Development of Automobile Bangkok Driving Cycle for Emissions and Fuel Consumption Assessment

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Abstract: The exhaust emissions and fuel consumption rate of newly registered automobiles in Thailand are now assessed from the European standard driving cycle. The European driving cycle shows the characteristics of vehicles operating conditions for various speeds and acceleration ranges, but does not represent realistic speed-time history of a vehicle in actual traffic. As the driving conditions are different, the assessment results using this driving cycle may not produce realistic amounts of emissions and fuel consumption of the cars under Bangkok traffic which is well known for its congestion. The objective of this research is therefore to propose a method to develop a driving cycle to represent Bangkok traffic. A method for selecting the representative road routes in Bangkok was firstly proposed. A gasoline passenger car equipped with a real time data logger was then used to collect speed-time data under actual traffic along the selected road routes in Bangkok urban area for two months. The driving characteristics were analyzed from the speed-time data and its target driving parameters were defined and evaluated. The method for generating the driving cycle was then proposed and described. After achieving a driving cycle, exhaust emissions and fuel consumption of a vehicle were measured by driving a car on a standard chassis dynamometer according to the obtained Bangkok driving cycle. Comparison of the exhaust emission test and fuel consumption test results obtained from the constructed driving cycle with those obtained from the presently-adopted European standard cycle had been made.

Keywords: Driving Cycle, Driving Pattern, Driving Characteristics, Exhaust Emissions, Fuel Consumption

1. INTRODUCTION

A driving cycle is a time series of vehicle speeds recorded at successive (equally spaced) time points [1]. It represents a typical driving pattern for the population of a city. For emission testing, a test driving cycle in the most general case, attempts to synthesize real driving conditions with respect to a number of measures, including speed, acceleration, specific power, trip patterns, road grade, and temperature. Driving cycles have been developed to provide a single speed-time profile that is representative of urban driving. Standard driving cycles have a wide range of uses [2]. Vehicle manufacturers need these cycles to provide a long term basis for design, tooling and marketing. Traffic engineers require driving cycles in the design of traffic control systems and simulation of traffic flows and delays. Environmentalists are concerned with the performance of the vehicle in terms of the pollutants generated, while negotiating specific driving patterns. Furthermore, a speed-time trace can provide a convenient laboratory-based means to estimate fuel consumption and emissions of vehicles within the respective urban areas.

In order to investigate the amounts of exhausted gas emissions and fuel consumption rates of vehicles traveling in Bangkok, a generic driving characteristic or pattern for any vehicle traveling in the traffic of the city under consideration must be established. So far there is no such driving cycle officially developed for representing Bangkok traffic. The driving cycle used for the assessment of the exhaust emissions of newly registered automobiles in Thailand is based upon the standard driving cycle of the European Community (called ECE cycle) [3] where the driving conditions are not the same. Furthermore, it is modal driving cycle which derived from various representative constant acceleration and speed driving modes contrast to the cycle that constructed from the real microtrips obtained from actual on-road driving data such as the US75 cycle and Melbourne peak cycle. Thus, this driving cycle may not produce a realistic assessment of the emissions for Bangkok traffic. Hence an appropriate driving cycle for motor vehicles in Bangkok is needed to be established.

Therefore the objective of this study is to develop a more realistic driving cycle for uses in the assessment of exhaust emissions and fuel consumption of automobiles traveling in Bangkok. It is hope that the developed Bangkok driving cycle, which is more realistic to represent Bangkok traffic conditions, can be adopted for tests of vehicles running in Bangkok in order to report the real world performance of vehicles in service. Thus providing information for Thailand’s energy and environmental agencies on how to set up proper national standards for the motor vehicles fuel consumption and exhaust emissions. It is also hoped that the proposed methods could be used for other big cities as well as for other types of vehicle.

2. METHODOLOGY

2.1 Road route selection

Typically, driving cycle for a city must be determined from the traffic data along the traveling road routes of those vehicles. The number of such possible road routes would be enormous and it is impossible to conduct actual measurements of the vehicle speed characteristics on the whole road routes. A possible way to resolve this problem is to select a number of road routes that can represent the dominant traffic situations throughout the city. However, research subjected to the detailed study on how to select appropriate road routes for collecting real on-road driving data has not been found. Most road routes were selected on the basis of the researchers’ simple judgments that these routes would cover the driving conditions from one end of the city to the other passing through the city downtown area. This study therefore intends to propose a methodology for road route selection so that the vehicle driving characteristics along these selected routes would represent the real traffic conditions for most vehicles traveling in the city.

To select the traveling road routes that can best represent the actual traffic, the real situations occur along each road route in the considered city must be known. Travel speed is a parameter commonly used to describe the real traffic situations [4] and it can be

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determined from the vehicle traffic flow data by using traffic flow model introduced by Greenshield [5]. The traffic flow data contains the collection of number of vehicles passing over sections of road along the main roads during a time interval at desired time periods of the day. These data collections are normally conducted by traffic authorities in most big cities.

The first step in the road route selection starts with the analysis of these traffic flow data. From the available vehicle flow data, a traffic flow model, is applied to determine the travel speed of the cars along each section of major road routes considered. Ascending these travel speeds determined for all road sections of all major road routes, the distribution of travel speeds of vehicles in the area can then be established. Moreover, the average speed for each major road route can be estimated from the speeds of its corresponding road sections. And eventually, by averaging the speeds of the whole road sections, the mean speed of vehicles traveling in the considered city can be determined.

The second step of the methodology is to select a few major road routes so that their distribution of vehicle speeds of all road sections along those selected major roads is closely matched to that of the whole major roads previously established. The matching can be justified by some statistical parameters e.g. variances and mean. These few major road routes are therefore expected to cover all driving speed patterns occurring in the city and can be used as representative road routes for conducting real driving tests to collect the driving characteristics (i.e. speed versus time data) of vehicles which will be later used for the construction of the driving cycle of vehicles traveling in the city.

The above described method is applied to the collected traffic flow data along 20 main road routes in Bangkok. Distribution of the vehicle travel speed from the whole 20 main road routes in Bangkok is shown in Fig. 1. Based on the set guideline from the above second step method seven road routes are then selected. These selected road routes give a good agreement of the distribution of travel speeds (as shown in Fig. 1) with that of the whole main road routes. They are consists of Silom Rd., Petchaburi Rd., Sukhumvit Rd., Ladprao Rd., Paholyothin Rd., Jarunsantisong Rd. and Wipawadee Rd.. According to the selection, Silom Rd. was selected to represent the highly congested traffic condition with average travel speed less than 10 km/h while Petchaburi Rd., Sukhumvit Rd., Ladprao Rd. and Paholyothin Rd. were selected to represent the congested traffic condition with average travel speed more than 10 km/h to 20 km/h. Jarunsantisong Rd. characterized the moderate traffic condition with average travel speed from more than 20 km/h to 30 km/h, and Wipawadee Rd. characterized the lightest traffic condition with average travel speed more than 30 km/h.

2.2 On-road driving data collection

The speed-time data collections were carried out using a real time logging system equipped on a selected sedan traveling along the routes under actual traffic. The selected vehicle was a Toyota Corona of the year 1993, gasoline engine, manual transmission with capacity of 1.6 liters. The instrumented vehicle was driven following the time schedule along the seven designated road routes which were selected in Section 2.1. The speed-time data in this study were collected during the morning peak period between 7:00 a.m. and 9:00 a.m. from November to December 2003. The morning peak period was observed to have the highest traffic volume beyond the capacity of the road system in Bangkok capable of handling [6]. As a result, the highest exhaust emissions and fuel consumption were reported during this period. Therefore, collecting speed-time data in the morning peak periods would capture the driving conditions that have the largest impact on exhaust emissions and fuel consumption. The data of each road route was carried out for two weeks.

2.3 Driving cycle development

From the speed-time data obtained from an on-roads collection, the acceleration (or deceleration) in every second throughout the trip and actual driving parameters are calculated. These actual driving parameters include average speed (Vavg), average running speed (Vavg1), times in acceleration (%Acc), in deceleration (%Dec), at cruise (%Cruise) and at idle (%Idle), number of stops per kilometer travel (stop/km), average acceleration (Accavg) and deceleration (Decavg) and positive kinetic energy (PKE). The actual driving parameters indicate the actual on-roads driving situations and are used as the criteria for the driving cycle construction. These real parameters will be called “Target Parameters”.

The driving cycle construction approach used in this study is based on building up a series connection of a number of microtrips randomly selected from the database containing a large number of real microtrips analyzed from the on-roads collected speed-time data. Fig.2 shows the examples of some collected speed-time profiles. As seen in the figure, there are eight microtrips separated from the entire speed-time data. Shape (sequence of driving speed) of each microtrip is clearly seen that it shows the individual driving characteristic. The whole driving data are separated into microtrips to determine the predominant patterns occurred in the actual
maintain consistency in comparisons the fuel used was taken from the same petrol station. In order to investigate the effects of driving cycles on emissions and fuel consumption, several experiments were then set up on a test vehicle. They were carried out at the Automotive Emission Laboratory of the Pollution Control Department of Thailand. The chassis dynamometer (SCHENCK EMDY48) roller is 48 inches in diameter. It simulates the vehicle’s moment of inertia, its rolling resistance and its aerodynamic drag when driving the vehicle following a driving schedule. The required cooling is provided by a fan mounted a short distance from the vehicle. The speeds of wind created from this fan are varied corresponding to the vehicle speed.

A computer simulation program has been developed in order to generate a driving cycle according to the proposed procedure. The program will extract the desired microtrips from the real microtrip database into five speed ranges. These speed ranges are given with an equal probability to be randomly chosen during the cycle simulation process. Similarly, in the selection of a microtrip from any speed range, each microtrip in the range is given an equal probability which can be calculated based on the number of microtrips in the range. To commence the driving cycle construction, the program will first generate a random number to select the speed range and then another random number to select a microtrip from the selected speed range. The values of three driving parameters (the average running speed (V1 avg), percentages of number of microtrips (%Nm) and their time spans (%Tm)) of the selected microtrip are calculated and compared with their corresponding target parameters prior to selecting the next microtrip. Whenever a new microtrip is selected and added to the previously selected ones to become a new set of microtrips, those three driving parameters for each speed interval of the new set of microtrip are determined to check whether they are lower or higher than their corresponding values of target parameters. The next step is to compare the determined average running speed (V1avg) of this new set of the selected microtrips with the target average speed. Depending on whether it is higher or lower, the next microtrip is then guided to be randomly selected from the proper speed ranges remaining in the updated database so that the new average speed would become closer to the target value. The satisfied microtrip is then connected to the previously established series of microtrips. The whole procedure is repeated until the desired running duration of the cycle is reached. The desired running duration of the cycle is the total driving cycle duration less the idle duration. The total duration of the driving cycle is considered based on the fact that it should be long enough to describe all traffic situations and obtain the emissions sufficiently. Therefore, the total driving cycle duration in this study is set at 1200 seconds which is within the range used by various well-known driving cycles [7,8]. The idle duration of the cycle is calculated in proportion to the percentage of idle duration of the real on-road driving data. Finally, when equal idle periods are inserted in-between these microtrips a driving cycle is formed. A number of generated driving cycles can be obtained from the simulation. In order to choose the one which can be best representative to the actual driving conditions, the driving parameters of the generated driving cycle must be closest to the target statistics.

2.3 Emissions and fuel consumption test

In order to investigate the effects of driving cycles on emissions and fuel consumption, several experiments were then set up on a test vehicle. They were carried out at the Automotive Emission Laboratory of the Pollution Control Department of Thailand. The gasoline engine, automatic transmission with capacity of 1.5 liters and odometer reading of 48,900 km. It was equipped with three-way catalytic converter (TWC). Unleaded gasoline with octane number 95 was used as the vehicle fuel for all tests. In order to maintain consistency in comparisons the fuel used was taken from the same petrol station.

The exhaust emissions measured in this study were carbon monoxide (CO), carbon dioxide (CO2), total unburned hydrocarbons (HC) and oxides of nitrogen (NOx). These exhaust gases were measured using a constant volume sampling (CVS) method. PIERBURG gas analyzer system was used to analyze the collected emissions. This gas analyzer system consists of three module analyzers: non-dispersive infrared analyzer (NDIR) to measure carbon monoxide (CO), flame ionization detector (FID) to measure total unburned hydrocarbons (HC) and chemiluminescence analyzer (CLA) to measure oxides of nitrogen (NOx). Fuel consumption is calculated using carbon balance method.

Emissions and fuel consumption of the test vehicle were tested following two different driving cycles. One of them is the developed Bangkok driving cycle (BDC). The other is the European driving cycle (ECE15+EUDC) which is currently used by Thai Industrial Standards Institute to test new gasoline vehicles. The tests were conducted twice for each driving cycle for the purpose of consistency.
3. RESULTS AND DISCUSSION

3.1 Bangkok driving speed patterns and distribution

In order to investigate on the speed range that most vehicles use in Bangkok, the vehicle speed distribution was analyzed from the collected on-road speed time data. Figure 3 shows the distribution of time of vehicle driving which would spend in each speed range when traveling in Bangkok during weekday and weekend. It can be observed that about 42% of vehicle driving on weekdays was spent at idle. The driving speeds that most frequently occurred (when idle speed was excluded) on weekdays were those of no more than 10 km/h and the frequencies diminished at higher speeds. Conversely, the highest proportion of driving speeds occurred on weekends was that of more than 40 km/h and the proportions diminished at lower speeds. The proportion of idle speed on weekends was only half of that on weekdays. In addition, it was also found that 16.8% of driving on weekends exceeded the speed of 60 km/h compared to 2.8% during weekdays. It indicates that vehicles spend a lot of time idling and moving at low speeds contributed from congested traffic during weekdays. This would be in contrast to the driving in the weekend period as afore mentioned.

![Fig. 3 Distribution of time spent in various speed ranges](image)

3.2 Generated Bangkok driving cycle

The driving cycle construction and selection procedures described above were applied to the on-road driving data collected from seven selected road routes of Bangkok. The obtained Bangkok driving cycle whose driving parameters is closest to target parameters is shown in Fig. 4. Several low-speed short microtrips mixed with a few higher-speed, long microtrips can be observed from the driving profile. Driving characteristics of this Bangkok driving cycle represent traffic in Bangkok are summarized in Table 1. The obtained Bangkok driving cycle is 5.71 kilometers in length, 1160 seconds (19.3 minutes) in time duration and involves 14 intermediate stops.

![Fig. 4 Bangkok driving cycle](image)

Table 1 also compares the characteristics of the Bangkok driving cycle with the ECE15+EUDC regulatory driving cycle which Thailand currently used as a legislative driving cycle. It shows that the average speed of Bangkok cycle is 89% less than that of the ECE15+EUDC cycle. Moreover, the Bangkok cycle exhibits about 37% greater idle time than ECE15+EUDC. For the value of PKE which indicates the amount of energy expended in accelerating a vehicle during a drive cycle test, the Bangkok cycle is different from the ECE15+EUDC cycle. The average acceleration rate of Bangkok cycle is also larger than that of the ECE15+EUDC cycle. On overall consideration, it can be concluded that the traffic in Bangkok is more serious than the ECE15+EUDC cycle. Therefore larger values in both emissions and fuel consumption would be obtained from the test of vehicles using the Bangkok driving cycle. For the microtrip characteristics, it is clearly seen that driving with low speeds of less than 10 km/h occurs most frequently in Bangkok cycle while it could not be observed these situations in the ECE15+EUDC cycle. From the microtrip characteristics discussed above, distinctive difference of driving patterns for different cities can be noticed. Prominence of microtrips in Bangkok are the short trips with low speed used and frequent stop (idle speed) as a result of the traffic problems. When particular attention is taken to the ECE15+EUDC cycle, it is obvious that the ECE15+EUDC cycle does not reflect the actual traffic situations in Bangkok and would no longer be suitable to be used as a standard test cycle for estimating the exhaust emissions and fuel consumption of automobiles running in Bangkok traffic.
3.3 Total emissions and fuel consumption

The results of the total exhaust emissions and fuel consumption obtained from the experimental tests under the newly developed Bangkok driving cycle (BDC) and the ECE standard cycle (ECE15+EUDC) are shown in Table 2. To help explaining the effect of driving parameters on the obtained results, the measured values for two sub cycles of the ECE standard driving cycle, i.e. ECE15 and EUDC, are also separately illustrated in the table.

From Table 2, there is a strong influence of the average speed on the emission factor of HC. It can be observed that the decrease in average speed of the cycle would result in the increment of emission factor (g/km) of HC. In general, CO polluted from vehicle equipped with a catalytic converter is sensitive to the acceleration variations [9]. The degree of fluctuations of the vehicle speed in the driving cycle hence would significantly influence the average emission rate of CO occurring during the cycle. Therefore the emission factor (g/km) of CO observed from the BDC cycle which has high fluctuations of the vehicle speed in the cycle is much greater than those of ECE cycle. The EUDC cycle has almost two and four times greater emission factor (g/km) of HC and CO of the BDC cycle. As for the NOx emissions, high temperature during combustion process results in increasing of NOx [1]. This high temperature can be caused from driving at high speeds and extreme accelerating during driving periods [10]. The extreme acceleration occurs when the speed is suddenly changed from a low level to a much higher level. It can be seen that the EUDC cycle, which is the last part of the driving pattern, contains a large portion of extreme accelerations at very high speeds (V > 80 km/h). However, the NOx emission factor (g/km) obtained from the ECE15+EUDC cycle is lower than that from BDC cycle. This is because the average speed of the ECE15+EUDC cycle is greater than that of the BDC cycle. Hence, for a given time period, the vehicle runs under the ECE15+EUDC cycle can travel much longer distance than it does under the BDC cycle. The amount of CO2 emitted from a motor vehicle is highly related to its fuel consumption rate; the more the fuel consumed, the more the CO2 emitted. The vehicle fuel consumption rate increases with the increasing driving speed. However, when the driving pattern of the cycle contains highly fluctuated driving speeds such as the BDC cycle, higher values of CO2 emission and its consequent fuel consumption are obtained despite it has lower average driving speed than the ECE15 cycle. Similarly, when the driving pattern is taken into consideration, the cycle with the low average vehicle speed and high variation of driving speed tends to have a high emission factor (g/km) of CO2. In the study, the BDC cycle which posses such driving conditions produces the greatest emission factor of CO2. The fuel consumption in terms of liters per 100 km distance travel is closely linked to the CO2 emission factor (g/km). The higher the CO2 emission factor, the higher the fuel consumption in l/km.

<table>
<thead>
<tr>
<th>Driving cycles</th>
<th>Driving parameters</th>
<th>Microtrip parameters</th>
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<tr>
<td></td>
<td>length (km)</td>
<td>duration (s)</td>
</tr>
<tr>
<td>BDC</td>
<td>5.71</td>
<td>1160</td>
</tr>
<tr>
<td>ECE15+EUDC</td>
<td>10.9</td>
<td>1180</td>
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<table>
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<tr>
<th></th>
<th>%Vmt</th>
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<td>21.4</td>
</tr>
<tr>
<td>10&lt;V≤20</td>
<td>14.3</td>
<td>14.3</td>
</tr>
<tr>
<td>20&lt;V≤30</td>
<td>7.1</td>
<td>7.1</td>
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<td>23.6</td>
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<td>V&gt;40</td>
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Table 1 Comparisons of Bangkok driving cycle (BDC) and European driving cycle (ECE15+EUDC)

<table>
<thead>
<tr>
<th>Driving cycle</th>
<th>Total time (s)</th>
<th>Distance (km)</th>
<th>Cruise period (%)</th>
<th>Idle period (%)</th>
<th>Average speed (km/h)</th>
<th>HC (g/km)</th>
<th>NOx (g/km)</th>
<th>CO (g/km)</th>
<th>CO2 (g/km)</th>
<th>Fuel consumption (l/100 km)</th>
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<tr>
<td>BDC</td>
<td>1160</td>
<td>5.71</td>
<td>23.8</td>
<td>37.7</td>
<td>17.7</td>
<td>0.134</td>
<td>0.557</td>
<td>2.093</td>
<td>206.371</td>
<td>8.48</td>
</tr>
<tr>
<td>ECE15</td>
<td>780</td>
<td>4.05</td>
<td>32.3</td>
<td>30.8</td>
<td>18.7</td>
<td>0.125</td>
<td>0.409</td>
<td>0.714</td>
<td>187.712</td>
<td>7.63</td>
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<tr>
<td>EUDC</td>
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<td>6.85</td>
<td>67.5</td>
<td>10</td>
<td>62.6</td>
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<td>0.564</td>
<td>0.470</td>
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<tr>
<td>ECE15+EUDC</td>
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<td>10.9</td>
<td>42.2</td>
<td>23.7</td>
<td>33.4</td>
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<td>0.506</td>
<td>0.561</td>
<td>167.611</td>
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Table 2 Total emissions and fuel consumption of the test vehicle under specified driving cycles

The relative increase in BDC cycle emissions and fuel consumption over the Thai currently-used ECE15+EUDC cycle are determined. Comparisons of the newly-developed BDC cycle and the Thai currently-used ECE15+EUDC cycle reveal that the emission factors (g/km) of HC and CO of the BDC cycle are almost two and four times greater than those of the ECE cycle respectively. For NOx emissions, although the ECE15+EUDC cycle is suffered from the extreme accelerations at high speed driving which result in high emission rate (g/s) of NOx, but because of its much less proportion of idle driving, the NOx emission factor (g/km) is found smaller than that of the BDC cycle by 10%. Under the BDC cycle, the test vehicle needs 1.67 more liters of fuel or about 23% more to cover 100 km distance than it does under the ECE15+EUDC cycle. All of these differences are mainly due to the greater proportion of idle periods and higher fluctuations of vehicle speed in the BDC cycle.

4. CONCLUSION

The objective of this research is to propose a method to develop a driving cycle to represent Bangkok traffic. This method has been tested with the on-road speed-time data collections on the selected road routes in Bangkok. After achieving a driving cycle, exhaust emissions and fuel consumption of a vehicle were measured by driving a car on a standard chassis dynamometer according to the obtained Bangkok driving cycle. Comparison of the exhaust emission test and fuel consumption test results obtained from the constructed driving cycle with those obtained from the presently-adopted European standard cycle had been made.

In the study of route selection, the methodology for selecting the best representative routes in Bangkok for gathering speed-time data collections on the selected road routes in Bangkok. After achieving a driving cycle, exhaust emissions and fuel consumption of a vehicle were measured by driving a car on a standard chassis dynamometer according to the obtained Bangkok driving cycle. Comparison of the exhaust emission test and fuel consumption test results obtained from the constructed driving cycle with those obtained from the presently-adopted European standard cycle had been made.

In the study of route selection, the methodology for selecting the best representative routes in Bangkok for gathering speed-time data collections on the selected road routes in Bangkok. After achieving a driving cycle, exhaust emissions and fuel consumption of a vehicle were measured by driving a car on a standard chassis dynamometer according to the obtained Bangkok driving cycle. Comparison of the exhaust emission test and fuel consumption test results obtained from the constructed driving cycle with those obtained from the presently-adopted European standard cycle had been made.
data to build up the Bangkok driving cycle was proposed. The basic traffic flow model was introduced to investigate the actual traffic situations in Bangkok. Consequently, the selections of road routes in Bangkok which best reflect the predominant driving patterns determined from the referred model were done. Seven road routes which closely matched on their vehicle speed distribution to that of the whole major roads established were then chosen. The selected road routes can best represent the Bangkok traffic which give the dominant patterns occur in actual traffic situations. Data collection along the selected road routes in Bangkok was conducted. The driving characteristics of Bangkok traffic were then investigated. The method in constructing driving cycle for Bangkok was then presented in this study. The presented method can construct driving cycle which gives the statistical parameters best match to the actual parameters. The Bangkok driving cycle which best represent the actual driving conditions in Bangkok was obtained. Comparisons of the obtained Bangkok driving cycle with Thai regulatory driving cycle were investigated. It can be concluded that the driving conditions of the European standard cycle which currently adopted for testing of vehicles in Bangkok on compliance with national emission standards certification are quite different from the Bangkok traffic situations.

From the emission testing result, it can be concluded that the emissions obtained from the Bangkok driving cycle is quite different from those obtained from ECE due to the different driving conditions. Consequently, the use of ECE driving cycle as the standard for testing newly registered automobile in Thailand is may not appropriate. Therefore there should be conduct the study to construct our own driving cycle for Thailand to regulate the emission standard. It is also hoped that the proposed methods of both route selection and driving cycle construction could be used for other big cities or the obtained driving cycle could be modified for other varying traffic situation. Such the proposed method could be adapted for other types of vehicle such as city buses and pick-up trucks.

5. ACKNOWLEDGMENTS

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6. REFERENCES