Final Report

Research Grant 2009

ATRANS

ASIAN TRANSPORTATION RESEARCH SOCIETY

Development of Onboard Measurement System Measuring Driving Pattern and Exhaust Emissions of Motorcycle and its Application in Khon Kaen City

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CHAPTER I INTRODUCTION

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

1.1 Statement of Problem

The driving cycle and emission factors for each vehicle type and city are the important data for the research and planning. They often are used to evaluate the proposing new-technology engine of vehicle, clearer energy, as well as the transportation and land use policy and plan to reduce the fuel consumption and exhaust emissions. The driving cycle is developed from the data collected by driving the testing vehicle on the real road network. The driving cycle is further applied to measure the fuel consumption emissions and the exhaust emissions of testing vehicle by simulating the engine of testing vehicle following to the driving cycle by using a chassis dynamometer in the laboratory. However, the measurement of fuel consumption and exhaust emissions is costly and it cannot measure exactly the amount of fuel consumption and exhaust emissions because the variation of stimulating the engine following a driving cycle as well as real load conditions in laboratory.

Therefore, this research aims to develop the onboard system to measure and collect the on-road data of the driving motorcycle, including a driving pattern and exhausting emissions. The developing system will be installed on the targeted motorcycle. The recorded data will further transferred into the computer to analyze and develop the driving cycle and the emission factors.

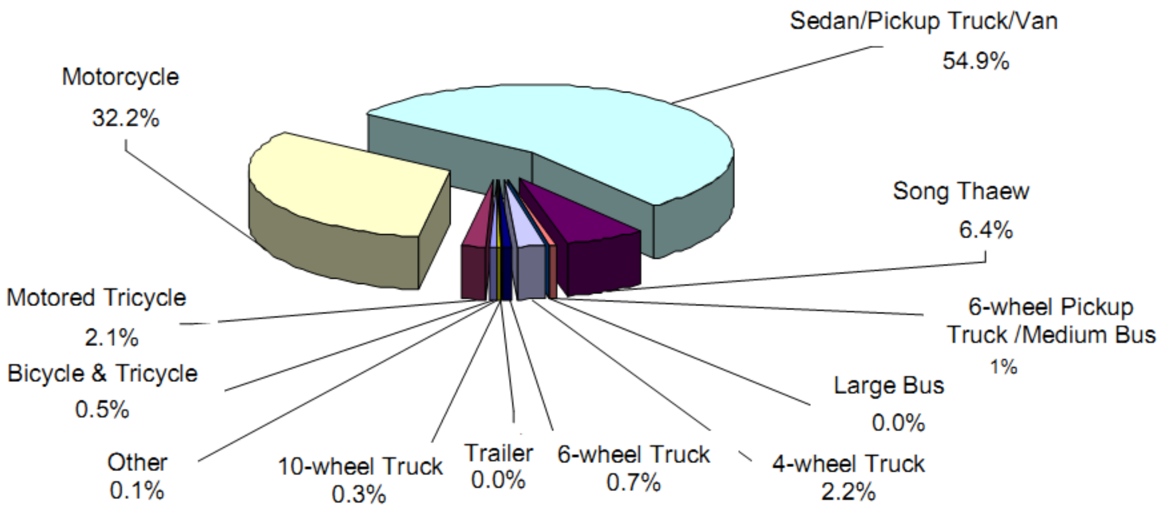
1.2 Objectives

This research has 3 main following objectives.

- To develop the onboard measurement system to measure driving pattern and exhaust emissions
- To measure and collect driving pattern and exhaust emissions of motorcycle driving in Khon Kaen city
- To construct the driving cycle and emission factors of motorcycle for Khon Kaen city

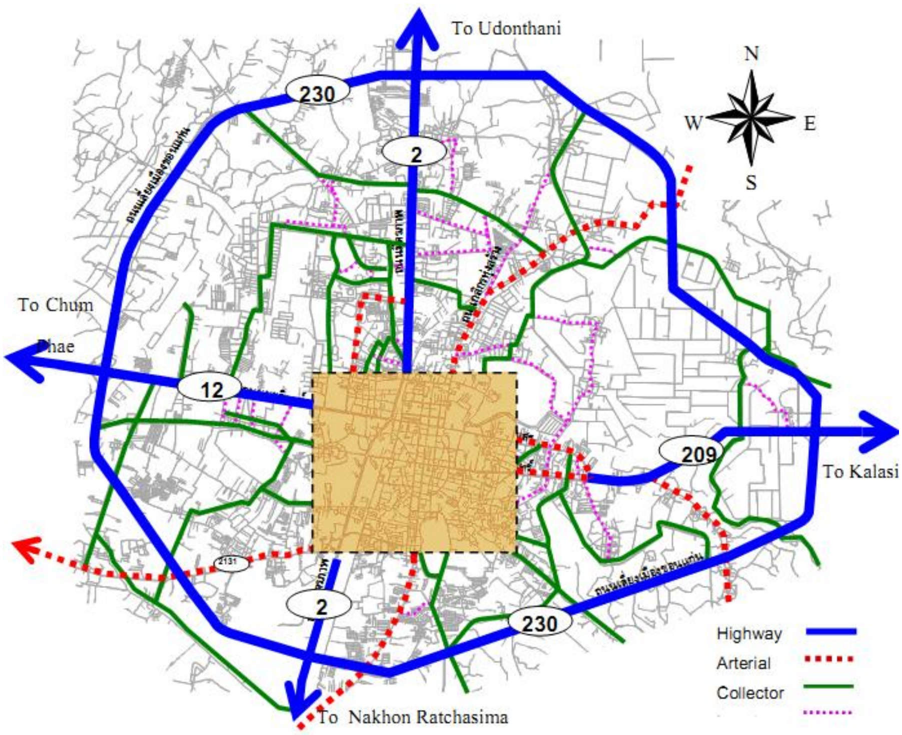
1.3 Study Area

Khon Kaen City was selected as a study area to apply the developing onboard measurement system since there are a huge number of motorcycles traveling in Khon Kaen City and also a high percentage of mode sharing, about 30% of mode share as displayed in Figure 1.1 (SIRDC, 2008). Khon Kaen city is one of regional provinces that has currently encountered with traffic congestion problem, especially on peak hours. The entire road network that serves for the whole Khon Kaen city is shown in Figure 1.2. This research focuses on the road network of Central Business District (CBD) of Khon Kaen City as presented in Figure 1.3. Since the ring road around the city is mostly used by inter-city traffic and logistic vehicles that want to escape from traffic congestion inside the city. There is not so much traffic volume, especially motorcycles, used this ring road network.



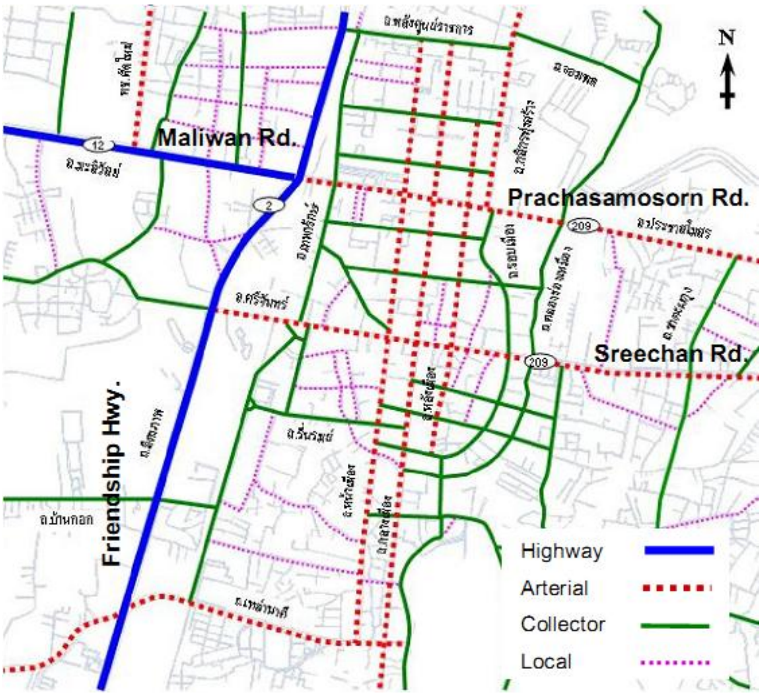
Source: SIRDC, 2008

Figure 1.1 Mode Share of Travel Trip in Khon Kaen City



Source: SIRDC, 2008

Figure 1.2 Road Network of Whole Khon Kaen city



Source: SIRDC, 2008

Figure 1.3 Road Network of CBD of Khon Kaen city

1.4 Literature Review

1.4.1 Researches on Onboard Exhaust Emissions Measurement

Yu (1998) collected the on-road emission data of highways in Houston area by using a remote emission sensor. The collected data was applied to develop the exhaust emission model to estimate CO and HC emissions. The model establishes relationships between the on-road vehicle exhaust emission rates and a vehicle's instantaneous speed profile. The emission model can be used to estimate the emission implications of alternative traffic control and management strategies. Hence, this emission model is ideal for traffic simulation and optimization analyses.

Sivanandan et al. (2008) used a portable gas analyzer to measure the tailpipe emissions (CO, HC and NO) of the test vehicles, including the motorized two-wheelers, three-wheelers and cars by short intervals of time. The test vehicles run under the lane restricted and the lane-less flow conditions in heterogeneous traffic in Chennai city, India. Instantaneous speeds of the vehicles were measured using an optical sensor fixed to the wheel. The results concluded that lane restricted flow generally produced reduced levels of tailpipe emissions compared to lane-less conditions.

1.4.2 Registered Driving Cycles

The governments in many countries use the registered driving cycle to restrict air pollutant from the vehicles. As earlier stated, the emissions of a vehicle can be measured from testing the chassis dynamometer following to the registered driving cycle and the exhaust emissions must not exceed the governmental standard level. Many countries have their own registered driving cycle, e.g. the US Federal Test Procedure 75 (US FTP 75) of US, the Economic Commission for Europe Cycle (ECE) of European, and the Japan 10-15 mode cycle of Japan (Ecopoint, 1997).

However, these driving cycles may not be the appropriate representatives for other countries that have the differences in the vehicle engine types, driving behaviors as well as traffic conditions. Therefore, to estimate accurately the emissions and fuel consumption from transport sector, they should develop their own driving cycle that is suitable to their specific condition of engine type, driving behavior and traffic condition.

1.4.3 Researches on Driving Cycle Development

Kent et al. (1978) have developed a Sydney's driving cycle. They used an average vehicle speed, the acceleration, and a time period of stop time as the target parameters. The objective of their work was to evaluate the emissions in the morning period of Sydney when encountered the traffic congestion.

Watson et al. (1982) have developed a driving cycle for Melbourne as the same way of previous research of Kent et al. (1978) but adding the fuel consumption assessment to their analysis. Two new target parameters, a Positive Kinetic Energy (PKE) and a time spent at each speed range, were also included in this study.

Ergeneman et al. (1997) have constructed a driving cycle for Istanbul, Turkey that consists of a speed, an acceleration, a deceleration, a stop time, and an average vehicle speed. They applied the variables being a group of parameters for micro-trip selection. They have compared the constructed driving cycle to the ECE driving cycle then found that the results of exhausted emission and fuel consumption were different.

Tong et al. (1999) have constructed a car driving cycle for a down town area of Hong Kong. Their target parameters were an average speed, an average running speed, an average acceleration, an average deceleration, an average driving distance, a time ratio of driving mode, a time spent at idle, a number of changing driving mode, and a Positive Kinetic Energy (PKE). Their constructing method was to select micro-trips randomly then calculated the target parameters from a selected driving cycle. The best selected driving cycle must have its target parameters closest to the parameters from a set of real data.

Chen et al. (2003) and Tsai et al. (2005) have developed a driving cycle for the motorcycles in Taiwan. The cycle was obtained from a linear combination of the randomly selected micro-trips from the real speed-time data. The target parameters that were used to justify the best driving cycle were a driving distance, a time spent in driving, an average speed, an average running speed, an acceleration, a deceleration, a percentage of time spent in idle, a time percentage of acceleration condition, a time percentage of deceleration condition, a time percentage of constant speed, and a number of changing driving mode.

Wang et al. (2008) have developed the car driving cycles for 11 states in China. Their target parameters were quite similar to previous research in Taiwan, Chen et al. (2003) and Tsai et al. (2005), except adding the Positive Kinetic Energy (PKE) with frequency of acceleration and deceleration. The cycle still was generated from the randomly selected micro-trips. The developed cycle has a time duration about 900-1,200 seconds.

Tamsanya and Chungpaibulpatana (2009) have constructed a car driving cycle in Bangkok by using 10 target parameters for comparison with the real driving condition. The parameters were quit same as the previous researches but the process to select micro-trips was different. This study divided speed-time data into speed ranges and each speed range will send its micro-trips into the combination of a driving cycle and the used one was cut off. So, there was no redundant micro-trip in the same driving cycle.

As result of reviewing of previous developed driving cycles, it found that the driving cycles developed from each city are different due to the differences in driving behavior and traffic condition of each city. To estimate accurately the emissions and fuel consumption from transport sector, each city needs to develop its own driving cycle. Bangkok driving cycle has been developed but it may not be an appropriate representative of other cities in Thailand.

CHAPTER 2 METHODOLOGY

This chapter explains the procedure of research method as displayed in Figure 2.1. Each method for each part of the research will be expressed as the following.

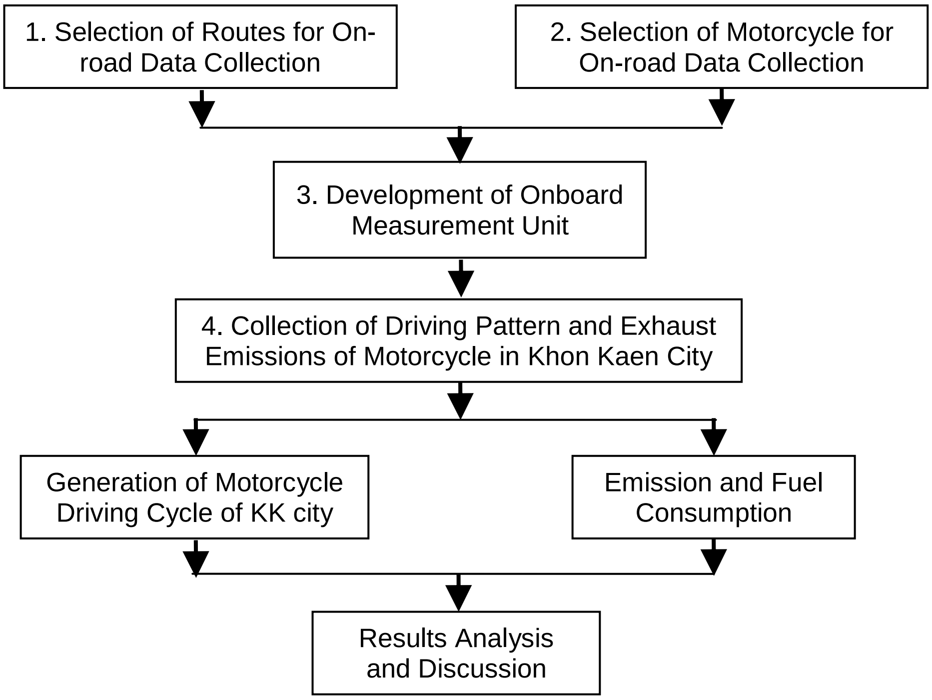
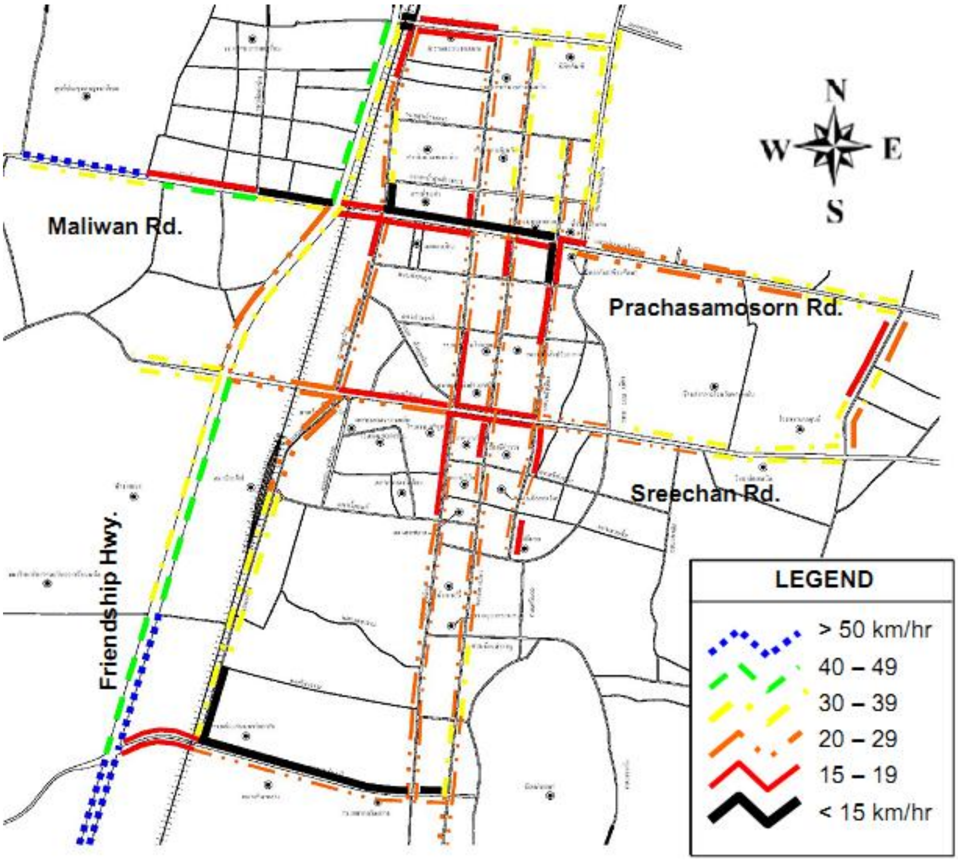


Figure 2.1 Research Procedure

2.1 Selection of Routes for On-road Data Collection

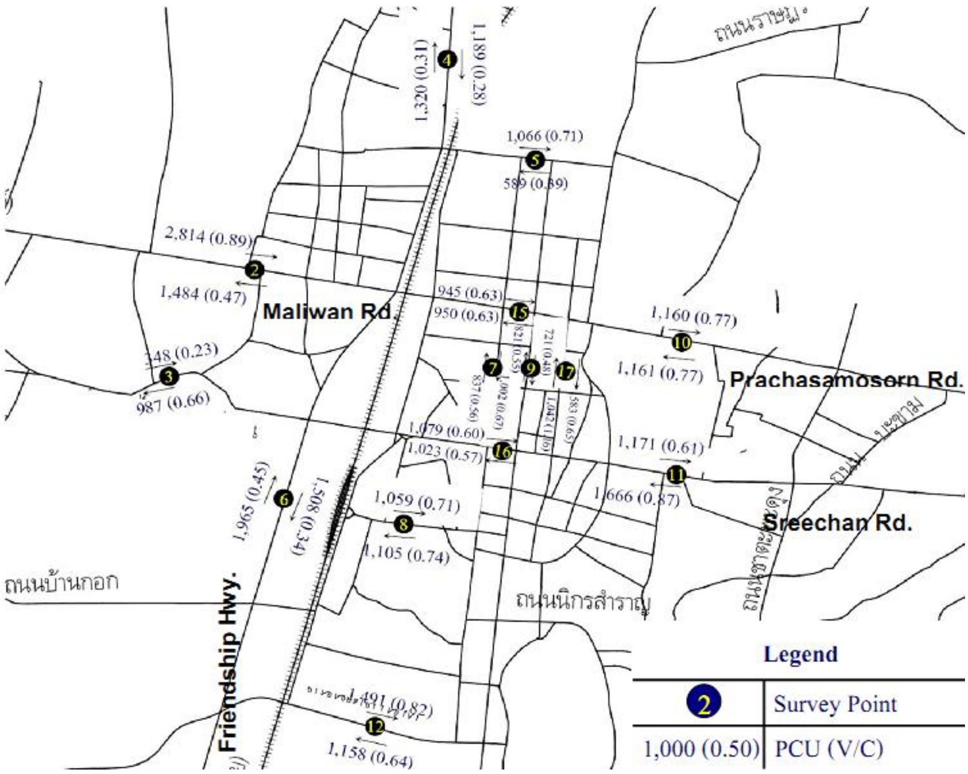
To achieve the good driving cycle representing all traffic and road conditions of Khon Kaen city, it is however impossible to drive the experimental motorcycle along all routes of Khon Kaen City road network. This research therefore selected a set of appropriated routes which are able to represent all traffic and road conditions in Khon Kaen city.

The road network of CBD of Khon Kaen city was categorized into 4 classes of road hierarchy, highway, arterial, collector, and local as shown in Figure 1.3. This research initially selected the possible routes from two major classes, highway and arterial, of road network of Khon Kaen city because there is low traffic volume on collectors and locals. Then, the representative routes of highway and arterials were selected in accordance with travel speed and traffic volume along those routes. This research applied the data of travel speed and traffic volume surveyed during peak hours by SIRDC (2008) as displayed in Figure 2.2 and 2.3.



Source: SIRDC, 2008

Figure 2.2 Average Travel Speed of Khon Kaen City Network



Source: SIRDC, 2008

Figure 2.3 Traffic Volume and V/C of Khon Kaen City Network

Consequently, the five routes were selected as illustrated in Table 2.1. The 3.9 km section of Friendship Hwy. was selected due to a representative of urban route with travel speed over 40 km/hr with a high traffic volume. The 3.0 km section of Sreechan Rd. was selected as a representative route with 30-39 km/hr travel speed with high traffic volume. The 3.8 km section of NhaMuang Rd. was selected as a representative route with 20-29 km/hr travel speed. The 2.8 km section of Prachasamosorn Rd. and 1.0 km section of Maliwan Rd. was selected as a representative route with travel speed under 20 km/hr. Thus, total route distance for on-board data collection is 14.5 km. Their locations are displayed in Figure 2.4.

Table 2.1 Selected Routes for On-road Data Collection

No.	Selected Route	Distance (km)	Travel Speed, km/hr (LOS)	Traffic Volume, PCU (V/C)
1.	Friendship Hwy.	3.9	≥ 50 (A) 40 – 49 (B)	1,737 (0.40)
2.	Sreechan Rd.	3.0	30 – 39 (C)	1,235 (0.66)
3.	NhaMuang Rd.	3.8	20 – 29 (D)	920 (0.62)
4.	Prachasamosorn Rd.	2.8	15 – 19 (E) < 15 (F)	1,054 (0.7)
5.	Maliwan Rd.	1.0	15 – 19 (E) < 15 (F)	2,149 (0.68)

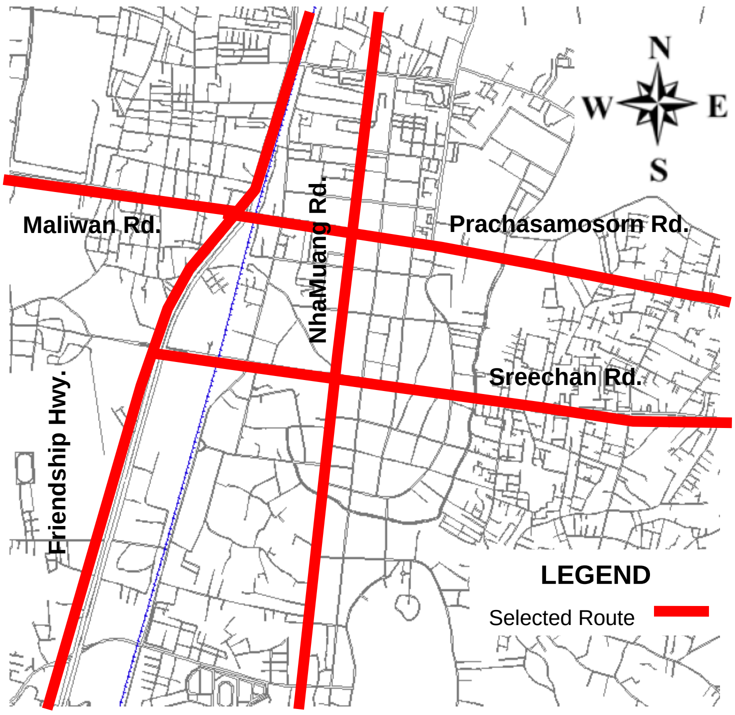


Figure 2.4 Selected Routes for On-road Data Collection

2.2 Selection of Motorcycle for On-road Data Collection

To select the model of motorcycle to be used in this research for on-road data collection, the consideration must be based on the fact that it can represent those motorcycles that are mostly driven in Khon Kaen city traffic. The engine capacity of motorcycle, identified by manufacture and model, may produce different speed pattern especially in the acceleration and deceleration. Thus, the numbers of motorcycle registered in Khon Kaen city was taken into consideration. Table 2.2 presents the number of motorcycle registered in Khon Kaen city during January to September 2009 by manufacture and engine capacity. This statistic was given by the Khon Kaen Land Transportation Authority Office (2009).

Table 2.2 Khon Kaen Motorcycle Registration by Manufacture and Engine Capacity

No.	Manufacture	Engine Capacity (cc.)				Total
		<100	101-125	126-150	>151	
1	Honda	6,499 (22.4%)	12,884 (44.4%)	132 (0.5%)	63 (0.2%)	19,578
2	Kawasaki	-	197 (0.7%)	2 (0.0%)	10 (0.0%)	209
3	Platinum	-	24 (0.1%)	17 (0.1%)	3 (0.0%)	44
4	Suzuki	-	708 (2.4%)	-	-	708
5	Yamaha	7 (0.0%)	8,117 (28.0%)	372 (1.3%)	-	8,496
	Total	6,506	21,930	523	76	**29,035**

Source: Khon Kaen Land Transportation Authority Office, 2009

The table shows that Honda with 101-125 cc. engine capacity was the first highest proportion for about 44% of the total registered motorcycles. The Yamaha with 101-125 cc. engine capacity was the second highest proportion account for 28% of the total registered motorcycles. Once it considered into the market share, there were two models, Wave and Click Models, which were popular in category of 101-125 cc. of Honda. In case of Yamaha's market share, Fino was the most popular model in category of 101-125 cc. of Yamaha. In addition, the recent and future market share of motorcycle sale was considered. Fino was recently popular and the trend of city model, like Fino, might become more popular in near future because it can be matched with life-style of people in the big city with smart characteristic and easy and comfortable driving from automatic transmission.

Therefore, this research selected the Fino model, a popular 115 cc. model of Yamaha. The selected motorcycle for on-board data collection was an used Yamaha Fino of year 2008, automatic transmission with capacity of 115 cc. as shown in Figure 2.5. The motorcycle was being equipped with a developing onboard measurement system.

Figure 2.5 Selected Used Motorcycle

2.3 Development of Onboard Measurement System

This research developed the onboard measurement system by integrating many measurement units to measure and to record the instantaneous driving pattern and exhaust emissions of motorcycle. The developed onboard measurement system consists of many units, including the data logger for processing and recording the collected data, a rear wheel speed sensor for measuring the speed, a GPS for measuring the position, an exhaust gas analyzer for measuring an amount of exhaust emissions, an engine revolution sensor for measuring an engine speed, air flow sensor for measuring a mass flow rate of intake air via a manifold of testing motorcycle. The position of installing the system units on motorcycle is displayed in Figure 2.6. The component and duty of system units are described in detail as below.

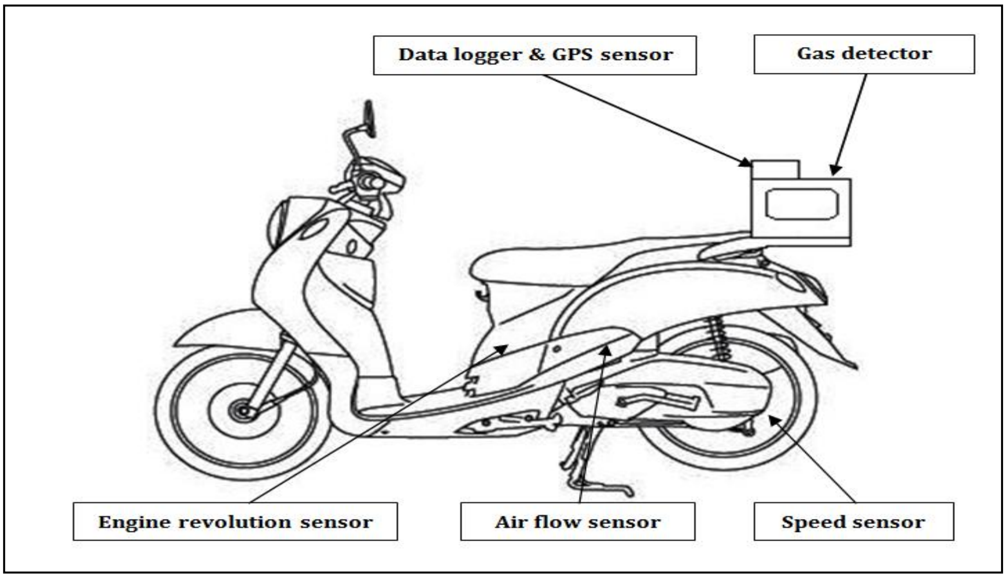


Figure 2.6 Component Units of Developed Onboard Measurement System

2.3.1 Data Logger

The data logger was designed and developed to process the data from several measurement units and to record the data into the data storage. It consists of 1) Microcontroller and 2) Memory storage as shown in Figure 27.

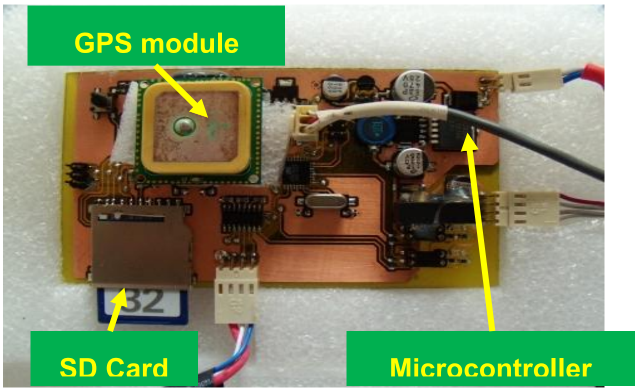


Figure 2.7 Data Logger

Since the microcontroller has to process and record the data within a short period because the data signal from many installing measurement units have to be converted to the recorded format and be recorded into the memory storage in every second. Therefore, the microcontroller for this system was designed for a real-time visibility to the recording data and an easy accessibility by dividing a microcontroller into two parts. The first part processes the data from a rear wheel speed sensor, engine speed sensor, and an air flow sensor. The second part processes the data from an exhaust gas detector, a GPS module as well as records all data into memory card. The transferring data among a microcontroller and installing measurement units presents by the detail diagram of onboard measurement system in Figure 2.8.

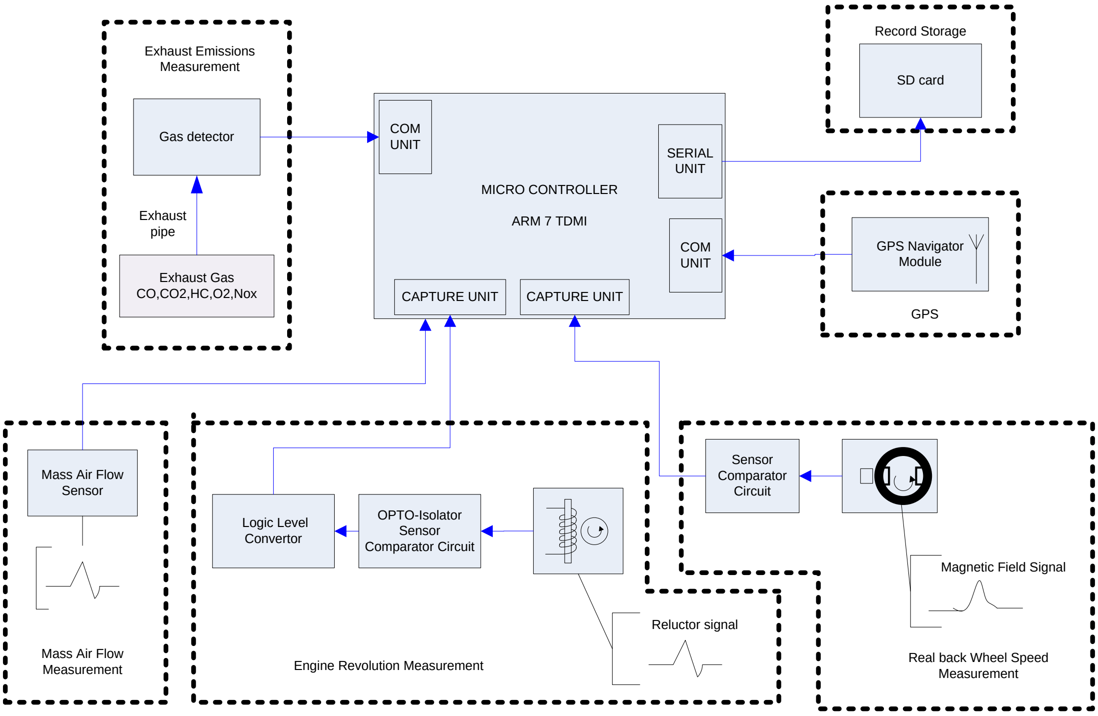


Figure 2.8 Detail Diagram of Onboard Measurement System

2.3.2 Rear Wheel Speed Sensor

To measure the speed of the motorcycle, a magnetic sensor was installed on the rear wheel of the motorcycle to detect the wheel rotation by a second. The magnetic poles were installed on the rear wheel as displayed in Figure 2.9. While the wheel is rotating, The magnetic pole will product the pulse. The pulse is then converted to the voltage signal by using a voltage converter circuit. Finally, the microcontroller will convert this voltage signal to speed-time data.

Figure 2.9 Magnetic Sensor on Rear Wheel of Motorcycle

2.3.3 Global Positioning System

To measure the current position and speed of the driving motorcycle, the GPS module is installed on the high position of a motorcycle. The installed GPS has accuracy of ± 1.0 meter and ± 0.1 m/sec for position and speed, respectively. The microcontroller will transfer the data of position and speed of driving motorcycle to the memory storage in every second.

2.3.4 Exhaust Gas Analyzer

To measure an amount of emissions and air, including CO, CO_2, O_2, HC, and NO_x, the mobile exhaust gas analyzer, INFRALYT SMART model as displayed in Figure 2.10, was installed on the rear side of motorcycle because the suction tube of the equipment can be connected to the exhaust pipe of motorcycle as shown in Figure 2.11.

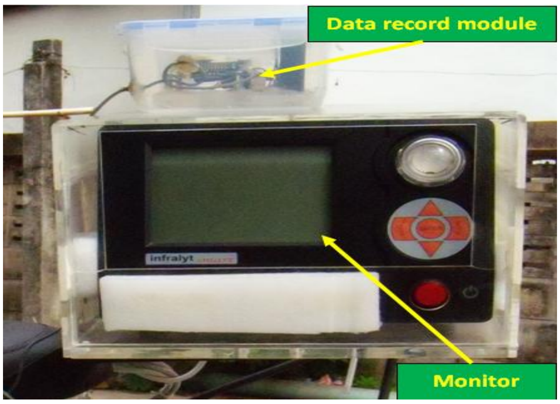


Figure 2.10 Emissions Measuring Equipment

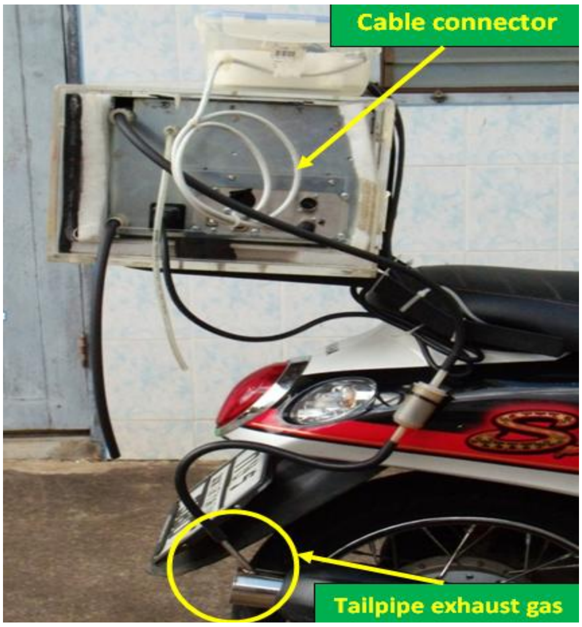


Figure 2.11 Emissions Measuring Unit Installed on Rear Side of Motorcycle

The suction tube will suck the exhaust gas into the equipment to analyze the amount of emissions. The analyzed data will be displayed on the monitor of equipment and recorded in to the memory storage by second. The equipment would be warmed up and set a zero calibration every time before conducting a driving test.

2.3.5 Engine Revolution Sensor

The engine revolution signal will be measured from the extracted signal data of the Capacitor Discharge Ignition (CDI) in the control unit of the motorcycle as shown in Figure 2.12. The microcontroller will receive the signal data from the sensor, convert the voltage signal to the engine speed data and record in the memory storage. This engine speed data will be further used for the research purpose on engine analysis.

Figure 2.12 Engine Revolution Sensor from Capacitor Discharge Ignition

2.3.6 Air flow Sensor

The air flow rate into intake manifold can be measured by the air flow sensor installing at entrance of the carburetor as displayed in Figure 2.13. The sensor can measure the amount of flow as high as 0-200 standard liters per minute (SLPM). The microcontroller will convert this voltage signal to the data of air flow rate into intake manifold and record the data to the memory storage.

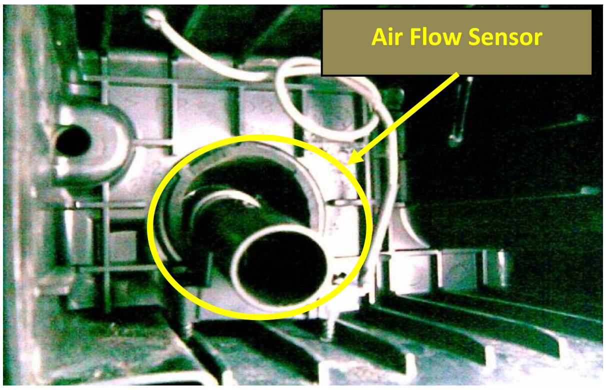


Figure 2.13 Air Flow Sensor Measuring Air Flow Entering Carburetor

2.3.7 Validation of Developed Onboard Measurement System

To validate the accuracy of measuring driving speed and exhaust emissions of developed measurement system, the run test was conducted by driving the motorcycle on selected route. The results of validation of driving speed and exhaust emissions measurement are displayed in Table 2.3 and Figure 2.14, respectively.

Table 2.3 Result of Validation of Rear Wheel Speed Sensor

Testing Speed	Dist.	Travel Time	Speed Reference	Speed Developed System	Error
(km/hr)	(m)	(s)	(km/h)	(km/h)	(%)
30	500	60.07	29.97	30.70	2.45
30	500	56.61	31.80	31.89	0.29
30	1000	113.85	31.62	31.86	0.76
30	1000	118.44	30.40	30.57	0.58
50	500	35.05	51.36	50.39	-1.9
50	500	35.59	50.58	51.33	1.49
50	1000	71.55	50.31	50.48	0.33
50	1000	71.82	50.13	50.47	0.69

As the result of testing accuracy of speed sensor, it implies that the driving speed measured by the developed onboard measurement system was absolutely equal to the reference speed that measured by the stop watch with an average error less than 1%.

To determine the accuracy of exhaust emissions measurement unit, The instantaneous driving speed proifle is plotted comparatively with amount of exhaust emissions as shown in Figure 2.14. The trend of the graph is described that once the speed of driving motorcycle increased with a constant acceleration, an amount of emitted CO_2 increased as displayed by Figure 2.14-(a) and (c). It explains that during a speed increasing, the engine combusts more gasoline and air, it produced more amount of CO_2. However, once the driving motorcycle increased a speed with increasing acceleration, an amount of emitted CO and NO_x increased as shown by Figure 2.14-(a), (b), and (f). Since an increasing acceleration caused the imperfect combustion emitted more an amount of CO and NO_x. Vice versa, while a driving motorcycle decelerated, an amount of emitted HC and O_2 increased as shown by Figure 2.14-(a), (b), and (e). Since the deceleration reduced the engine combustion, the remaining combusted gasoline and air therefore increased. Consequently, it implies that driving behavior highly influences to amount of emitted exhaust gas.

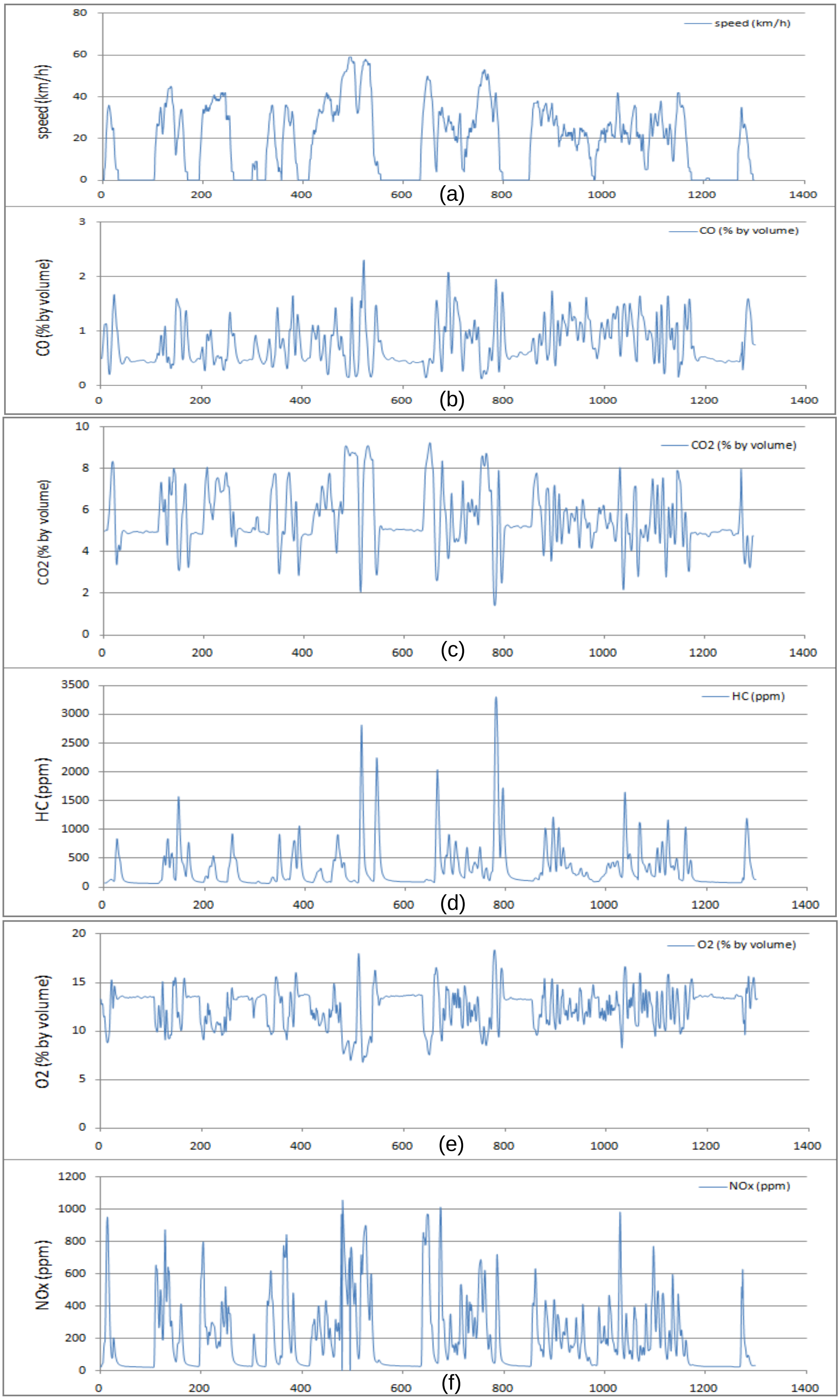


Figure 2.14 Instantaneous Speed Profile Comparing with Exhaust Emissions (a) Speed, (b) CO, (c) CO_2, (d) HC, (e) O_2, (f) NO_x

CHAPTER 3 Development Applications in Khon Kaen City

This chapter presents the application of developed onboard measurement system to measure and collect the driving pattern and the exhaust emissions. The collected data was further used to develop the driving cycle and emission factors for the motorcycle driving in Khon Kaen City.

3.1 On-road Data Collection

The developed onboard measurement system was applied to collect the on-road data, including driving pattern and exhaust emissions, of motorcycle driving on Khon Kaen City road network. The selected motorcycle was drove on the selected routes during the morning peak hours (7.00-10.00 AM) in weekday and weekend period. The Table 3.1 shows the schedule of on-road data collection. Totally, the on-road data was collected for 210 hours.

Table 3.1 Schedule of On-road Data Collection

No.	Selected Routes	Distance (km)	Time	Day	Total Time (hr.)
1	Friendship Hwy.	3.9	7:00-9:00	21	42
2	Sreechan Rd.	3.0	7:00-9:00	21	42
3	NhaMuang Rd.	3.8	7:00-9:00	21	42
4	Prachasamosorn Rd.	2.8	7:00-9:00	21	42
5	Maliwan Rd.	1.0	7:00-9:00	21	42
	Sum	13.5		105	210

3.1.1 Analysis of Collected Speed-time Data

In general, the development of driving cycle is to simulate the driving pattern of a vehicle in a form of a speed-time graph. The graph displays a various pattern of the acceleration, a deceleration, and a stop rate. These values represent the vehicle driving behavior that influences in the difference of fuel consumption and emission rates. To establish the best motorcycle driving cycle for Khon Kaen City, this study considered the nine target parameters as displayed in Table 3.2. These parameters were used as the selection criteria. The difference of target parameters between a constructed driving cycle and collected real data would be minimized.

As results of collecting the speed-time data, the target parameters for each selected routes by weekdays and weekend have been analyzed as shown in Table 3.3 and 3.4, respectively. It reveals that Sreechan Road had the lowest average speeds during weekdays and weekend, V_{avg} = 21.281 km/h and 23.964 km/h, respectively. It means that the Sreechan road encountered the most critical traffic congestion during all periods.

Table 3.2 Considered Target Parameters

Parameter	Symbol	Definition
1.Average speed, km/h	V_{avg}	Average speed in a cycle, including idle periods
2.Average running speed, km/h	$V1_{avg}$	Average speed in a cycle, excluding idle periods
3.Average acceleration, m/s^2	Acc_{avg}	Rate of change of speed above 0.27 m/s^2
4.Average deceleration, m/s^2	Dcc_{avg}	Rate of change of speed below - 0.27 m/s^2
5.Time spent in acceleration, %	Acc	Fraction of time accelerating for ≥ 0.27 m/s^2
6.Time spent in deceleration, %	Dec	Fraction of time decelerating for ≤ 0.27 m/s^2
7.Time spent at Idle, %	Idle	Fraction of time having zero speed
8.Time spent at Cruise, %	Cruise	Fraction of time having absolute speed changes ≤ 0.27 m/s^2
9.Positive kinetic energy	PKE	Positive acceleration kinetic energy

Vice versa, the Friendship Highway had the highest average speed, V_{avg} = 29.519 km/h and 31.770 km/h. It means that the Friendship Highway provided the highest mobility at all periods. Once it compares the target parameters between weekdays and weekend, it found that they are not obviously different, even the traffic condition in weekdays revealed more congested than weekend. It is therefore practical to combine the target parameters of weekdays and weekend for developing driving cycle. The summarized target parameters are displayed by time period as shown in Table 3.5.

Table 3.3 Analyzed Target Parameters of Weekdays

Selected Route	V_{avg} (km/h)	$V1_{avg}$ (km/h)	Acc_{avg} (m/s^2)	Dec_{avg} (m/s^2)	Idle (%)	Cruise (%)	Acc (%)	Dec (%)	PKE (m/s^2)
1. Friendship Hwy.	29.519	39.583	0.651	-0.679	24.771	17.928	29.270	28.031	0.432
2. Sreechan Rd.	21.281	28.303	0.683	-0.717	23.870	15.002	31.296	29.831	0.510
3. NhaMuang Rd.	24.308	30.954	0.636	-0.686	20.687	17.509	32.062	29.743	0.454
4.Prachasamosorn & Maliwan Rd.	23.366	28.954	0.654	-0.686	18.406	17.236	32.951	31.407	0.471

Table 3.4 Analyzed Target Parameters of Weekend

Selected Route	V_{avg} (km/h)	$V1_{avg}$ (km/h)	Acc_{avg} (m/s^2)	Dec_{avg} (m/s^2)	Idle (%)	Cruise (%)	Acc (%)	Dec (%)	PKE (m/s^2)
1. Friendship Hwy.	31.770	42.639	0.646	-0.679	24.809	19.553	28.517	27.121	0.404
2. Sreechan Rd.	23.964	32.116	0.672	-0.737	24.511	15.831	31.201	28.457	0.483
3. NhaMuang Rd.	25.622	30.223	0.561	-0.666	14.523	21.841	34.553	29.083	0.390
4. Prachasamosorn & Maliwan Rd.	25.603	32.623	0.672	-0.747	20.602	17.493	32.588	29.317	0.464

Table 3.5 Summarized Target Parameters by time period

Target parameters	Weekdays	Weekend	a Week
V_{avg} (km/h)	24.308	26.699	24.968
$V1_{avg}$ (km/h)	30.954	34.180	31.842
Acc_{avg} (m/s^2)	0.636	0.636	0.636
Dec_{avg} (m/s^2)	-0.686	-0.708	-0.692
Idle (%)	20.687	21.095	20.799
Cruise (%)	17.509	18.667	17.828
Acc (%)	32.062	31.735	31.971
Dec (%)	29.743	28.503	29.401
PKE (m/s^2)	0.454	0.433	0.448

3.2 Development of Motorcycle Driving Cycle

The driving cycle would be constructed by randomly selecting the micro-trips from the collected speed-time data. Once a driving cycle has been generated, its target parameters would be compared to those of the real collected data. The most appropriate driving cycle is one that had the smallest differences. The procedure of driving cycle development could be explained as the following.

3.2.1 Micro-trips Classification

In general, the driving cycle is a linear combination of the several micro-trips. The micro-trip is the sequence of driving data between a successive stop, more than 3 seconds, in the trip. The micro-trips would be arranged together by their average speed ranges to develop a driving cycle. In this study, the micro-trips have been classified into five speed ranges which are $0 < v \leq 10$ km/h, $10 < v \leq 20$ km/h, $20 < v \leq 30$ km/h, $30 < v \leq 40$ km/h, and $v > 40$ km/h. Once the five ranges of the micro-trips data base have been constructed, the time fraction of the micro-trips by a speed range would be calculated as shown in Table 3.6. This time fraction of constructed cycle would be as same as the real collected data. Therefore, to achieve the previous mentioned procedure, the algorithm for a driving cycle development is necessary.

Table 3.6 Time of Micro-trip by Speed Range

Speed Range (km/h)	Micro-trip Time (s)	Time fraction (%)
$0 < v \leq 10$	2,149	0.90
$10 < v \leq 20$	8,778	3.69
$20 < v \leq 30$	94,603	39.80
$30 < v \leq 40$	97,051	40.83
$v > 40$	35,089	14.76

3.2.2 Algorithm for Driving Cycle Development

The previous research on driving cycle in Thailand was the development of driving cycle of passenger car in Bangkok (Tamsanya and Chungpaibulpatana, 2008). The algorithm of driving cycle development of that previous study was used as a prototype of this study. The algorithm for developing a driving cycle is displayed in Figure 3.1.

In the algorithm process, the random selected micro-trips were arranged in the pre-defined driving cycle duration. This study used 1,200 sec. for the duration of cycle time since this duration was widely used in many developed driving cycles. The duration of cycle time normally was during 600-1,500 sec. according to the standard of emission testing. The programming language was used to arrange all micro-trips into the five speed ranges and to calculate the 9 target parameters. The time fractions of the micro-trip and the idle time were also determined.

In particular, the time fraction of micro-trip and idle time in this approach would be the same of the real condition. Therefore during the driving cycle generation, the micro-trips were randomly picked up from the slower to faster speed ranges and the running time together with idle time could not exceed the time fraction from the collected existing data. Once the micro-trip has been completely connected into 5 speed ranges, its 9 target parameters were calculated again to compare with those of the collected existing data. The average error (%) could be calculated from the Equation 3.1.

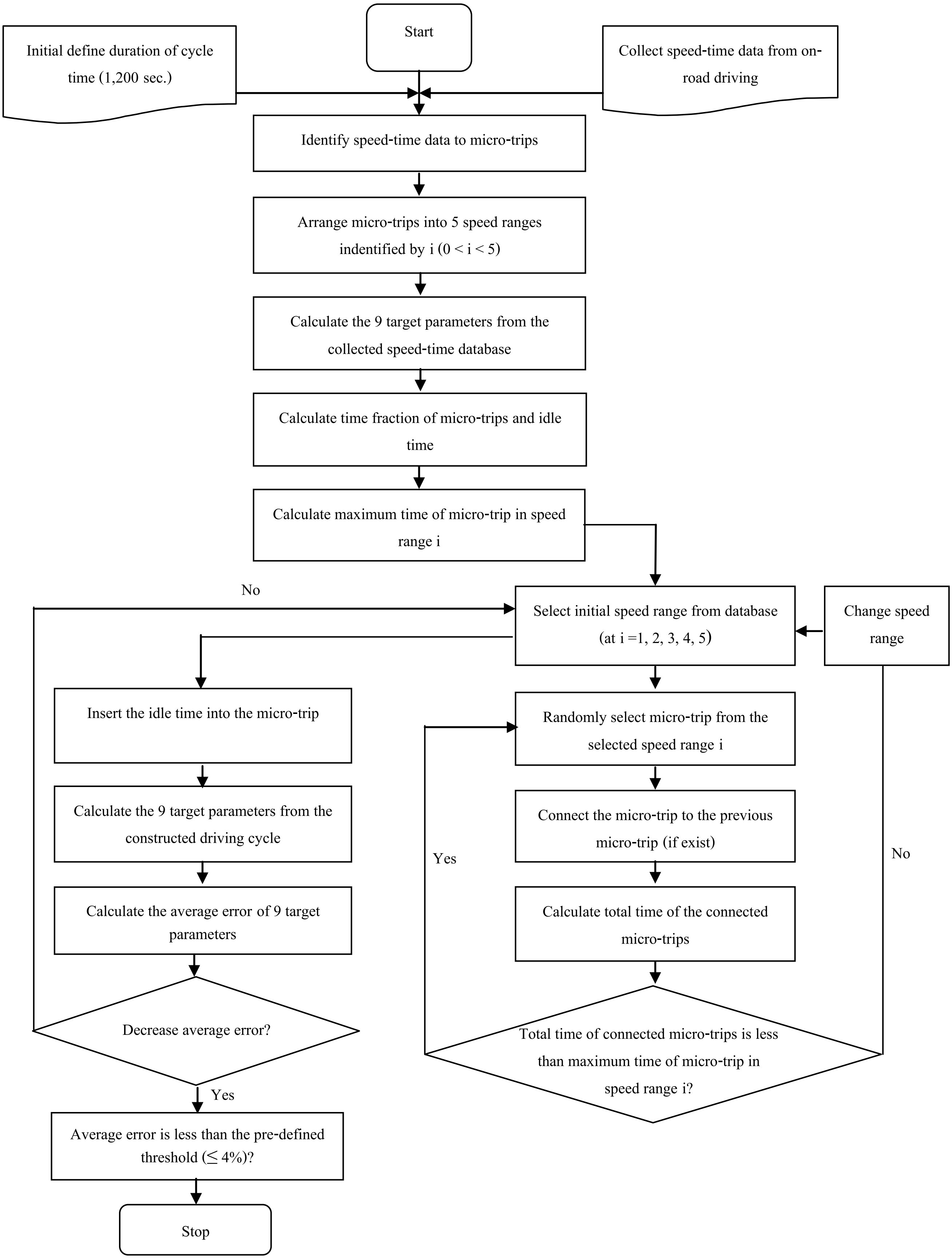


Figure 3.1 Algorithm for Driving Cycle Development

$$E\ (\%) = \frac{\sum_{i=1}^{9} d_i}{9} \tag{3.1}$$

where as

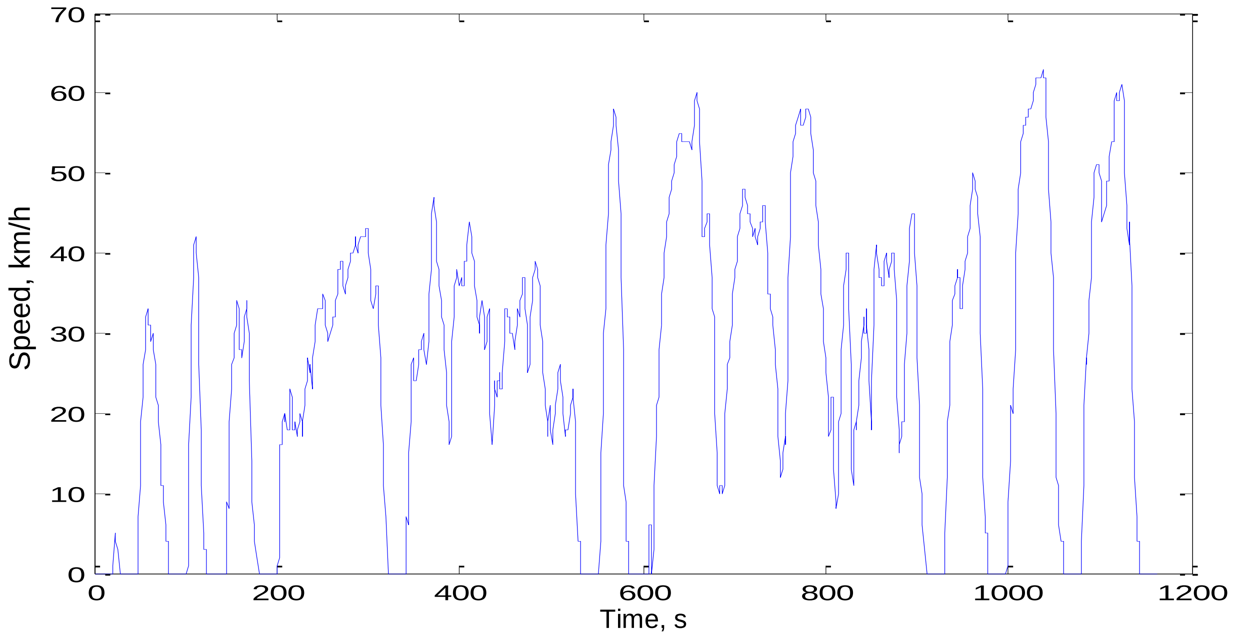
$$d_i(\%) = \left(\frac{Parameter\_i_{developed} - Parameter\_i_{collected}}{Parameter\_i_{collected}}\right) x100$$

This average error will be used as criteria to select the most appropriate driving cycle. The processes in algorithm would be repeated if the average error increases. The process would be stopped if the average error was not excess a pre-defined threshold, 4 %.

3.2.3 Result of Driving Cycle Development

As the accuracy of developed algorithm, the average error of the constructed driving cycle was only about 2 % that is similar to the previous algorithm (Tamsanya and Chungpaibulpatana, 2008). This is because of the fraction of running and idle times in the developed cycle similar to that of collected existing data. Additionally, all micro-trips are still maintained in the process of random selection.

As result of driving cycle development, the driving cycle of motorcycle in Khon Kaen city was developed as shown in Figure 3.2. Its target parameters were quite close to that of the collected existing data with 2.113% average error. This driving cycle has the highest speed (63 km/h), the highest acceleration (2.778 m/s^2), the highest deceleration (-2.787 m/s^2) with its duration of cycle time, 1,164 seconds, and distance of 8.113 km.



V_{max}= 63 km/h; Acc_{max}= 2.778 m/s^2; Dec_{max}= -2.787 m/s^2; length = 1,164 s; distance= 8.113km

Figure 3.2 Developed driving cycle of motorcycle in Khon Kaen city

3.2.4 Comparison of Motorcycle Driving Cycle of Khon Kaen City with Others

Table 3.7 shows the developed Khon Kaen motorcycle driving cycle (KMDC) comparing with the driving cycles with other cities, including Bangkok Driving Cycle (BDC), European driving cycle (ECE), and Taiwan Motorcycle driving cycle (TMDC). The figures in parentheses of the driving cycles of other cities show the percentage of differences of parameters comparing with Khon Kaen motorcycle driving cycle. It reveals that the parameters of Khon Kaen motorcycle driving cycle are rather different from those of other cities even same country but different city, like Bangkok. The average speed of Khon Kaen, V_{avg} = 24.97 km/h, is higher than the average speed of Bangkok, V_{avg} = 17.4 km/h. It means that the traffic condition of Khon Kaen city is less congested than Bangkok. Average acceleration and average deceleration of Khon Kaen city, Acc_{avg}= 0.636 m/s^{2}and Dec_{avg}= -0.692 m/s^2, are less than those of Bangkok, Acc_{avg}= 0.71 m/s^{2}and Dec_{avg}= -0.71 m/s^2. It indicates that the driving behavior in Khon Kaen city is less aggressive than the driving behavior in Bangkok. Once it therefore applies the driving cycle of Bangkok to estimate the emission and fuel consumption from the motorcycle in Khon Kaen city may lead to the overestimated results.

Table 3.7 Comparison of Developed Driving Cycle with Other Driving Cycles

Target Parameters	Khon Kaen Motorcycle Driving Cycle (KMDC)	Bangkok Driving Cycle (BDC)	European Driving Cycle (ECE)	Taiwan Motorcycle Driving Cycle* (TMDC)
V_{avg}, km/h	24.97	17.4 (-30.3%)	33.4 (33.8%)	16.62 (-33.4%)
$V1_{avg}$, km/h	31.84	28.1 (-11.8%)	44.4 (39.4%)	23.66 (-25.7%)
Acc_{avg}, m/s^2	0.636	0.71 (11.6%)	0.541 (-14.9%)	0.68 (6.9%)
Dec_{avg}, m/s^2	-0.692	-0.71 (-2.6%)	-0.789 (-14%)	-0.68 (1.7%)
%Idle	20.8	37.7 (81.3%)	23.7 (13.9%)	30 (44.2%)
%Cruise	17.83	23.7 (32.9%)	42.2 (136.7%)	22 (23.4%)
%Acc.	31.97	15.2 (-52.5%)	18.3 (-42.8%)	24 (-24.9%)
%Dec.	29.4	23.4 (-20.4%)	15.8 (-46.3%)	24 (-18.4%)
PKE, m/s	0.448	0.45 (-0.4%)	0.224 (-50.0%)	-

3.3 Development of Emission Factors

The collected data of speed profile and exhaust emissions was used to develop the emission factors for the motorcycle driving in Khon Kaen city. The emission factors of each exhaust gas, including CO, CO_2, NO_x, and HC, were developed as displayed in Figure 3.3 to 3.6, respectively.

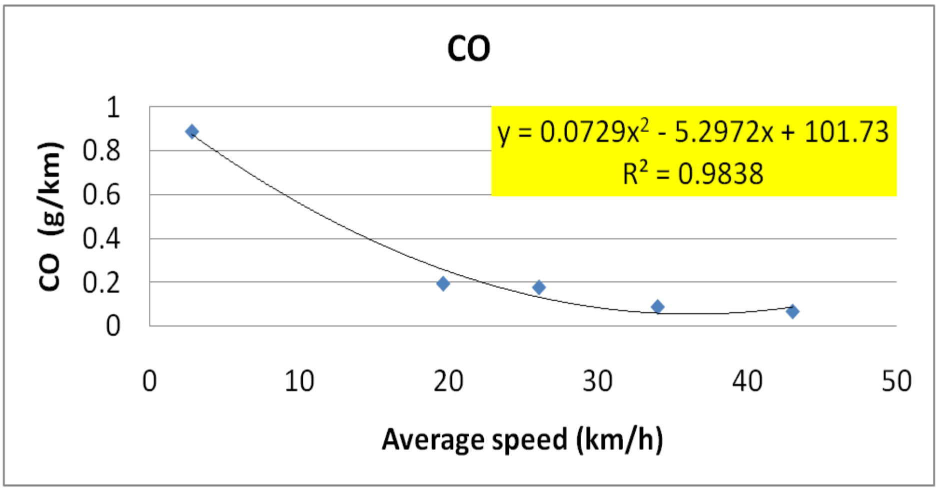


Figure 3.3 CO Emission Factor

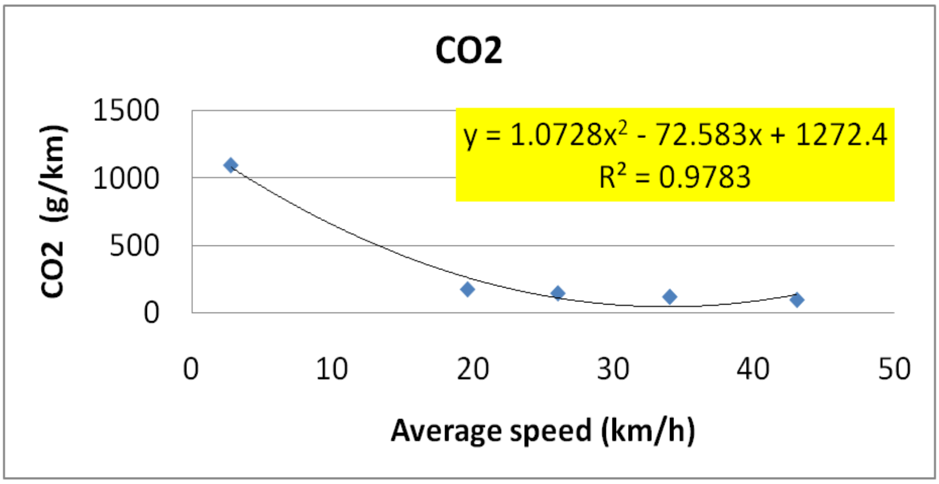


Figure 3.4 CO_2 Emission Factor

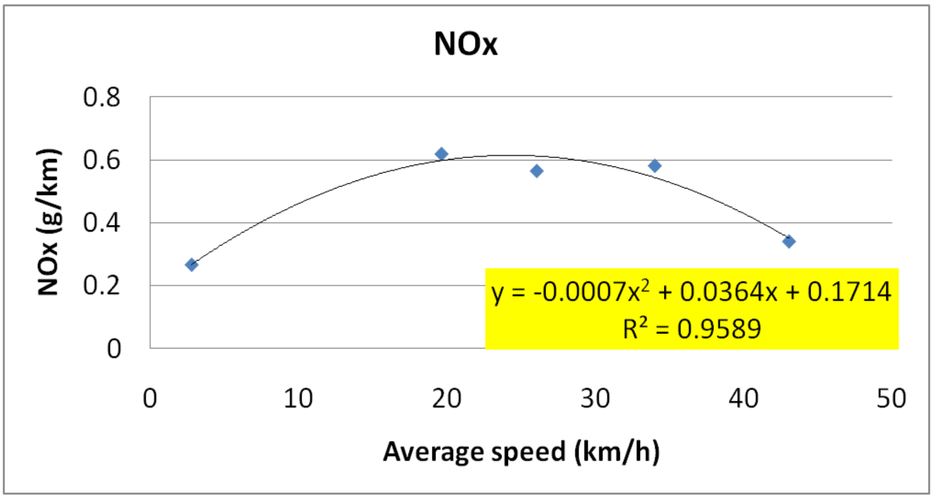


Figure 3.5 NO_x Emission Factor

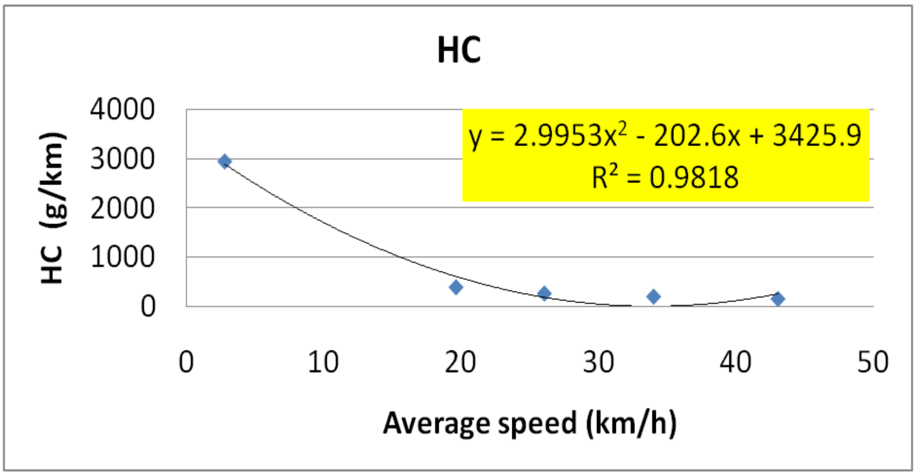


Figure 3.6 HC Emission Factor

CHAPTER 4 CONCLUSIONS AND FURTHER STUDIES

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

4.1 Conclusions

This research was developed the onboard measurement system for installing on motorcycle to measure and record by second the various parameters of a motorcycle driving on the road, including a speed, a position, the exhaust emissions and etc. The microcontroller in data logger unit will process the signal data from several measurement units and record it into the memory storage for transferring to a computer for further analysis. The results of running test shows that the developed equipment collected the data properly as an amount of emissions have a high relative with the speed at that moment. The developed equipment was applied to collect the driving patter and exhaust gas of the testing motorcycle driving on the selected routes of road network of Khon Kaen city. The collected data was further used to develop the driving cycle and emission factors of Khon Kaen city. Therefore, this developed equipment would be useful to install to any type of motorcycle to collect the on-road data in any city for a development of driving cycle and emission factor for each motorcycle type and each city. It would be considered as an economic alternative method that measuring the emissions with real loads rather than a typical method, using the Chassis Dynamometer with simulating loads.

4.2 Further Studies

For the further studies, the on-road measured emissions from developed onboard measurement system will be compared with the emissions measured in the laboratory by a chassis dynamometer. As the next step of onboard measurement system development, the fuel measurement sensor will be integrated with the system to measure the fuel consumption.

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Final Report
Research Grant 2009

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