and energy usage in terms of emission reduction, the transportation models are applied with the emission models. The emission factor models were applied with a macroscopic transportation model, i.e. a demand forecasting model, to evaluate the public transit systems and the alternative cleaner energies in terms of the reduction of emissions as an entire road network (Satiennam et al., 2007(a); Satiennam et al., 2007(b); Satiennam et al., 2010). The emission rate model was applied with a microscopic transportation model, i.e. a traffic simulation, to estimate the emissions reduction at a specific area. There are many previous research studies that developed an emission factor model and emission rate models (Yu, 1998; Tsai et al., 2000; Haan and Keller, 2000). The emissions used to develop these models were measured from the simulating vehicle in the laboratory where its speed was simulated following the driving cycle and its loads were created by the chassis dynamometer. Such automotive emission laboratory is not available in some Asian developing countries due to its expensive cost. And it is almost impossible to transport the local vehicle type to test its emissions in other countries. Therefore, the on-road emission model, developed from the on-road data collected by installing mobile measuring equipment on a driving vehicle on the road network, is the interesting alternative approach for Asian developing countries. There are many previous studies researching on the on-road emissions (Chan et al., 2004 and 2005; Wang et al., 2012; Kam et al., 2012; Kousoulidou et al., 2013), but there is no research on the on-road emissions of the motorcycle in Asian developing countries.

Therefore, this research aims to develop the motorcycle onboard measurement system for collecting on-road driving data, the driving cycle, the on-road emission models and fuel consumption rate model for a motorcycle. In addition, this research also aims to present their application by evaluation of traffic management strategies for motorcycle in term of emissions and fuel consumption reduction.

1.2 Objectives

This research has 4 main following objectives.

1) To develop the onboard measurement system for collecting on-road driving data of motorcycle
2) To develop real-world on-road exhaust emission rate models
3) To develop real-world on-road fuel consumption rate model
4) To present an application of developed models to evaluate the traffic management strategies for motorcycle

1.3 Scope of Study

The scope of study is described as below.

1) On-road data for development of emission and fuel consumption models was collected on selected routes along Khon Kaen City's road network.
2) To evaluate the traffic management strategy for motorcycle, it was simulated to implement on the selected section of Sreechan Rd. by traffic simulation.
3) Two strategies of traffic management for motorcycle at signalized intersection are evaluated in term of traffic flow, emissions and fuel consumption reduction. The two strategies are:

   (1) Exclusive zone for motorcycle stopping for signal as displayed in Figure 1.1

Figure 1.1 Exclusive zone for motorcycle stopping for signal

   (2) Exclusive nleft-lane and Hook Turn for motorcycle as presented in Figure 1.2

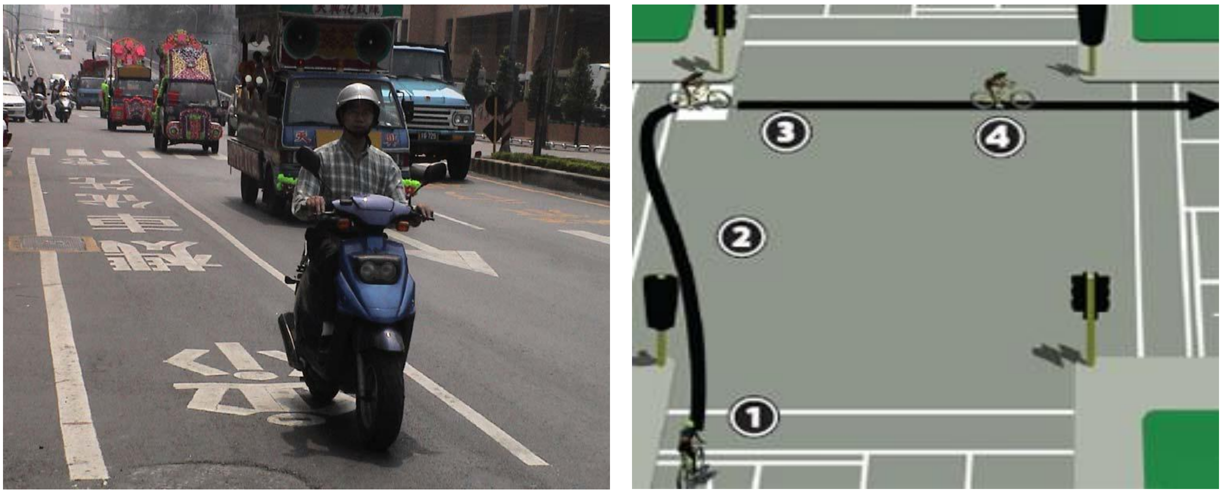

Figure 1.2 Exclusive left-lane and Hook Turn for motorcycle

1.4 Literature Review

1.4.1 Researches on On-road Exhaust Emission and Fuel Consumption Models

There are many previous studies researching on the on-road emissions and fuel consumption as follows.

Yu (1998) developed the on-road exhaust emission models for estimating CO and HC emissions by incorporation with traffic simulation model where a vehicle's instantaneous speed profile can be tracked consistently. This model was developed based on the on-road emission data collected from five highway locations in Houston area using a remote emission sensor. The developed on-road emission models presents the relationships between the on-road vehicle exhaust emission rates and a vehicle's instantaneous speed profile.

Chan et al. (2004 and 2005) investigated emissions (CO, HC and NO) of the real world on-road petrol and diesel vehicles at nine sites in Hong Kong by using the remote sensing measurement technique. A regression analysis approach based on the measured vehicle emission data was also used to estimate the on-road emission factors of petrol and diesel vehicles with respect to the effects of instantaneous vehicle speed and acceleration/deceleration profiles for local urban driving patterns. The results show that the model years, engine sizes and driving patterns of petrol and diesel vehicles have a strong correlation on their emission factors. This study made a comparison between the average diesel and petrol vehicle emissions factors in Hong Kong. The deviation of the average emission factors of aggregate petrol vehicle reflects on the variability of local road condition, vehicle traffic fleet and volume, driving pattern, fuel composition and ambient condition etc. This study finally established the database of the correlation of petrol and diesel vehicle emission factors on different model years and vehicle types for urban driving patterns.

Wang et al. (2012) determined the NOx and black carbon (BC) emission factors of 440 on-road diesel trucks by conducting on-road chasing studies in Beijing and Chongqing, China. The NOx and BC EF distributions were reported.

Kam et al. (2012) conducted an on-road sampling campaign on two major surface streets in Los Angeles, CA, to characterize PM components. This study calculated the fuel-based emission factors (mass of pollutant per kg of fuel) to assess the emissions profile of a light-duty vehicle (LDV) traffic fleet characterized by stop-and-go driving conditions that are reflective of urban street driving. This study also compared its emission factors with those of previous freeway, roadway tunnel, and dynamometer studies based on an LDV fleet to determine how various environments and driving conditions may influence concentrations of PM components. The results revealed that the emission factors from the dynamometer studies for metals, trace elements, and organic species are lower than the this study.

Kousoulidou et al. (2013) developed and validated the passenger car emission factors using real world operation data. In total, six passenger cars of different technologies were studied. The tested vehicles were operated under various driving conditions and over two different routes in the region of Lombardia, Italy. A portable emissions measurement system (PEMS) was used to measure tailpipe emissions and exhaust gas flows of on-board the vehicle. In addition, all vehicles were tested over the European type-approval driving cycle (NEDC) with the same PEMS equipment. The emission factors originally measured on the road are also compared to the corresponding COPERT average speed emission factors. In general, emissions of CO_2, THC and CO correlate fairly well with COPERT, for all vehicles. But this study could not be concluded in case of NOx emissions, more experimental data is necessary.

As a conclusion of reviewing on previous researches concerning to on-road emission models, there are many studies researched on on-road emission factors of various vehicle types, mainly including petrol vehicle, diesel vehicle and truck but there is a lack of research on the on-road emission models of the motorcycle, especially an on-road exhaust emission rate model. The developed on-road emission rate models can be applied with microscopic transportation model to evaluate the proposing traffic management policies for the motorcycle, e.g. a motorcycle lane or a stop waiting zone at signalized intersection in term of the emission reduction. The outputs of traffic simulation model, e.g. a speed-time profile (km/hr, s) of each motorcycle and a motorcycle volume traveling along a specific area, are used together with the emission rate models by gas type to estimate an amount of emissions of the motorcycles traveling along a specific road section or intersection.

1.4.2 Researches on Motorcycle Traffic Simulation

Cho and Wu (2004) proposed a motorcycle traffic flow model containing longitudinal and lateral movement models, then developed a motorcycle traffic flow. The simulation result indicated that the proposed model is reasonable, and it can reflect some motorcycle traffic flow phenomena.

Rongviriyapanich et al. (2010) developed a microscopic traffic simulation to evaluate the effects of motorcycles on traffic operations at signalized intersections. Field surveys were conducted to study the effects of motorcycles on other traffic by examining discharge headway. This study found that the effects of motorcycles could be measured in terms of an increase in the start-up lost time of signal phase. On average, each motorcycle was found to increase the start-up lost time by 0.25 sec and it took approximately 0.25 sec for each motorcycle to discharge from the intersection. This study was also found that presence of motorcycles does not affect the saturation headway of traffic.

As a conclusion of reviewing on previous researches regarding to a motorcycle traffic simulation, there are a few studies attempted to evaluate the effect of traffic flow with a presence of motorcycle mixed with other traffics by developing their own microscopic traffic simulation. But there is a lack of a study relating a evaluation of traffic management strategy for a motorcycle, possibly, because, there still is a limitation of the current traffic simulation platforms which do not provide a build-in function to model a motorcycle behavior, especially, an overtaking the leading vehicle in the same lane.

CHAPTER 2 RESEARCH METHODOLOGY

This chapter explains the procedure of research method as displayed in Figure 2.1. The scope of this research is classified into two parts. The development part is the approaches which are developing the models of on-road emissions and fuel consumption. The application part is the approaches which are applying the developed models to evaluate the traffic management strategy for motorcycle. Each method for each part of the research will be expressed as the following.

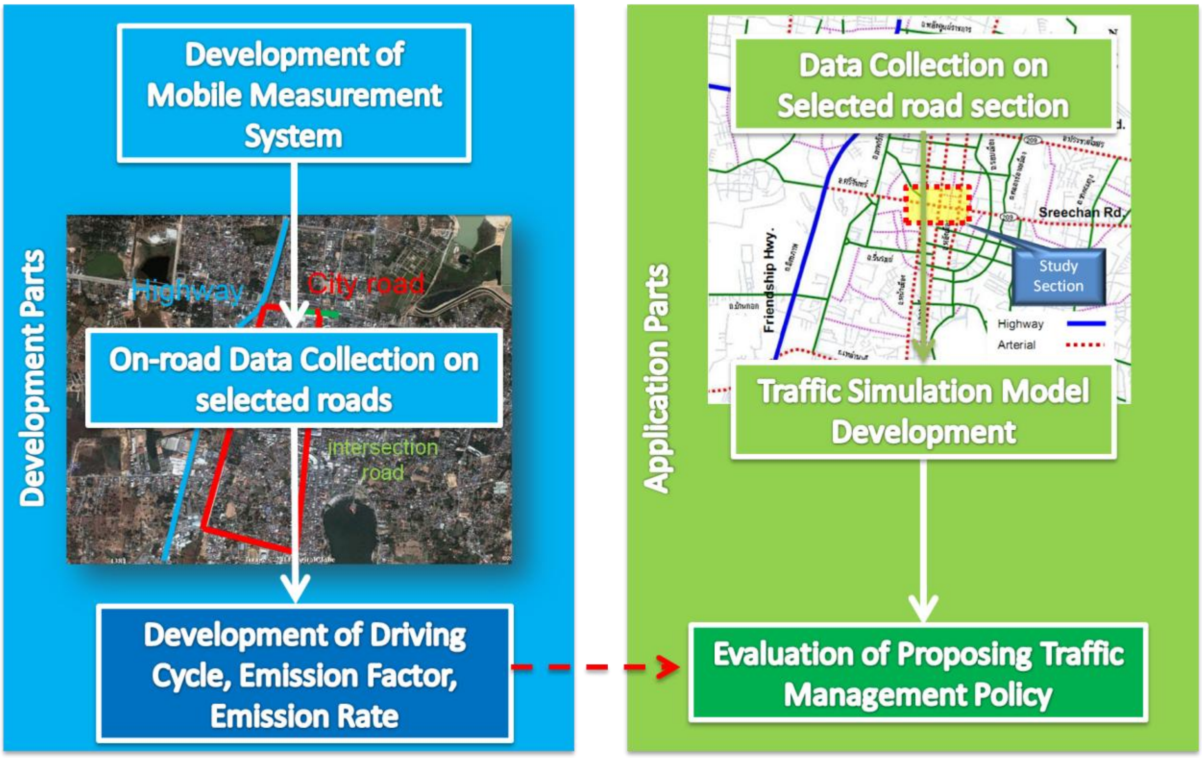

Figure 2.1 Research Procedure

2.1 Onboard Measurement System Development

This study further developed the onboard measurement system of previous study (Satiennam, 2009) by installing fuel consumption sensor to collect more on-road data, additional fuel consumption. The upgraded onboard measurement system consists of many units, including a data logger for processing and recording the collected data, a rear wheel speed sensor for measuring a speed, an exhaust gas analyzer for measuring an amount of exhaust emissions, a GPS for measuring the position as well as a fuel consumption sensor as displayed in Figure 2.2 to 2.5. The gas analyzer measures the emissions of CO, CO_2 and HC by Non-Depressive

Infrared (NDIR) technique. The emissions of O_2 and NOx are measured by Electro-Chemical Cell technique. The system would be installed on the rear of the motorcycle driving on the road network to instantaneously measure and continuously record the speed-time profile, the exhaust emissions and fuel consumption.

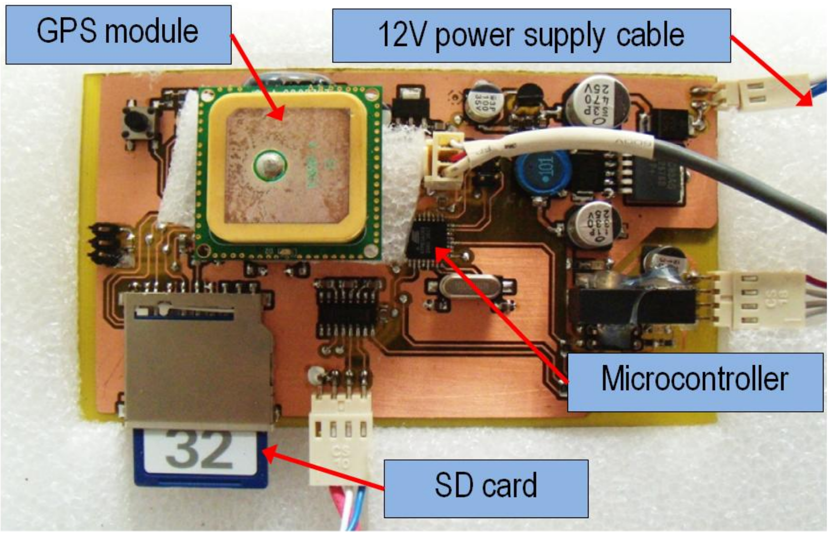

Figure 2.2 Data Logger

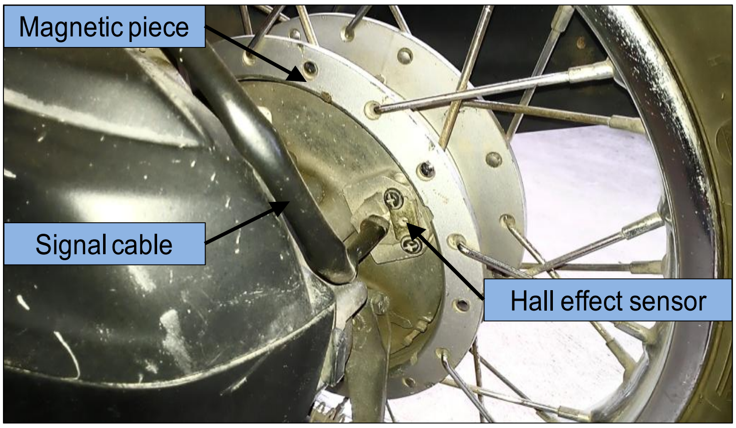

Figure 2.3 Magnetic Sensor on Rear Wheel of Motorcycle

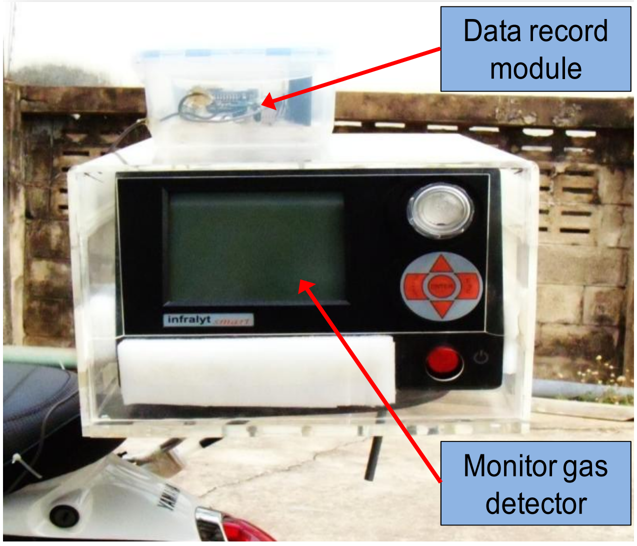

Figure 2.4 Installation of Exhaust Gas Analyzer

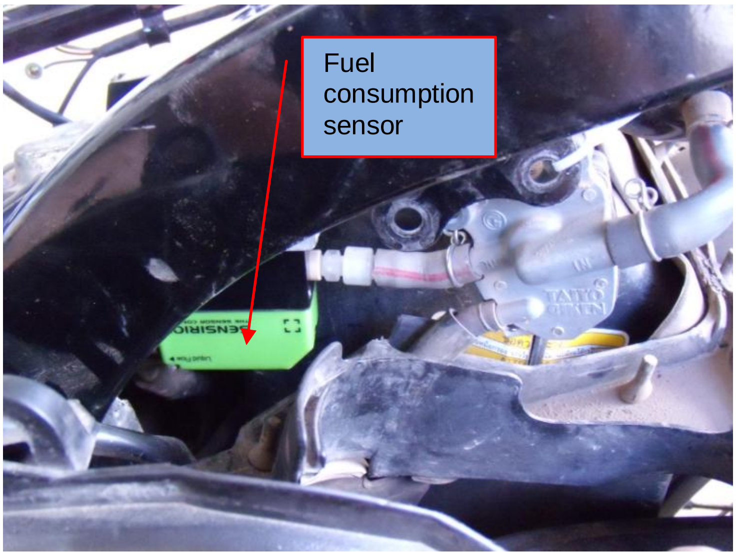

Figure 2.5 Fuel Consumption Sensor

2.2 Collection of On-road Data

This study continuously selected Khon Kaen City as a study city, as same as a previous study (Satiennam, 2009), due to high motorcycle mode share (about 30%). The onboard measurement system was installed on the motorcycle to drive on the selected routes of Khon Kaen City road network to measure the driving pattern, exhaust emissions and fuel consumption. The selected routes were classified into three road types, including Highway, Urban road and dense signalized intersection road (Idle mode), as shown in Figure 2.6. The driving data was collected during the morning peak hour between 7:00 a.m. to 9:00 a.m.

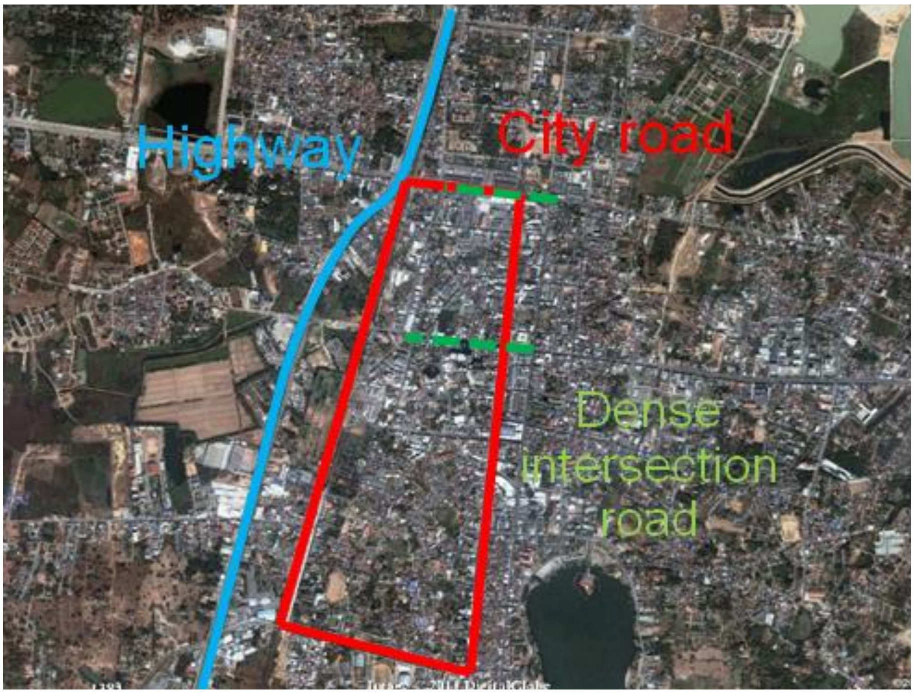

Figure 2.6 Selected Routes on KKC Road Network

2.3 On-road Exhaust Emission and Fuel Consumption Models Development

The on-road emission rate model presents the instant amount of emission (gram/sec) corresponding to instantaneous speed-time profile (km/hr, s). The on-road exhaust emissions (CO, CO2, HC, and NOx) and speed profile of motorcycle driving on road network simultaneously collected by every second were applied to develop the on-road exhaust emission rate model by using the linear regression analysis.

As similar to a development of on-road exhaust emission rate model, the on-road fuel consumption rate model presents the instant amount of fuel consumption (gram/sec) corresponding to instantaneous speed-time profile (km/hr, s). The on-road fuel consumption and speed profile of motorcycle driving on road network simultaneously collected by every second were applied to develop on-road fuel consumption rate model by using the linear regression analysis.

2.4 Survey of Road Geometric and Traffic Data

To present an application of developed models of on-road emission and fuel consumption, this study would apply the models to evaluate the traffic management strategy for motorcycle in term of emissions and fuel consumption reduction. A section of Sreechan Rd. with three signalized intersections was selected to implement the traffic management strategy for motorcycle since the Sreechan Rd. is the main arterial through CBD of Khon Kaen city with a high number of traveling motorcycle as shown in Figure 2.7. A cross section of study road section is two-way two-lane with left roadside parking lane presented in Figure 2.8. The three signalized intersections are the Sreechan-NaMuang intersection, the Sreechan-KrangMuang intersection and the Sreechan-RungMuang intersection as displayed in Figure 2.9. The data of road geometric and traffic, collected for traffic simulation model development, is summarized in Table 2.1

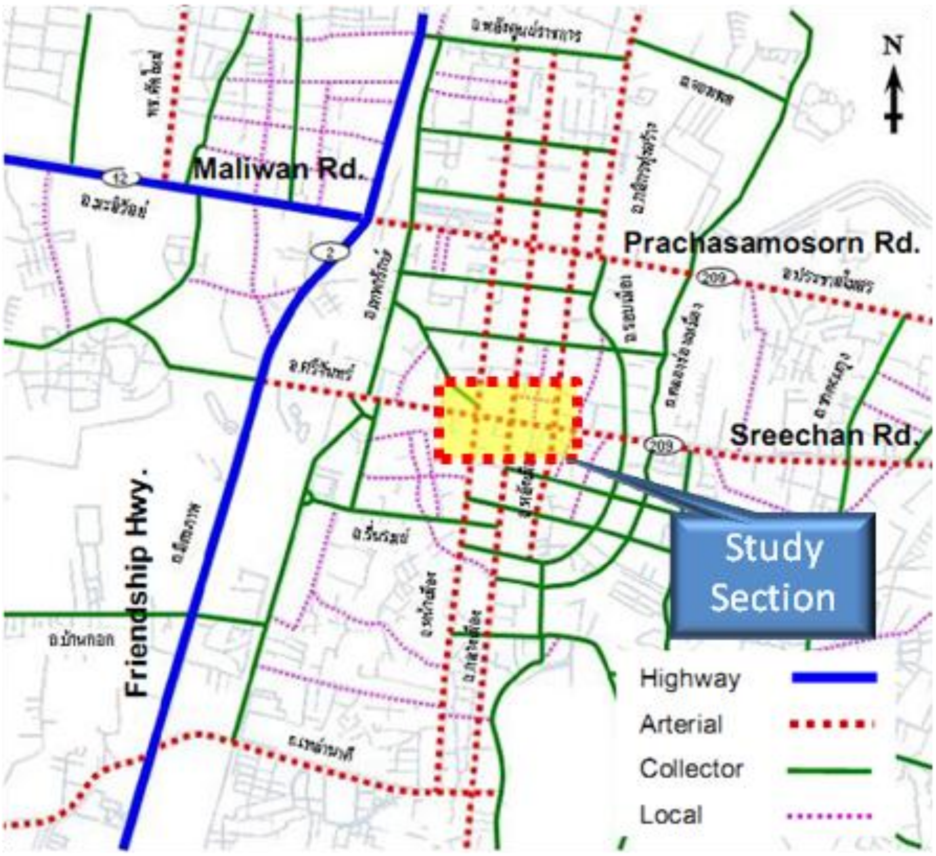

Figure 2.7 A Study Section of Sreechan Rd. on KKC Road Network

Figure 2.8 Cross Section of Sreechan Rd.

Figure 2.9 Study Section with Three Signalized Intersections

Table 2.1 Summary of road geometric and traffic data collection

Collected Data	Details

1. Geometric Data	○ Road layout and Geometry (Sreechan Rd., NaMuang Rd., KrangMuang Rd. and RungMuang Rd.)
	  ○ Cross Section (No. of lane, lane width, side walk, etc)
	  ○ Right Turning lane at intersection (width, length)
	  ○ Photo of Cross Section

2. Traffic Control Data	○ Signal Phasing ○ Speed Limit

3. Demand and Traffic Data	○ Traffic Volume at intersection and mid-block
	  ○ Vehicle type (PC, Pickup, MC, Song thaew, total vehicle (PCU))
	  ○ AM peak (7:30-8:30), PM peak (17:30-18:30)
	  ○ Every 15 min.
	  ○ Total 8 OD matrices
	○ Average Delay (sec/veh.)
	○ Queue Length
	○ Travel time

4. Public Transportation Data	○ Song Thaew Route
	  ○ Bus stop type and location
	  ○ Dwell time, Frequency

5. Driving Behavior Parameter	○ Spot Speed by vehicle type for Desired speed distribution
	  ○ Approach Speed
	  ○ Cross Speed
	  ○ Turning Speed

6. Vehicle Model	○ Vehicle model by vehicle type for emission estimation
	  ○ CAR (NGV, LPG, Gasoline, diesel)
	  ○ MC

7. Other Data	○ Accident Data

2.5 Traffic Simulation Model Development

The framework of this study for traffic simulation model development is displayed in Figure 2.9.

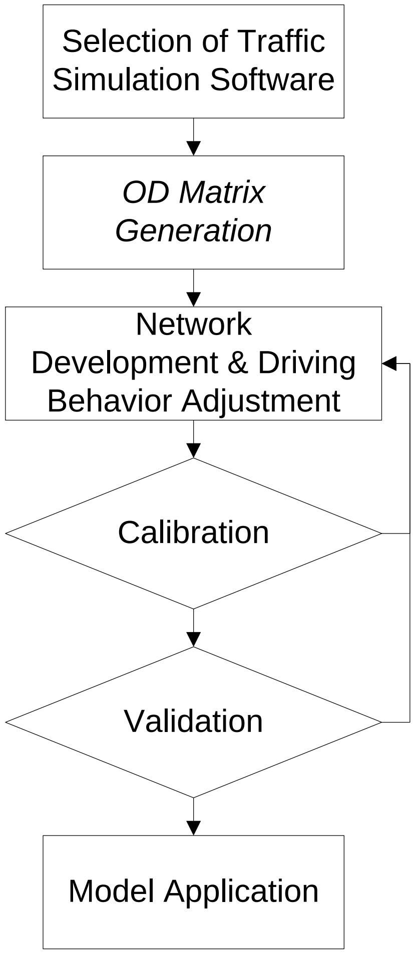

Figure 2.9 Framework of traffic simulation model development

2.5.1 Selection of Traffic Simulation Software

To evaluate the traffic management strategy for motorcycle at signalized intersection in term of emissions and fuel consumption, the traffic simulation software that enables to simulate the behavior of individual vehicle traveling pass through signalized intersection, especially motorcycle, is required. This study selected the VISSIM software because the VISSIM currently is only one of traffic simulation software that has a function enabling to model lateral behavior of motorcycle when the motorcycle taking over the slower or stopping other vehicles at signalized intersection. Moreover, the VISSIM can measure the speed-time profile of individual vehicle while it travel passing the signalized intersection. The speed-time profile of individual vehicle, i.e. instant speed and acceleration rate by every second, is necessary information as an input data for emissions and fuel consumption rate models.

2.5.2 OD Matrix Generation

This study would create the OD matrix by applying the program of OD Matrix Creator With Route Choice (V1.0.1) developed by James Cox from Department of Transport, Australia. The turning count data in intersections during morning peak hour (7:30 – 8:30 AM) would be applied to develop the morning peak hour OD matrix for a process of model calibration. The turning count data in intersections during evening peak hour (4:30 – 5:30 PM) would be applied to develop the evening peak hour OD matrix for a process of model validation. The OD matrix would also classified into four vehicle types as follow.

1) Motorcycle (MC)
2) Passenger Car (PC)
3) Pickup Truck and Van (LT)
4) 6-Wheel Truck and Bus (HT)

These OD matrixes would be inputted in VISSIM through a function of Turning Movements.

2.5.3 Model Calibration and Validation

To calibrate the developing traffic simulation model, this study simulates the morning peak hour OD matrix (7:30-8:30 AM) on the developing network. The results from modeling, including traffic flow and maximum queue length, are compared with same traffic measures simultaneously surveyed during the same period of morning peak hour OD matrix. The differences and GEH value are checked with criteria and they must pass the acceptance target as presented in Table 2.2. The GEH value is calculated by Equation 2.1. The traffic simulation model is developed similar to real condition as much as possible by adjusting the driving behavior parameters until the target traffic measures are accepted.

To validate the calibrated traffic simulation model, the evening peak hour OD matrix (4:30-5:30 PM) would be simulated on the calibrated developing network. The traffic measures resulted from modeling are compared with same traffic measures collected during the same period of evening peak hour OD matrix. The differences and GEH value are checked with criteria and they must pass the acceptance target as presented in Table 2.2. The target traffic measures must be accepted unless the driving behavior parameters will be adjusted again in the repeating calibration process.

Table 2.2 Criteria and Measures for Model Calibration and Validation

Criteria and Measures	Calibration Acceptance Targets
Hourly Flows, Model Versus Observed	
Individual Links Flows	
Within 15%, for 700 veh/h < Flow < 2,700 veh/h	> 85% of cases
Within 100 veh/h, for Flow < 700 veh/h	> 85% of cases
Within 400 veh/h, for Flow > 700 veh/h	> 85% of cases
GEH Statistics < 5	> 85% of cases
Total Link Flows	
Within 5%	All Accepting Links
GEH Statistics < 4	All Accepting Links
Maximum Queue Length, Model Versus Observed	
Queue Length by Individual Approach	
Within 20%	

Source:

$$GEH = \sqrt{\frac{(V-C)^2}{(V+C)/2}} \tag{2.1}$$

Where as

V = Modeled traffic flow

C = Surveyed traffic flow

2.6 Calculation of Emissions and Fuel Consumption

This study calculated the emissions and fuel consumption by individual vehicle. The individual vehicle's instant emissions and fuel consumption of each time step are calculated by applying the developed emission and fuel consumption rate models with a velocity and an acceleration rate of each time step of that individual vehicle, resulted from the traffic simulation model. Total emission and fuel consumption of the individual vehicle are the summary of instant emission and fuel consumption at each time step of that vehicle. Total emission and fuel consumption of all vehicles are calculated by Equation 2.2.

Total Emission/Fuel Consumption =

$$\sum_{k}^{3}\sum_{j}^{m}\sum_{i}^{n} \text{Instant Emission/Fuel Consumption of a Vehicle} \tag{2.2}$$

Where as

i = 1, 2, 3, ..., n (Number of time step)

j = 1, 2, 3, …, m (Number of vehicle)

k = 1 = Motorcycle, 2 = Passenger Car, 3 = Pickup truck

2.7 Evaluation of Traffic Management Strategy for Motorcycle

This study applied the developed on-road emission and fuel consumption models to evaluate the strategy of traffic management for motorcycle at signalized intersection in term of reduction of emissions and fuel consumption. Two strategies, 1) Exclusive zone for motorcycle stopping for signal and 2) Exclusive left-lane and Hook Turn for motorcycle, were evaluated. The developed traffic simulation model was applied to simulate the traffic management strategy for motorcycle implementing on the study road section. To evaluate the strategy, condition with implementing by each strategy would be compared with the existing condition. Thus, the three scenarios are determined as follows.

1) Scenario1: Existing condition
2) Scenario2: Condition with implementing Exclusive zone for motorcycle stopping for signal
3) Scenario3: Condition with implementing Exclusive left-lane and Hook Turn for motorcycle

The evaluation parameters, including, traffic Measure Of Effectiveness (MOEs), emissions and fuel consumption, are considered to determine the most appropriate the traffic management strategy for a motorcycle at signalized intersection. The traffic MOEs consists of average travel time, average delay and average queue length by motorcycles, other vehicles, and all vehicles. The emissions include CO_2, CO, HC, and NO_x of motorcycles, other vehicles, and all vehicles. The fuel consumption is also considered by motorcycles, other vehicles, and all vehicles.

CHAPTER 3 RESULTS AND DISCUSSIONS

This chapter presents the results and discussions of on-road data collection, traffic data survey, on-road emission and fuel consumption rate model development, traffic simulation development and traffic management strategy evaluation.

3.1 Results of On-road Data Collection

The results of driving a test motorcycle on real-world road to collect on-road data present in Table 3.1.

Table 3.1 Summary of collected on-road data

No.	Selected Routes	Distance (km)	Time	Day	Total Time (hr.)
1	Friendship Hwy.	3.9	7:00-9:00	14	28
2	Sreechan Rd.	3.0	7:00-9:00	14	28
3	NaMuang Rd.	3.8	7:00-9:00	14	28
4	Prachasamosorn Rd.	2.8	7:00-9:00	14	28
5	Maliwan Rd.	1.0			
	Sum	13.5		56	112

3.2 Results of Traffic Data Survey

The results of survey of existing traffic volume reveal that there was high number of motorcycles traveling along the study road section as presented in Figure 3.1. The traffic congestion at study road section is not so severe as average delay identified in the Level Of Service (LOS) of intersections from A to D during morning peak hour (AM 7:30-8:30) and evening peak hour (PM 4:30-5:30) as the detail results displayed in Figure A-1 to A-3 in Appendix A. The range of average desired speeds approaching to the intersections of all vehicle types are 42-45 km/hr as results displayed in detail in Table A-1 in Appendix A. The range of average desired left turning, crossing, right turning speeds of all vehicle types are 11-17 km/hr, 23-28 km/hr, and 22-24 km/hr, respectively.

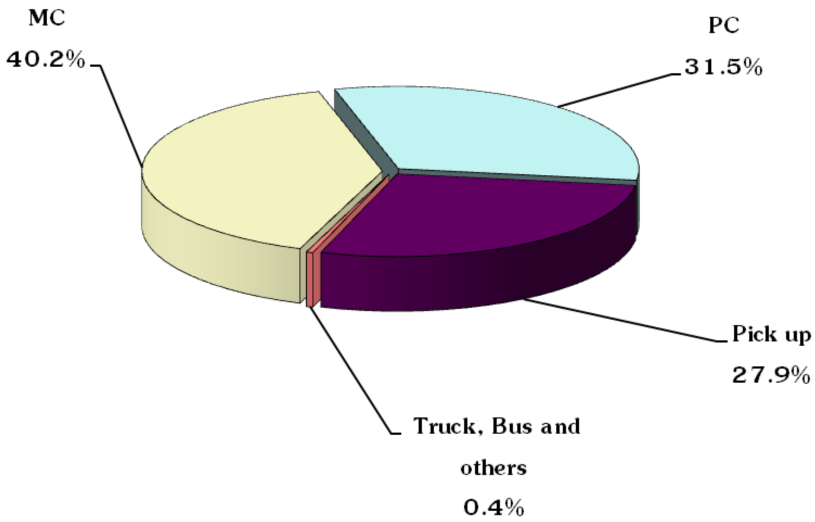

Figure 3.1 Mode share on study road section

3.3 Results of On-road Emission Rate Model Development

The on-road emissions and speed profile of motorcycle driving on road network simultaneously collected by every second were applied to develop on-road emission models by using the regression analysis. The results of model development were displayed in Table 3.2. As the results, the relations between emissions of CO2, HC and NOx and instant speed as well as acceleration rate are very high as their values of R^2 are very close to 1, except that the relation of CO emission and instant speed as well as acceleration is not high. These developed on-road emission rates were further applied to evaluate the traffic management strategy for motorcycle in term of emissions in the next chapter.

Table 3.2 On-road emission rate models of motorcycle

On-road Emission Rate Models of MC	R^2
$LN(EMR_{CO}) = 0.101 - 0.002u + 0.449a$	0.571
$LN(EMR_{CO2}) = 0.269 + 0.005u - 0.548a$	0.961
$LN(EMR_{HC}) = 0.005 - 0.000099u + 0.014a$	0.811
$LN(EMR_{Nox}) = -0.001 + 0.000089u - 0.015a$	0.931
where as EMR = Emission Rate (g/s), u =Instant Speed (km/hr), a = Acceleration Rate (m/s^2)	

As development of emission rate models of other vehicle types, the emission data measured in Automotive Emissions Laboratory of Pollutant Control Department was applied to develop the emission rate models. The models were classified into two types of fuel usage, Gasoline and Diesel engine. The results of model development were presented in Table B-1 in Appendix B.

3.4 Results of On-road Fuel Consumption Rate Model Development

The on-road fuel consumption and speed profile of motorcycle driving on road network simultaneously collected by every second were applied to develop on-road fuel consumption rate model by using the regression analysis. The result of model development was displayed in Table 3.3. As the result, the relation between fuel consumption and instant speed as well as acceleration rate is very high as its value of R^2 is highly close to 1. The comparison of collected and modeled fuel consumption rate is displayed in Figure 3.2. This developed on-road fuel consumption rate model was further applied to evaluate the traffic management strategy for motorcycle in term of fuel consumption reduction in the next chapter.

Table 3.3 Fuel consumption rate model of motorcycle developed by collected data

On-road fuel consumption rate model of MC	R^2
FR = 0.0041 + 0.004u - 0.277a	0.838
where as FR = Fuel Consumption Rate (ml/s), u = Instant Speed (km/hr), a = Acceleration Rate (m/s^2)	

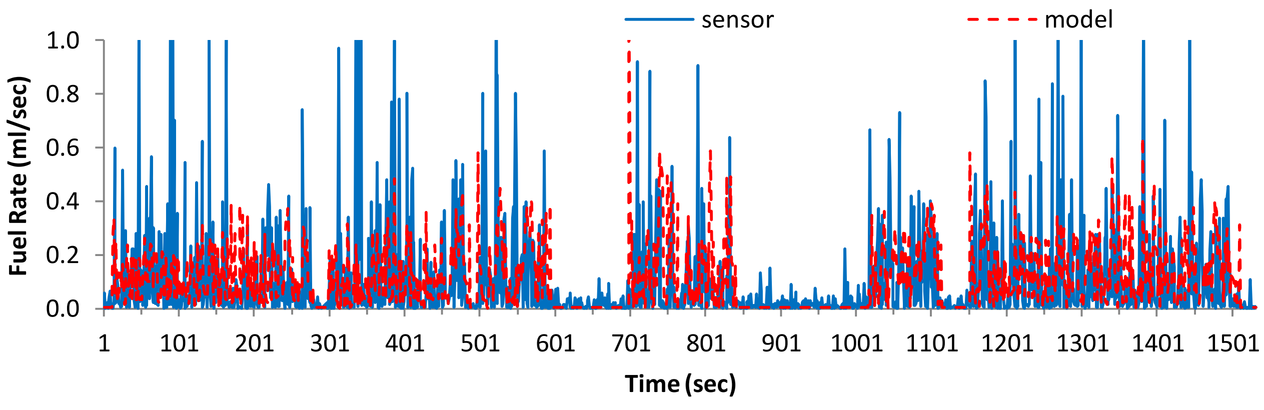

Figure 3.2 Comparison of collected and modeled fuel consumption rate

Alternatively, the fuel consumption rate model also was calculated by amount of emissions. The result of model development was presented in Table 3.4. However, this study selected the on-road fuel consumption rate model developed by collected data to calculate the amount of fuel consumption of motorcycles driving through study road section because the this model is more accurate since it was developed from collected on-road data.

Table 3.4 Fuel consumption rate model of motorcycle developed by calculated data

On-road fuel consumption rate model of MC	**R^2**
FR = 0.131 +0.0001u +0.959a	0.963
where as FR = Fuel Consumption Rate (ml/s), u = Instant Speed (km/hr), a = Acceleration Rate (m/s^2)	

As development of fuel consumption rate models of other vehicle types, the emission data measured in Automotive Emissions Laboratory of Pollutant Control Department was calculated to develop the fuel consumption rate models. The models were classified into two types of fuel usage, Gasoline and Diesel engine. The results of model development were presented in Table B-2 in Appendix B.

3.5 Results of Traffic Simulation Development

3.5.1 Results of OD Matrix Generation

The results of OD Matrix generation are displayed in Table B-1 for the morning peak hour OD Matrix and Table B-2 for the evening peak hour OD Matrix in Appendix B.

3.5.2 Results of Model Calibration and Validation

The results of model calibration at Sreechan-NaMuang, Sreechan-KrangMuang and Sreechan-RungMuang Intersections are presented in Table C-1, Table C-2 and Table C-3 of Appendix C, respectively. The results of model validation at Sreechan-NaMuang, Sreechan-KrangMuang and Sreechan-RungMuang Intersections are presented Table D-1, Table D-2 and Table D-3 of Appendix D, respectively.

3.6 Results of Traffic Management Strategy Evaluation

3.6.1 Results of Traffic Flow Measures of Effectiveness Evaluation

The evaluation results of traffic flow measures of effectiveness are displayed in Table 3.5. As results of motorcycle’s traffic flow measures of effectiveness, both strategies could improve the motorcycle’s traffic flow measures from the existing condition. The strategy of exclusive zone for motorcycle stopping for signal (decreasing 13.7% of average travel time, 4.8% of average delay of motorcycles from the existing condition) could improve traffic flow measures of motorcycle less than the strategy of exclusive left-lane and hook turn for motorcycle (decreasing 23.9% of average travel time, 30.4% of average delay of motorcycles from the existing condition).

As results of traffic flow measures of effectiveness of other vehicles, both strategies also could improve traffic flow measures of other vehicles from the existing condition. The strategy of exclusive zone for motorcycle stopping for signal (decreasing 18.9% of average travel time, 21.3% of average delay of other vehicles from the existing condition) could improve traffic flow measures of other vehicles more than the strategy of exclusive left-lane and hook turn for motorcycle (decreasing 4.4% of average travel time, 5.1% of average delay of other vehicles from the existing condition).

As results of traffic flow measures of effectiveness of all vehicles in the system, both strategies could consequently improve traffic flow measures of all vehicles from the existing condition. The strategy of exclusive zone for motorcycle stopping for signal (decreasing 15.2% of average travel time, 17.2% of average delay, 22.6% of average queue length of all vehicles from the existing condition) could improve traffic flow measures of all vehicles more than the strategy of exclusive left-lane and hook turn for motorcycle (decreasing 3.3% of average travel time, 3.4% of average delay, 12.9% of average queue length of all vehicles from the existing condition).

Table 3.5 Evaluation Results of Traffic Flow Measures of Effectiveness

Vehicle Type	**1. Existing**	**2. MC Stopping Zone**	**3. MC lane & Hook turn**
	Average Travel Time, sec.		
Motorcycle	63.5	54.8 (-13.7%)	48.3 (-23.9%)
Other Vehicles	143.1	116.1 (-18.9%)	136.8 (-4.4%)
All Vehicles	125.9	106.7 (-15.2%)	121.8 (-3.3%)
	Average Delay, sec.		
Motorcycle	50.4	48.0 (-4.8%)	35.1 (-30.4%)
Other Vehicles	127.2	100.1 (-21.3%)	120.8 (-5.1%)
All Vehicles	111.7	92.5 (-17.2%)	107.9 (-3.4%)
	Average Queue Length, veh.		
All Vehicles	31	24 (-22.6%)	27 (-12.9%)

3.6.2 Results of Emissions Evaluation

The evaluation results of emissions are displayed in Table 3.6. As results of motorcycle's emissions reduction, both strategies could reduce emissions of motorcycles from the existing condition. The strategy of exclusive zone for motorcycle stopping for signal (decreasing 5.0% of CO_2 emission, 3.3% of CO emission, 1.9% of HC emission, 2.0% of NOx emission of other vehicles from the existing condition) could reduce emissions of motorcycles less than the strategy of exclusive left-lane and hook turn for motorcycle (decreasing 8.9% of CO_2 emission, 15.4% of CO emission, 23.0% of HC emission, 23.0% of NOx emission of motorcycles from the existing condition).

As results of emissions of other vehicles, both strategies also could reduce emissions of other vehicles from the existing condition. The strategy of exclusive zone for motorcycle stopping for signal (decreasing 9.1% of CO_2 emission, 8.7% of CO emission, 8.6% of HC emission, 8.9% of NOx emission of other vehicles from the existing condition) could reduce emissions of other vehicles more than the strategy of exclusive left-lane and hook turn for motorcycle (decreasing 3.8% of CO_2 emission, 5.7% of CO emission, 7.0% of HC emission, 3.5% of NOx emission of other vehicles from the existing condition).

As results of emissions of all vehicles in the system, both strategies could consequently reduce emissions of all vehicles from the existing condition. The strategy of exclusive zone for motorcycle stopping for signal signal (decreasing 7.4% of CO_2 emission, 8.2% of CO emission, 8.4% of HC emission, 8.7% of NOx emission of other vehicles from the existing condition) could reduce emissions of all vehicles more than the strategy of exclusive left-lane and hook turn for motorcycle signal (decreasing 6.0% of CO_2 emission, 6.8% of CO emission, 7.6% of HC emission, 4.2% of NOx emission of other vehicles from the existing condition).

Table 3.6 Results of Emissions Evaluation

Vehicle Type	**1. Existing**	**2. MC Stopping Zone**	**3. MC lane & Hook turn**
	CO_2 Emission, kg		
Motorcycle	690.1	655.7 (-5.0%)	628.4 (-8.9%)
Other Vehicles	932.5	847.2 (-9.1%)	896.8 (-3.8%)
All Vehicles	1,622.6	1,502.9 (-7.4%)	1,525.3 (-6.0%)

	CO Emission, kg		
Motorcycle	338.7	327.5 (-3.3%)	286.6 (-15.4%)
Other Vehicles	2,823.3	2,576.6 (-8.7%)	2,661.2 (-5.7%)
All Vehicles	3,162.0	2,904.0 (-8.2%)	2,947.8 (-6.8%)
	HC Emission, kg		
Motorcycle	134.0	131.4 (-1.9%)	103.2 (-23.0%)
Other Vehicles	3,484.7	3,184.9 (-8.6%)	3,240.0 (-7.0%)
All Vehicles	3,618.8	3,316.2 (-8.4%)	3,343.2 (-7.6%)
	NOx Emission, kg		
Motorcycle	134.2	131.5 (-2.0%)	103.3 (-23.0%)
Other Vehicles	3,806.7	3,467.1 (-8.9%)	3,673.2 (-3.5%)
All Vehicles	3,940.9	3,598.6 (-8.7%)	3,776.5 (-4.2%)

3.6.2 Results of Fuel Consumption Evaluation

The evaluation results of fuel consumption are displayed in Table 3.7. As results of motorcycle’s fuel consumption, both strategies could reduce fuel consumption of motorcycles from the existing condition. The strategy of exclusive zone for motorcycle stopping for signal (decreasing 2.8% of fuel consumption of motorcycle from the existing condition) could reduce fuel consumption of motorcycles less than the strategy of exclusive left-lane and hook turn for motorcycle (decreasing 18.5% of fuel consumption of motorcycles from the existing condition).

Table 3.7 Results of Fuel Consumption Evaluation

Vehicle Type	1. Existing	2. MC Stopping Zone	3. MC lane & Hook turn
	Fuel Consumption, kg		
Motorcycle	44.60	43.34 (-2.8%)	36.36 (-18.5%)
Other Vehicles	177.44	147.56 (-16.8%)	170.45 (-3.9%)
All Vehicles	222.04	190.90 (-14.0%)	206.81 (-6.9%)

As results of fuel consumption of other vehicles, both strategies also could reduce emissions of other vehicles from the existing condition. The strategy of exclusive zone for motorcycle stopping for signal (decreasing 16.8% of fuel consumption of other vehicles from the existing condition) could reduce fuel consumption of other vehicles more than the strategy of exclusive left-lane and hook turn for motorcycle (decreasing 3.9% of fuel consumption of other vehicles from the existing condition).

As results of fuel consumption of all vehicles in the system, both strategies could consequently reduce fuel consumption of all vehicles from the existing condition. The strategy of exclusive zone for motorcycle stopping for signal (decreasing 14.0% of fuel consumption of other vehicles from the existing condition) could reduce fuel consumption of all vehicles more than the strategy of exclusive left-lane and hook turn for motorcycle signal (decreasing 6.9% of fuel consumption of other vehicles from the existing condition).

CHAPTER 4 CONCLUSIONS AND RECOMMENDATIONS

This chapter concludes the results of this research and explains the next research topics for the further studies.

4.1 Conclusions

Motorcycle has become a popular mode in many Asian cities with its high accessibility. It is a private vehicle for almost low-income households due to cheap and advantage for a short distance travel in the congested cities. However, motorcycle was recorded as highest mode violated traffic rules and involved in traffic accidents. To alleviate this problem, appropriate traffic management and control concerning with motorcycle is necessary rather than traffic rule education and traffic law enforcement. To evaluate traffic control strategy in term of emission and fuel consumption reduction, an estimation of on-road emissions and fuel consumption by traffic simulation is necessary. It requires emission and fuel consumption models sensitive to instantaneous speed profile of motorcycle. The existing driving cycle of motorcycle may not be a good representative for driving cycle of other cities. Therefore, the objectives of this study are to develop emission and fuel consumption rate models and to present an application of developed models to evaluate the traffic management strategies for motorcycle.

This study selected Khon Kaen City as a study city due to high motorcycle mode share. The onboard measurement system was installed on the motorcycle to drive on the selected routes of Khon Kaen City road network to measure the driving pattern, exhaust emissions and fuel consumption. The on-road emissions, fuel consumption and speed profile of motorcycle driving on road network simultaneously collected by every second were applied to develop on-road emission and fuel consumption models by using the regression analysis. As the results of regression analysis, the on-road emission and fuel consumption rate models were developed with high relations between emissions and fuel consumption, and instant speed and acceleration rate. .

The traffic management strategy for motorcycle at signalized intersection was analyzed and evaluated by applying a micro traffic simulation. The study road section was a section of Sreechan Rd. with 3 signalized intersections in Khon Kaen City. This study surveyed the data of geometric and traffic characteristics to develop a micro traffic simulation of study section by applying VISSIM. The two strategy of traffic management strategy for motorcycle at signalized intersection, consisting of 1) Exclusive zone for motorcycle stopping for signal and 2) Exclusive left-lane and Hook Turn for motorcycle were analyzed and evaluated. This study developed the simulation model (Calibration) by using traffic condition during morning peak hour (7:30 – 8:30 AM) and validated the simulation model by using traffic condition during evening peak hour (4:30 – 5:30 PM). The traffic flow resulted from simulation model (velocity and acceleration by period of each vehicle of all vehicle type) were applied with fuel consumption rates and emission rates to calculate the amount of fuel consumption and emissions of all vehicles traveling pass the intersections. To evaluate the strategy, this study compared the intersection’s level of service, fuel consumption and emissions of condition with implementing strategy with existing condition. The evaluation results reveal that both strategies could improve the level of service of the intersections by decreasing travel time, delay and queue length at intersections. Also, the fuel consumption and emissions of vehicles travelling through intersections decreased. The strategy of exclusive zone for motorcycle stopping for signal could more improve intersection’s level of service and less fuel consumption and emissions of vehicles than the strategy of exclusive left-lane and Hook Turn for motorcycle.

4.2 Recommendations

There are many recommendations for further studies as follows.

- The developed on-road and fuel consumption rate models will be further applied to evaluate other traffic planning, such as a design of traffic signalized control at intersection or a design of coordination control of signalized intersections for minimizing emissions and fuel consumption.
- The developing onboard measurement system can be further used to collect the on-road data that can be used to develop the eco-driving cycle for a motorcycle that can be applied for a development of an eco-driving assistance system for a motorcyclist for reducing fuel consumption and emissions.

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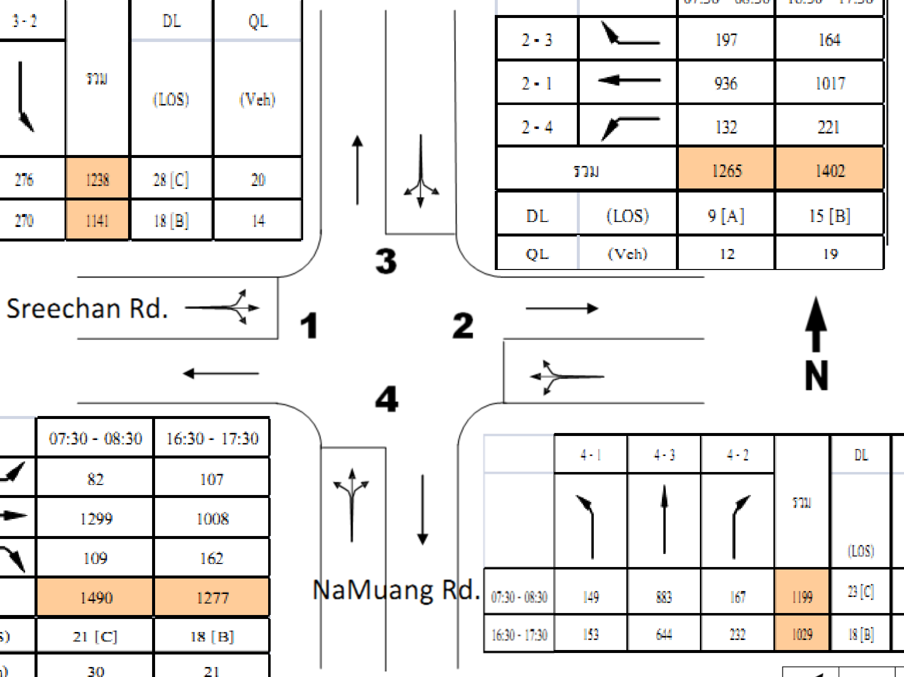
	3 - 1	3 - 4	3 - 2	รวม	DL (LOS)	QL (Veh)
07:30 - 08:30	230	732	276	1238	28 [C]	20
16:30 - 17:30	214	657	270	1141	18 [B]	14

		07:30 - 08:30	16:30 - 17:30
2 - 3		197	164
2 - 1		936	1017
2 - 4		132	221
รวม		1265	1402
DL	(LOS)	9 [A]	15 [B]
QL	(Veh)	12	19



		07:30 - 08:30	16:30 - 17:30
1 - 3		82	107
1 - 2		1299	1008
1 - 4		109	162
รวม		1490	1277
DL	(LOS)	21 [C]	18 [B]
QL	(Veh)	30	21

	4 - 1	4 - 3	4 - 2	รวม	DL (LOS)	QL (Veh)
07:30 - 08:30	149	883	167	1199	23 [C]	30
16:30 - 17:30	153	644	232	1029	18 [B]	19

Traffic Control: Fixed Time Signal

Cycle length: 85 Sec.

Phase	A	B
Green	40	35
Yellow	2	2
All Reds	3	3

Figure A-1 Existing traffic volume at Sreechan-NaMuang intersection

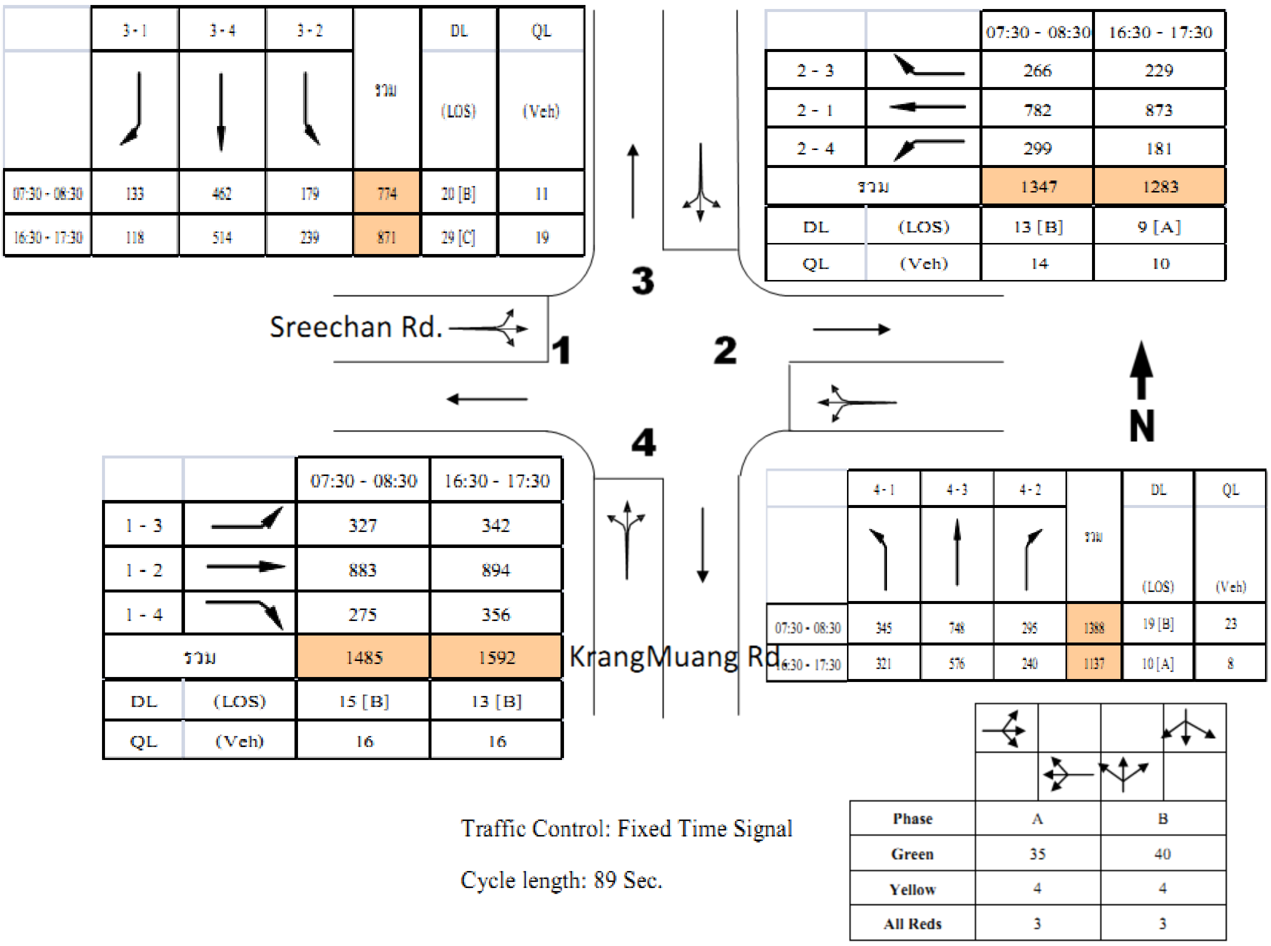
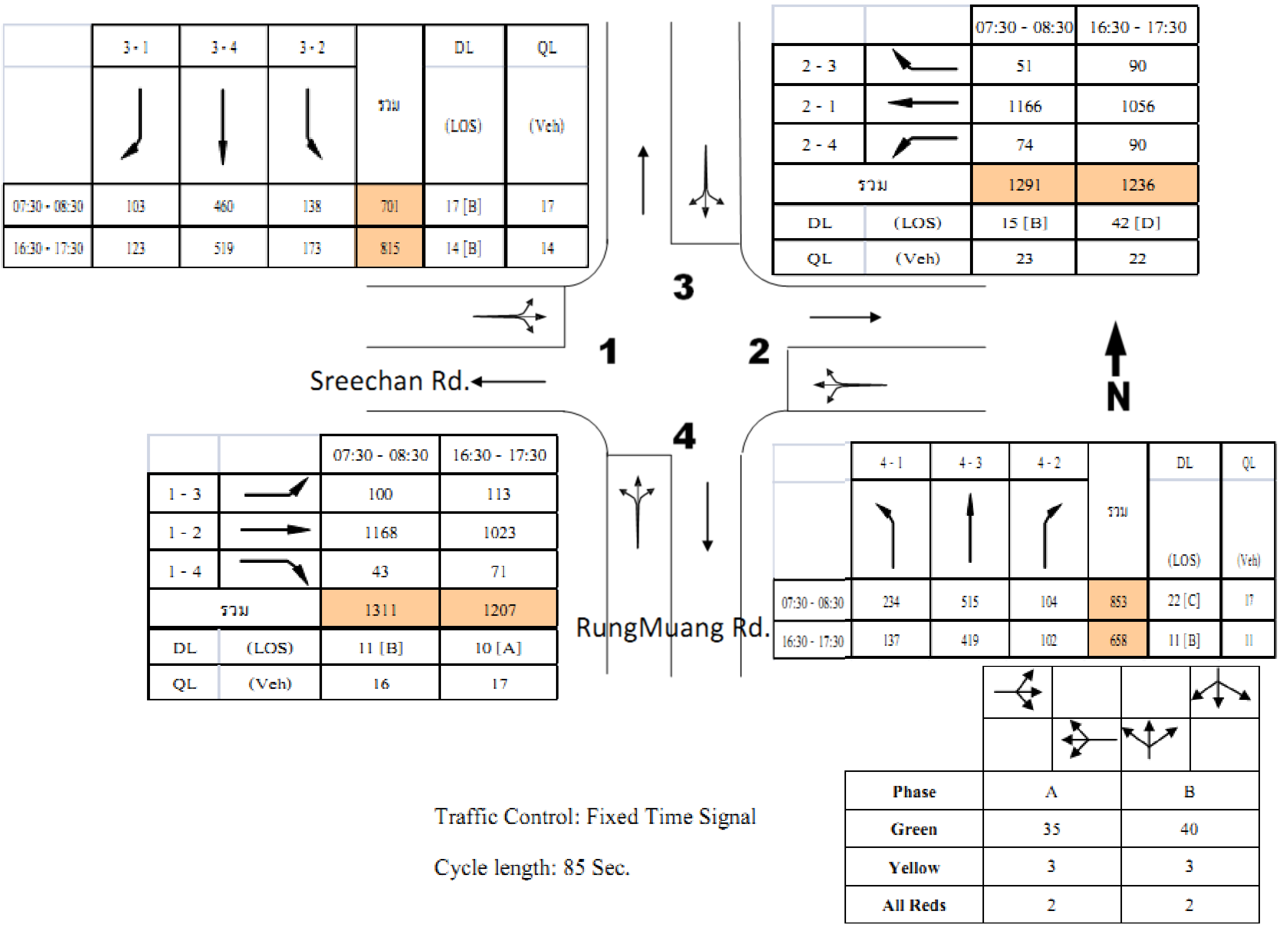


Figure A-2 Existing traffic volume at Sreechan-KrangMuang intersection



	3 - 1	3 - 4	3 - 2	รวม	DL (LOS)	QL (Veh)
07:30 - 08:30	103	460	138	701	17 [B]	17
16:30 - 17:30	123	519	173	815	14 [B]	14

		07:30 - 08:30	16:30 - 17:30
2 - 3		51	90
2 - 1		1166	1056
2 - 4		74	90
รวม		1291	1236
DL	(LOS)	15 [B]	42 [D]
QL	(Veh)	23	22

		07:30 - 08:30	16:30 - 17:30
1 - 3		100	113
1 - 2		1168	1023
1 - 4		43	71
รวม		1311	1207
DL	(LOS)	11 [B]	10 [A]
QL	(Veh)	16	17

	4 - 1	4 - 3	4 - 2	รวม	DL (LOS)	QL (Veh)
07:30 - 08:30	234	515	104	853	22 [C]	17
16:30 - 17:30	137	419	102	658	11 [B]	11

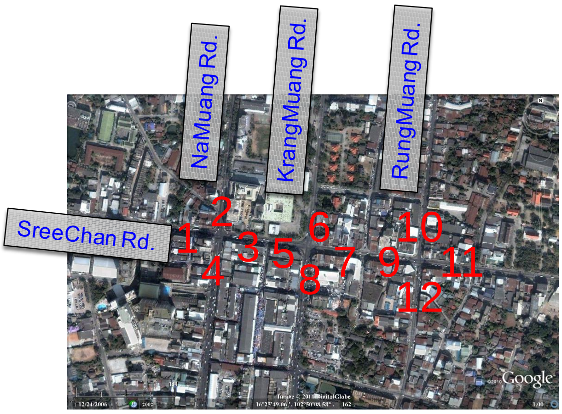
Phase	A	B
Green	35	40
Yellow	3	3
All Reds	2	2

Figure A-3 Existing traffic volume at Sreechan-RungMuang intersection

Table A-1 Desired approach speed at intersections

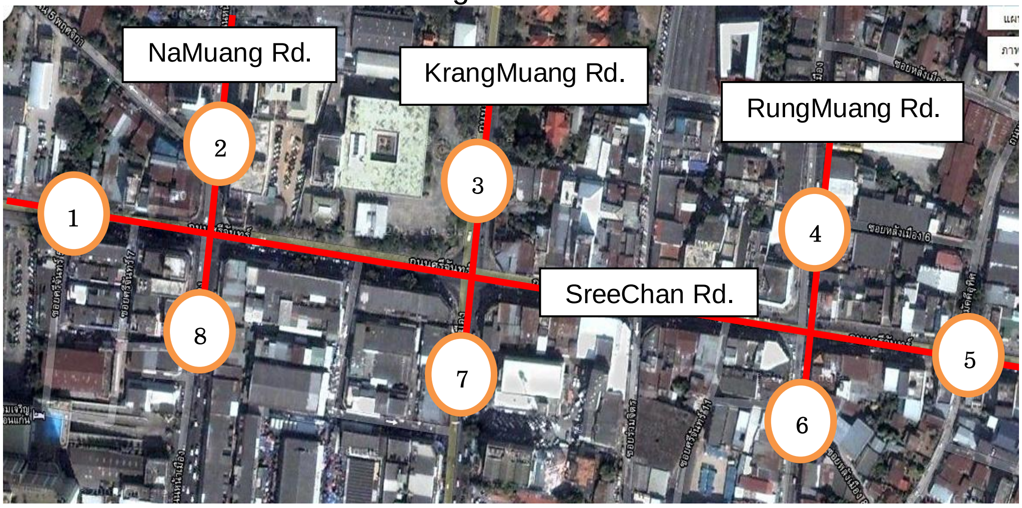
Desired Approaching Speed (km/hr)					**Remark**
Direction	**MC**	**PC**	**Pick up Truck/Van**	**6 wheel Truck/Bus**	
1	67.44	62.01	64.07	70.00	
2	53.98	52.58	56.44	60.82	
3	31.71	32.18	27.79	-	
4	31.34	33.56	30.75	17.78	
5	40.31	47.75	41.00	32.94	
6	48.12	48.22	46.29	36.18	
7	32.41	31.62	30.16	-	
8	50.97	46.92	43.43	-	
Average	44.54	44.36	42.49	43.54	

Table A-2 Desired turning and crossing speed at intersections

Desired Turning and Crossing Speed (km/hr)						Remark
Direction		MC	PC	Pick up Truck/Van	6 wheel Truck/Bus	
1	Left	12.00	16.45	15.01	-	
	Cross	22.56	23.03	21.91	18.72	
	Right	18.57	17.48	14.56	-	
2	Left	19.75	11.91	10.15	5.74	
	Cross	24.57	23.20	25.17	26.16	
	Right	26.46	14.47	15.77	13.56	
3	Left	15.42	12.35	14.80	-	
	Cross	22.03	19.66	18.71	13.78	
	Right	37.13	28.95	28.45	-	
4	Left	11.54	8.59	9.01	-	
	Cross	26.61	22.65	20.66	27.25	
	Right	13.49	15.54	17.60	-	
5	Left	19.61	16.33	16.66	12.23	
	Cross	37.01	31.72	32.28	27.50	
	Right	30.97	26.16	27.21	18.92	
6	Left	16.41	9.78	10.22	-	
	Cross	24.44	19.61	18.63	-	
	Right	20.64	11.69	13.36	9.82	
7	Left	17.31	13.81	14.19	11.03	
	Cross	29.28	27.74	28.39	25.86	
	Right	20.10	18.17	21.05	39.95	
8	Left	18.39	16.48	16.95	15.59	
	Cross	31.75	30.62	26.83	18.60	
	Right	24.91	24.73	23.24	-	
9	Left	18.82	14.97	14.26	11.32	
	Cross	28.26	31.74	26.66	21.01	
	Right	24.99	28.90	20.58	28.60	
10	Left	18.17	12.93	13.11	-	
	Cross	26.60	23.37	22.52	-	
	Right	18.64	14.54	15.84	-	
11	Left	15.59	15.03	13.27	-	
	Cross	35.66	36.04	34.11	31.46	
	Right	-	-	10.86	-	
12	Left	20.86	16.28	15.96	13.27	
	Cross	28.02	27.20	26.06	-	
	Right	24.24	17.60	18.33	-	
Average	Left	16.99	13.74	13.63	11.53	
	Cross	28.07	26.38	25.16	23.37	
	Right	23.65	19.84	18.90	22.17	

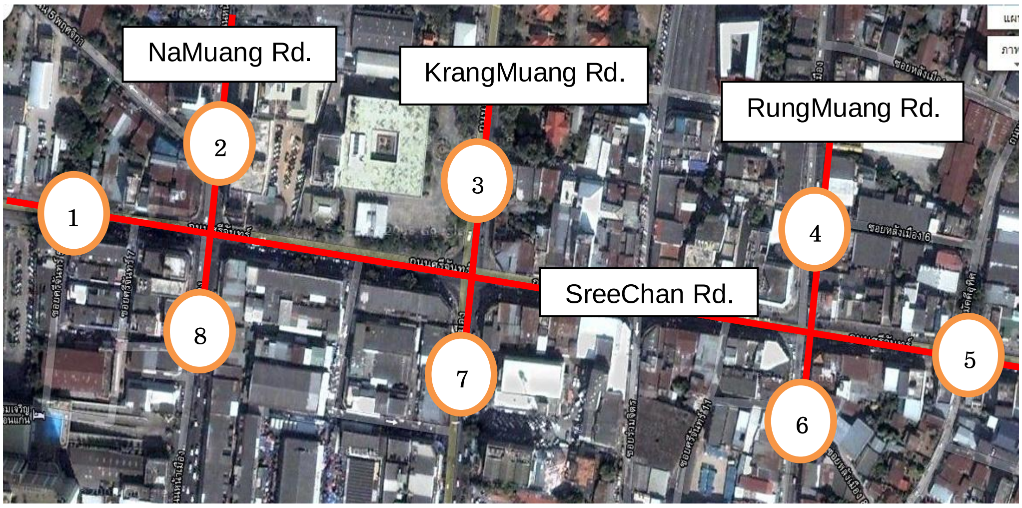
APPENDIX B RESULTS OF O-D MATRIX GENERATION

Table B-1 Results of Morning Peak Hour O-D Matrix Generation



Origin \ Destination	zone 1	zone 2	zone 3	zone 4	zone 5	zone 6	zone 7	zone 8
	Motorcycle (veh)							
zone 1		36	49	14	231	2	72	93
zone 2	64		16	10	11	5	15	230
zone 3	33	27		12	14	1	87	27
zone 4	12	12	13		22	330	11	12
zone 5	147	25	29	27		42	93	35
zone 6	8	9	9	292	36		8	8
zone 7	123	32	197	15	97	2		51
zone 8	71	294	13	8	10	4	15	
	Car (veh)							
zone 1		31	50	10	207	6	74	75
zone 2	77		19	8	13	5	16	206
zone 3	30	24		9	16	1	91	19
zone 4	10	10	10		19	254	10	10
zone 5	152	23	50	22		30	75	30
zone 6	9	8	10	254	33		9	6
zone 7	111	31	201	12	78	2		44
zone 8	59	258	16	8	11	4	15	
	Truck (veh)							
zone 1		29	60	5	178	4	61	31
zone 2	152		16	7	10	4	14	191
zone 3	17	16		6	25	3	154	10
zone 4	9	8	8		47	122	5	7
zone 5	118	10	77	30		13	87	7
zone 6	16	9	16	134	37		19	7
zone 7	89	13	244	3	110	0		8
zone 8	56	290	13	4	6	4	11	
	Bus (veh)							
zone 1		5	1	0	0	0	0	0
zone 2	0		1	0	0	0	0	2
zone 3	0	0		0	0	0	0	0
zone 4	0	1	0		0	0	0	0
zone 5	0	1	0	0		0	1	0
zone 6	0	0	0	0	0		0	0
zone 7	0	0	1	0	1	0		0
zone 8	0	0	0	0	0	0	0	

Table B-2 Results of Evening Peak Hour O-D Matrix Generation



Destination / Origin	zone 1	zone 2	zone 3	zone 4	zone 5	zone 6	zone 7	zone 8
	Motorcycle (veh)							
zone 1		56	47	16	124	7	53	61
zone 2	77		17	8	8	5	13	303
zone 3	50	18		16	31	6	135	28
zone 4	15	11	13		33	310	14	13
zone 5	152	13	14	21		19	59	24
zone 6	7	6	6	319	38		9	7
zone 7	100	17	206	15	123	8		28
zone 8	47	252	18	12	11	6	16	
	Car (veh)							
zone 1		27	43	6	148	2	70	54
zone 2	99		20	7	13	5	20	107
zone 3	29	12		7	26	2	91	12
zone 4	6	6	7		24	102	6	6
zone 5	150	7	38	24		27	38	8
zone 6	10	6	12	86	28		7	5
zone 7	61	8	105	5	27	2		13
zone 8	46	86	27	7	18	4	23	
	Truck (veh)							
zone 1		35	47	5	163	4	55	50
zone 2	83		17	5	13	5	21	193
zone 3	35	15		7	17	5	173	21
zone 4	11	10	9		48	139	10	8
zone 5	160	7	53	34		31	64	14
zone 6	10	7	8	101	35		7	10
zone 7	64	12	177	5	76	3		17
zone 8	52	211	20	5	13	4	18	
	Bus (veh)							
zone 1		0	5	0	2	0	0	0
zone 2	0		0	0	0	0	0	2
zone 3	0	0		0	0	0	0	0
zone 4	0	0	0		2	1	1	1
zone 5	1	0	0	0		1	1	0
zone 6	0	0	0	0	0		0	0
zone 7	0	0	0	0	0	0		3
zone 8	0	0	0	0	0	0	0	

APPENDIX C CALIBRATION OF TRAFFIC SIMULATION MODEL

Table C-1 Results of Calibration of Traffic Simulation Model at Sreechan-NaMuang Intersection

Link Name	**Observed**	**Modeled**	**Difference or GEH**	**Criteria**	**Criteria Threshold**	**Pass / Fail**
Traffic Flow (veh/hr)						
Sreechan WB-L	89	85	-4	<700	within 100	pass
Sreechan WB-T	1097	1023	-7%	>700&<2700	within 15%	pass
Sreechan WB-R	148	143	-5	<700	within 100	pass
Sreechan NB-L	226	217	-9	<700	within 100	pass
Sreechan NB-T	560	554	-6	<700	within 100	pass
Sreechan NB-R	257	242	-15	<700	within 100	pass
Sreechan EB-L	190	201	11	<700	within 100	pass
Sreechan EB-T	826	797	-4%	>700&<2700	within 15%	pass
Sreechan EB-R	220	208	-12	<700	within 100	pass
Sreechan SB-L	155	143	-12	<700	within 100	pass
Sreechan SB-T	717	751	5%	>700&<2700	within 15%	pass
Sreechan SB-R	170	166	-4	<700	within 100	pass
GEH Statistic						
Sreechan WB-L	89	85	0.43	GEH	< 5	pass
Sreechan WB-T	1097	1023	2.27	GEH	< 5	pass
Sreechan WB-R	148	143	0.41	GEH	< 5	pass
Sreechan NB-L	226	217	0.60	GEH	< 5	pass
Sreechan NB-T	560	554	0.25	GEH	< 5	pass
Sreechan NB-R	257	242	0.95	GEH	< 5	pass
Sreechan EB-L	190	201	0.79	GEH	< 5	pass
Sreechan EB-T	826	797	1.02	GEH	< 5	pass
Sreechan EB-R	220	208	0.82	GEH	< 5	pass
Sreechan SB-L	155	143	0.98	GEH	< 5	pass
Sreechan SB-T	717	751	1.25	GEH	< 5	pass
Sreechan SB-R	170	166	0.31	GEH	< 5	pass
Maximum Queue Length (Veh)						
Sreechan WB	30	26	-13%	Queue	within 20%	pass
Sreechan NB	20	24	20%	Queue	within 20%	pass
Sreechan EB	12	12	0%	Queue	within 20%	pass
Sreechan SB	30	34	-13%	Queue	within 20%	pass

Table C-2 Results of Calibration of Traffic Simulation Model at Sreechan-KrangMuang Intersection

Link Name	Observed	Modeled	Difference or GEH	Criteria	Criteria Threshold	Pass / Fail
Movement Flow (veh/hr)						
Sreechan WB-L	307	294	-13	<700	within 100	pass
Sreechan WB-T	797	695	-13%	>700&<2700	within 15%	pass
Sreechan WB-R	267	285	18	<700	within 100	pass
Sreechan NB-L	125	99	-26	<700	within 100	pass
Sreechan NB-T	328	341	13	<700	within 100	pass
Sreechan NB-R	212	224	12	<700	within 100	pass
Sreechan EB-L	255	247	-8	<700	within 100	pass
Sreechan EB-T	758	695	-8%	>700&<2700	within 15%	pass
Sreechan EB-R	258	239	-19	<700	within 100	pass
Sreechan SB-L	444	430	-14	<700	within 100	pass
Sreechan SB-T	574	589	15	<700	within 100	pass
Sreechan SB-R	293	282	-11	<700	within 100	pass
GEH Statistic						
Sreechan WB-L	307	294	0.75	GEH	< 5	pass
Sreechan WB-T	797	695	3.73	GEH	< 5	pass
Sreechan WB-R	267	285	1.08	GEH	< 5	pass
Sreechan NB-L	125	99	2.46	GEH	< 5	pass
Sreechan NB-T	328	341	0.71	GEH	< 5	pass
Sreechan NB-R	212	224	0.81	GEH	< 5	pass
Sreechan EB-L	255	247	0.50	GEH	< 5	pass
Sreechan EB-T	758	695	2.34	GEH	< 5	pass
Sreechan EB-R	258	239	1.21	GEH	< 5	pass
Sreechan SB-L	444	430	0.67	GEH	< 5	pass
Sreechan SB-T	574	589	0.62	GEH	< 5	pass
Sreechan SB-R	293	282	0.65	GEH	< 5	pass
Maximum Queue Length (Veh)						
Sreechan WB	16	13	-19%	Queue	within 20%	pass
Sreechan NB	11	10	-9%	Queue	within 20%	pass
Sreechan EB	14	12	-14%	Queue	within 20%	pass
Sreechan SB	23	21	-9%	Queue	within 20%	pass

Table C-3 Results of Calibration of Traffic Simulation Model at Sreechan-RungMuang Intersection

Link Name	Observed	Modeled	Difference or GEH	Criteria	Criteria Threshold	Pass / Fail
Movement Flow (veh/hr)						
Sreechan WB-L	122	133	11	<700	within 100	pass
Sreechan WB-T	992	983	-1%	>700&<2700	within 15%	pass
Sreechan WB-R	41	40	-1	<700	within 100	pass
Sreechan NB-L	82	81	-1	<700	within 100	pass
Sreechan NB-T	527	532	5	<700	within 100	pass
Sreechan NB-R	157	153	-4	<700	within 100	pass
Sreechan EB-L	69	54	-15	<700	within 100	pass
Sreechan EB-T	1046	964	-8%	>700&<2700	within 15%	pass
Sreechan EB-R	70	61	-9	<700	within 100	pass
Sreechan SB-L	211	199	-12	<700	within 100	pass
Sreechan SB-T	543	549	6	<700	within 100	pass
Sreechan SB-R	100	94	-6	<700	within 100	pass
GEH Statistic						
Sreechan WB-L	122	133	0.97	GEH	< 5	pass
Sreechan WB-T	992	983	0.29	GEH	< 5	pass
Sreechan WB-R	41	40	0.16	GEH	< 5	pass
Sreechan NB-L	82	81	0.11	GEH	< 5	pass
Sreechan NB-T	527	532	0.22	GEH	< 5	pass
Sreechan NB-R	157	153	0.32	GEH	< 5	pass
Sreechan EB-L	69	54	1.91	GEH	< 5	pass
Sreechan EB-T	1046	964	2.59	GEH	< 5	pass
Sreechan EB-R	70	61	1.11	GEH	< 5	pass
Sreechan SB-L	211	199	0.84	GEH	< 5	pass
Sreechan SB-T	543	549	0.26	GEH	< 5	pass
Sreechan SB-R	100	94	0.61	GEH	< 5	pass
Maximum Queue Length (Veh)						
Sreechan WB	16	18	-13%	Queue	within 20%	pass
Sreechan NB	17	18	6%	Queue	within 20%	pass
Sreechan EB	23	27	17%	Queue	within 20%	pass
Sreechan SB	17	20	18%	Queue	within 20%	pass

Table D-1 Results of Validation of Traffic Simulation Model at Sreechan-NaMuang Intersection

Link Name	Observed	Modeled	Difference or GEH	Criteria	Criteria Threshold	Pass / Fail
Movement Flow (veh/hr)						
Sreechan WB-L	118	109	-9	<700	within 100	pass
Sreechan WB-T	820	823	1%	>700&<2700	within 15%	pass
Sreechan WB-R	165	175	10	<700	within 100	pass
Sreechan NB-L	201	188	-13	<700	within 100	pass
Sreechan NB-T	604	595	-9	<700	within 100	pass
Sreechan NB-R	259	242	-17	<700	within 100	pass
Sreechan EB-L	229	213	-16	<700	within 100	pass
Sreechan EB-T	873	812	-7%	>700&<2700	within 15%	pass
Sreechan EB-R	166	173	7	<700	within 100	pass
Sreechan SB-L	145	134	-11	<700	within 100	pass
Sreechan SB-T	549	509	-7	<700	within 100	pass
Sreechan SB-R	226	213	-13	<700	within 100	pass
GEH Statistic						
Sreechan WB-L	118	109	0.84	GEH	< 5	pass
Sreechan WB-T	820	823	0.10	GEH	< 5	pass
Sreechan WB-R	165	175	0.77	GEH	< 5	pass
Sreechan NB-L	201	188	0.93	GEH	< 5	pass
Sreechan NB-T	604	595	0.37	GEH	< 5	pass
Sreechan NB-R	259	242	1.07	GEH	< 5	pass
Sreechan EB-L	229	213	1.08	GEH	< 5	pass
Sreechan EB-T	873	812	2.10	GEH	< 5	pass
Sreechan EB-R	166	173	0.54	GEH	< 5	pass
Sreechan SB-L	145	134	0.93	GEH	< 5	pass
Sreechan SB-T	549	509	1.74	GEH	< 5	pass
Sreechan SB-R	226	213	0.88	GEH	< 5	pass
Maximum Queue Length (Veh)						
Sreechan WB	21	23	10%	Queue	within 20%	pass
Sreechan NB	14	16	14%	Queue	within 20%	pass
Sreechan EB	19	16	-16%	Queue	within 20%	pass
Sreechan SB	19	22	16%	Queue	within 20%	pass

Table D-2 Results of Validation of Traffic Simulation Model at Sreechan-KrangMuang Intersection

Link Name	Observed	Modeled	Difference or GEH	Criteria	Criteria Threshold	Pass / Fail
Movement Flow (veh/hr)						
Sreechan WB-L	333	295	-38	<700	within 100	pass
Sreechan WB-T	751	768	2%	>700&<2700	within 15%	pass
Sreechan WB-R	350	337	-13	<700	within 100	pass
Sreechan NB-L	136	150	14	<700	within 100	pass
Sreechan NB-T	399	390	-9	<700	within 100	pass
Sreechan NB-R	263	241	-22	<700	within 100	pass
Sreechan EB-L	219	196	-23	<700	within 100	pass
Sreechan EB-T	745	698	-6%	>700&<2700	within 15%	pass
Sreechan EB-R	155	145	-10	<700	within 100	pass
Sreechan SB-L	356	359	3	<700	within 100	pass
Sreechan SB-T	490	512	22	<700	within 100	pass
Sreechan SB-R	283	258	-25	<700	within 100	pass
GEH Statistic						
Sreechan WB-L	333	295	2.14	GEH	< 5	pass
Sreechan WB-T	751	768	0.62	GEH	< 5	pass
Sreechan WB-R	350	337	0.70	GEH	< 5	pass
Sreechan NB-L	136	150	1.17	GEH	< 5	pass
Sreechan NB-T	399	390	0.45	GEH	< 5	pass
Sreechan NB-R	263	241	1.39	GEH	< 5	pass
Sreechan EB-L	219	196	1.60	GEH	< 5	pass
Sreechan EB-T	745	698	1.75	GEH	< 5	pass
Sreechan EB-R	155	145	0.82	GEH	< 5	pass
Sreechan SB-L	356	359	0.16	GEH	< 5	pass
Sreechan SB-T	490	512	0.98	GEH	< 5	pass
Sreechan SB-R	283	258	1.52	GEH	< 5	pass
Maximum Queue Length (Veh)						
Sreechan WB	16	14	-13%	Queue	within 20%	pass
Sreechan NB	19	19	0%	Queue	within 20%	pass
Sreechan EB	20	24	20%	Queue	within 20%	pass
Sreechan SB	18	17	-6%	Queue	within 20%	pass

Table D-3 Results of Validation of Traffic Simulation Model at Sreechan-RungMuang Intersection

Link Name	**Observed**	**Modeled**	**Difference or GEH**	**Criteria**	**Criteria Threshold**	**Pass / Fail**
Movement Flow (veh/hr)						
Sreechan WB-L	143	131	-12	<700	within 100	pass
Sreechan WB-T	860	824	-4%	>700&<2700	within 15%	pass
Sreechan WB-R	76	61	-15	<700	within 100	pass
Sreechan NB-L	107	115	8	<700	within 100	pass
Sreechan NB-T	552	567	15	<700	within 100	pass
Sreechan NB-R	188	165	-23	<700	within 100	pass
Sreechan EB-L	78	66	-12	<700	within 100	pass
Sreechan EB-T	886	812	-8%	>700&<2700	within 15%	pass
Sreechan EB-R	79	66	-13	<700	within 100	pass
Sreechan SB-L	131	144	13	<700	within 100	pass
Sreechan SB-T	506	492	-14	<700	within 100	pass
Sreechan SB-R	101	119	18	<700	within 100	pass
GEH Statistic						
Sreechan WB-L	143	131	1.03	GEH	< 5	pass
Sreechan WB-T	860	824	1.24	GEH	< 5	pass
Sreechan WB-R	76	61	1.81	GEH	< 5	pass
Sreechan NB-L	107	115	0.76	GEH	< 5	pass
Sreechan NB-T	552	567	0.63	GEH	< 5	pass
Sreechan NB-R	188	165	1.73	GEH	< 5	pass
Sreechan EB-L	78	66	1.41	GEH	< 5	pass
Sreechan EB-T	886	812	2.54	GEH	< 5	pass
Sreechan EB-R	79	66	1.53	GEH	< 5	pass
Sreechan SB-L	131	144	1.11	GEH	< 5	pass
Sreechan SB-T	506	492	0.63	GEH	< 5	pass
Sreechan SB-R	101	119	1.72	GEH	< 5	pass
Maximum Queue Length (Veh)						
Sreechan WB	17	18	6%	Queue	within 20%	pass
Sreechan NB	14	12	-14%	Queue	within 20%	pass
Sreechan EB	22	24	9%	Queue	within 20%	pass
Sreechan SB	16	19	19%	Queue	within 20%	pass

Table E-1 Emission rate models of Gasoline and Diesel engines

Emission Rate Models	**R^2**
$LN(EMR_{CO})_{Gasoline} = -7.287 + 0.032u + 0.134a$	0.537
$LN(EMR_{CO2})_{Gasoline} = -1.003 + 0.02u + 0.51a$	0.575
$LN(EMR_{HC})_{Gasoline} = -9.083 + 0.08u + 0.263a$	0.253
$LN(EMR_{NOx})_{Gasoline} = -9.083 + 0.038u + 0.774a$	0.280
$LN(EMR_{CO})_{Diesel} = -6.266 + 0.034u + 0.048a$	0.595
$LN(EMR_{CO2})_{Diesel} = -0.239 + 0.028u + 0.193a$	0.494
$LN(EMR_{HC})_{Diesel} = -7.900 + 0.013u + 0.34a$	0.532
$LN(EMR_{NOx})_{Diesel} = -5.031 + 0.025u - 0.237a$	0.297
where as EMR = Emission Rate (g/s), u =Instant Speed (km/hr), a = Acceleration Rate (m/s^2)	

Table E-2 Fuel consumption rate models of Gasoline and Diesel engines

Fuel consumption rate models	**R^2**
$(FR)_{Gasoline} = -0.167 + 0.015u + 0.17a$	0.632
$(FR)_{Diesel} = -0.162 + 0.043u + 0.074a$	0.682
where as FR = Fuel Consumption Rate (ml/s), u = Instant Speed (km/hr), a = Acceleration Rate (m/s^2)	

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