DRIVING CYCLE FOR SMALL AND MEDIUM DUTY ENGINE:
CASE STUDY OF IPOH

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ABSTRACT

Driving cycles is a series of data points representing the speed of vehicle verses time sequenced profile developed for certain road, route, specific area or city. It is widely used of application for vehicle manufacturers, environmentalists and traffic engineers. The purposes of this study are; to analyse the real world driving pattern and to develop a driving cycle for small and medium duty engines in Ipoh, Malaysia. This study carried out a survey to describe the motorcycle and car driving cycle on the selected three routes in the peak hour periods of the traffic condition, which are morning, afternoon and evening peak periods. The study used a GPS equipment to record vehicle travel speeds (second by second). The driving characteristics were analysed from speed time data and its target statistic parameters were defined. The method for generating the driving cycle has been described. The analysis results show that there are significant difference of driving characteristic and driving cycle between motorcycle and car for Ipoh city. The characteristic of the developed driving cycle for car was compared with three well established worldwide driving cycles. This information gives a clear message that those driving cycle such as ECE driving cycle (for instance) is not suitable to predict the emission standard in Ipoh. The driving cycle for motorcycle also had been compared with existing motorcycles driving cycles for Malaysia. It shows that the average speed of the developed Ipoh motorcycles driving cycle is higher than motorcycles driving cycle for Malaysia. The result clearly shows the driving cycle is dependent on specific area or city due to the different of traffic flow.
ABSTRAK

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LIST OF ABBREVIATIONS

CAD - Computer Added Design
CAN - Control Area Network
COV - Coefficient of Variations
DCR - Driving Conditions of Recognition
DMDC - Delhi Driving Cycle
ECE - Economic commission Europe
EMDC - Edinburg Driving Cycle
EUDC - Extra Urban Driving Cycle
FTP - Federal Test Procedure
GIS - Geographical Information System
GPS - Global Positioning system
NEDC - New European driving Cycle
PKE - Positive Kinetic Energy
RMS - Root Mean square acceleration
SAFD - Speed Acceleration Frequency Distribution
SD - Standard Deviation
UDDS - Urban Dynamometer Driving Schedule
US - United State
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CHAPTER 1

INTRODUCTION

1.1 Background of the study

Driving cycle is a graph of speed of vehicle versus time obtained from the real live situation or real world. This cycle is usually developed for a specific area or city, certain road and routes. With the production of driving cycle, it represents a typical driving pattern for the population a place or city whether it involves the free flow or saturated traffic. Definition of driving cycle also based on operating conditions such as the idle state, acceleration, deceleration and steady state to represent the type of pattern in an area of the city (Y. Liu et al., 2014).

Standard driving cycle such as Japanese and Europe driving cycle widely used in manufacturing vehicles, environmentalist and traffic engineer. For manufacturing vehicles, driving cycle used to provide a long term basic for design, tooling and marketing. Vehicles Traffic engineers require driving cycles in the design of traffic control systems and simulation of traffic flows. Environmentalists are concerned with the performance of the vehicle in terms of the pollutants generated based on specific driving patterns.

In addition, a speed time profile of driving cycle can be used to estimate fuel consumption and emissions of vehicles using dynamometer test. Researchers such as Faiz et al. (1996) and Hui et al. (2007) have carried out this system in their field. The driving cycle is also important to evaluate the driver’s behaviour in a study area. For instance, Andry et al. (2013) have developed the motorcycle driving behaviours on heterogeneous traffic for Makassar, Indonesia.

Generally, there are two categories of driving cycle, legislative and non-legislative. Legislative cycles is to control emission by authorities from motors vehicle so as not to exceed the statutory emission standard. For example, the U.S
FTP 75 cycle are currently is used in the United State of America and also Japan 10-15 mode cycles is used in Japan to control vehicle emissions. Non–legislative cycles are developed for estimation of exhaust emission and fuel consumption. The Europe cycle and Sydney cycle, are some of the examples.

The development of driving cycles of vehicle involves three steps: test route selection, data collection, and cycle construction, as mentioned by Amirjamshidi (2013). Table 1.1 presents a summary of studies of real world driving cycles in the literature, including location, study objective, data collection that are used to development of the driving cycle.

Table 1.1: Development methods and objectives of selected driving cycles

<table>
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<th>Study</th>
<th>Location</th>
<th>Main study Objective</th>
<th>Data collection Method</th>
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<td>Amirjamshidi (2013)</td>
<td>Toronto</td>
<td>Develop and demonstrate a method for efficiently developing driving cycles that represent specific combination of roadways class, time of day and vehicles attributes.</td>
<td>Traffic simulation model and GPS receivers recording data</td>
</tr>
<tr>
<td></td>
<td>Waterfront Area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y. Liu et al. (2014)</td>
<td>Guangzhou China</td>
<td>Analysis Driving cycle of long distance based on principal component analysis and cluster Algorithm (kinematic fragments)</td>
<td>GPS Data acquisition system (vehicle tracking method)</td>
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<td>Tamsanya et al. (2006)</td>
<td>Bangkok Thailand</td>
<td>Develop driving cycles for used in the assessment of exhaust emission and fuel consumption</td>
<td>A real time logging system</td>
</tr>
<tr>
<td>Saleh et al. (2010)</td>
<td>Edinburgh and Delhi</td>
<td>An investigation of real world driving cycle motorcycles</td>
<td>Advanced GPS techniques</td>
</tr>
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Table 1.1: (continued)

<table>
<thead>
<tr>
<th>M. Syafiza et al. (2014)</th>
<th>Semanggi intersection</th>
<th>Develop the driving cycles and analysis emission and fuel consumptions for light duty trucks, heavy duty trucks, light duty bas, heavy duty bus and motorcycles.</th>
<th>GPS equipment and chassis dynamometer</th>
</tr>
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<tr>
<td>Andry et al. (2013)</td>
<td>Makassar city Indonesia</td>
<td>Analyse acceleration and deceleration parameters as dominant behaviour on the driving cycles.</td>
<td>GPS equipment (Garmin Etrex 30)</td>
</tr>
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1.2 Statement of the problem

Driving cycle is a represent of traffic behaviour in an area or certain city. Various standard driving cycles have been developed such as Japan cycle, Indian cycle, European cycle, and so on. However, each one of the developed driving cycle is not representing the actual situation in Ipoh, the capital city of the state of Perak, Malaysia. Therefore, a driving cycle in Ipoh is needed to provide information related to the actual driving cycle. With the developed of this driving cycle can help other researchers to continue the studies related to exhaust pollution and fuel consumption in Ipoh city.

1.3 Objectives of the study

This study will develop real world driving cycles for the city of Ipoh. The specific objectives of this study are:

i. To understand and analyse the real world driving cycle pattern for small and medium duty engines.

ii. To develop a driving cycle for small and medium duty engines.
1.4 Scopes and limitations of the research

i. Driving cycle has been simplified because of time and budget constraints. Classification of drive cycles and related factors (e.g. urban/rural, time of day, speed, engine size and the characteristics of the driver) could have been extended to include more factors, the types of roads, time, vehicle type, and other. For this study, only one type of vehicle for car and motorcycles was used in all runs to avoid discordance in the data and to try to minimise errors.

ii. This research will only focus on 4-stoke gasoline engine with capacity of 100 cc for small duty engine and 1500 cc for medium duty engine.

iii. The number of routes was limited to three of roads. Three peak-hour periods of the traffic condition were measured in this study which are: morning, afternoon, and evening peak periods. The routes that have been studied are an urban route in Ipoh, the capital city of the state of Perak.

iv. The GPS system was used as a tracking and recording the driving pattern along the study area.

1.5 Structure of the thesis

Following this introductory chapter, the thesis begins by a review of the past research in developed of driving cycles. The literature review reported chapter two is focused on details several of driving cycles, definition of driving cycle, data collection and methodology to development the driving cycles.

Chapter three discusses the data collection in this work. The selected of routes, piloting the data collection is firstly presented and then, the equipment used for data collection, the routes and assessment parameter are used in the study will be discussed. This chapter also discuss the developing of the driving cycle.

Chapter four present results and the preliminary analysis obtained from monitoring and measuring of car and motorcycles and using the GPS on selected routes in the study. Chapter four also has further analysis of the results which are presented and investigated using techniques of regression analysis. Finally, chapter five concludes for the research of this study. A summary of the findings of each
chapter is discussed, and finally suggestions for future work and a summary of the thesis as a whole are presented.

1.6 Novelty of the research

The novel aspects of this work include:

i. Development of driving cycles for cars and motorcycles on the same routes for Ipoh, the capital city of Perak.

ii. The will be analysis of parameters and investigation of driving cycle.
CHAPTER 2

LITERATURE REVIEWS

2.1 Definition of a driving cycle

The literature review shows that there is a collective opinion among experts regarding the definition of the driving cycle. A driving cycle for a vehicle is defined as “a represent speed-time profile for a study area within which a vehicle can be idling, accelerating, decelerating, or cruising” Amrijamshidi (2013). Andry et al. (2013) define a driving cycle as represent “a speed time sequenced profile developed for certain road, route, specific area or city”. Tamsanya et al. (2006) states that a driving cycle is “represent a typical driving pattern for population of a city”. Naghizadeh (2003) define “a drive cycle is a speed-time sequence developed for a certain type of vehicles in a particular environment to the driving pattern with the purpose of represent measuring and regulating exhaust gas emissions and monitoring fuel consumption”.

2.2 The use of driving cycle

Drive cycle is used to estimate emissions pollutant and analysis of fuel consumption for vehicles. There have been studies around the world to determine the driving cycle for private cars, light duty vehicles, trucks and motorcycles. Watson (1978) used the emission data obtained from the car drive cycle for predicting air pollution. The test procedures included 40 cars and based on tree driving cycles; AS 2077 city (US city), Melbourne peak, and Melbourne cold start. The test also performed in steady speed cruising within 120 km/h. All of the above procedures are performed on the chassis dynamometer. Literature review indicates that the emission is dependent on the number of variables. The variables involved include speed, vehicle, fuel, road,
traffic volume, and others. Morey (2000) stated that vehicle emissions are affected by acceleration. The data collected on the basis of the concept of non-lock condition, where there is no target of vehicles in use.

Faiz et al. (1996) also mentioned that pollutant emission of vehicle levels depending on vehicle characteristics, operating conditions, level of maintenance, fuel characteristics, temperature, humidity, and altitude as presented in Table 2.1.

Table 2.1: Factors that affect the pollutant emissions of vehicles (Faiz et al., 1996)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Description</th>
</tr>
</thead>
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| Vehicle         | • Engine type and technology-diesel, two strokes, four strokes, Otto, types of transmission system.  
• Exhaust, crankcase and evaporative emission control system in place  
• Engine mechanical condition and adequacy of maintenance  
• Air conditional, trailer towing and adequacy of maintenance |
| Fuel            | • Fuel properties and quality  
• Alternative fuel |
| Fleet           | • Vehicle mix (number and type of vehicles in use)  
• Vehicle utilization (Kilometres per vehicle per year) by vehicle type  
• Age profile of the vehicle fleet  
• Traffic mix and choice of mode for passengers  
• Clean fuels program |
| Operating       | • Altitude, temperature, humidity (for NO\textsubscript{2} emissions)  
• Vehicle use pattern – number and length of trips, number of cold starts, speed, loading, aggressiveness of driving behaviour.  
• Degree of traffic congestion, capacity and quality of road infrastructure and traffic control system.  
• Transport demand management program |
Driving behaviours and patterns differ according to venue or city and also country. It is therefore difficult to use driving cycle developed for one city to another city, even in the same country. In this regard, the release of the study to be done by producing driving cycle in real world driving tests in specific areas.

According to Barlow et al. (2009), there are several factors which affect the emission levels. Among them are vehicle-related factors such as model, size, fuel type, technology level and mileage, and operational factors such as speed, acceleration, gear selection and road gradient. However, the factor stated also depends on different types of vehicle such as cars, vans, buses, trucks and motorcycles. In Malaysia, vehicle emission regulations based on United Nations Economic Commission for Europe specification ECE 15 were introduced in September 1992 (Faiz et al., 1996).

Tamsanya et al. (2006) have developed a driving cycle for vehicular to study the emissions and fuel consumption in Bangkok. The vehicle was measured on a standard chassis dynamometer. Based on the study conducted, emission factor and fuel consumption will be affected by the average speed. Fuel consumption is closely linked to carbon dioxide (CO₂) emission factors. The higher the fuel consumption resulted in the higher the CO₂ emission factor, as shown in Table 2.2. This table also shows the results of the fuel consumption according to different driving cycle.

Table 2.2: Total emission and fuel consumption of the test vehicle under specified driving cycle (Tamsanya et al., 2006)

<table>
<thead>
<tr>
<th>Driving cycle</th>
<th>Total time (s)</th>
<th>Distance (km)</th>
<th>Cruise period (%)</th>
<th>Idle period (km/h)</th>
<th>Average speed</th>
<th>HC</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>0.13</td>
<td>0.557</td>
<td>2.093</td>
<td>206.3</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>0.12</td>
<td>0.409</td>
<td>0.714</td>
<td>187.7</td>
<td>7.63</td>
</tr>
<tr>
<td>EUDC</td>
<td>400</td>
<td>6.85</td>
<td>67.5</td>
<td>10</td>
<td>62.6</td>
<td>0.04</td>
<td>0.564</td>
<td>0.470</td>
<td>155.7</td>
<td>6.32</td>
</tr>
<tr>
<td>ECE15-EUDC</td>
<td>1180</td>
<td>10.9</td>
<td>42.2</td>
<td>23.7</td>
<td>33.4</td>
<td>0.07</td>
<td>0.506</td>
<td>0.561</td>
<td>167.6</td>
<td>6.81</td>
</tr>
</tbody>
</table>
2.3 Driving cycle models

Usually there are two categories of driving cycle have been developed in the world; legislative and non-legislative. Legislative used to control the exhaust emission of a vehicle, must not to exceed the emission standards. Set by the authorities. The US FTP 75 cycles, ECE cycle and Japan 10-15 modes cycles used in the United State of America, Europe and Japan respectively to control vehicle emissions. Tutuianu et al. (2014) have been developing a world-wide harmonized light duty driving cycle legislative-based. This study is intended to represent typical driving characteristic around the world. The data obtained from a range of contracting parties in the following regions: EU Switzerland, India, Japan, Korea, and USA.

Non-legislative was developed to study the estimation of exhaust emissions and fuel consumption. The cycle such as Sydney driving cycle and Hong Kong is categorized as non-legislative driving cycle (Adnan et al., 2011).

The driving cycle is also divided into two types; steady state and transient driving cycle (Barlow et al., 2009). A steady state cycle often used to transport heavy duty diesel engines. It’s a speed-time sequence for the constant engine and constant load modes. On the other hand, a transient driving cycle categories as changes occurring more or less on the vehicle speed and load the engine. This cycle is related to the period as constant acceleration, deceleration and speed, and done on real driving pattern road test.

2.3.1 USA driving cycle

In the United States, the development cycle was named the Federal Test Procedure (FTP-75) used for emission certification testing of cars and light duty trucks (Naghizadeh, 2003). The FTP-75 cycle (Figure 2.1) obtain from phase 1 and phase 2 as known as FTP 72 (Figure 2.2) or Urban Dynamometer Driving Schedule (UDDS). The third phase starts after the engine is stopped for 10 minutes. Therefore, the FTP 75 cycle consists of the following parts:
Phase 1
This phase is known as cold transient with distances 5.8 km. The ambient temperature in this phase ranges 20-30 °C and duration about 505 s.

Phase 2
This phase is known as cold stabilized with distances 6.3 km. The duration about 505 s starts from 506 until 1369s.

Phase 3
This phase is known as hot start phase with distances 5.8 km. The duration about 505 s starts from 0 until 505s.

Detailed descriptions of each driving cycle, as shown in Table 2.3

Table 2.3: The main characteristic of FTP 72 and 75 driving cycles
(Barlow et al., 2009)

<table>
<thead>
<tr>
<th>Cycle name</th>
<th>Total time (s)</th>
<th>Distance (m)</th>
<th>Cruise period (%)</th>
<th>Accelerating period (%)</th>
<th>Average speed (km/h)</th>
<th>PKE m/s²</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTP72</td>
<td>1369</td>
<td>11996.85</td>
<td>18.04</td>
<td>36.96</td>
<td>31.6</td>
<td>4.307</td>
</tr>
<tr>
<td>FTP75</td>
<td>1874</td>
<td>17786.59</td>
<td>20.06</td>
<td>36.45</td>
<td>34.2</td>
<td>4.197</td>
</tr>
</tbody>
</table>

Figure 2.1: US EPA Urban Dynamometer Driving Schedule (FTP-75) (Barlow et al., 2009)
2.3.2 New European driving cycles (NEDC)

The cycle is consisting of two parts; urban driving cycle (ECE 15) and Extra-urban driving cycle (EUDC). For ECE 15 cycle, it is repeated 4 times of 195 s and is plotted from 0 s to 780 s while EUDC cycle of 400 s duration is plotted from 780 s to 1180s (Figure 2.3).
The first part of driving cycle is representing for urban. The characteristics of this section are as follow; low vehicle speeds, low engine load, and low exhaust temperature. On the other hand, the EUDC in the second part is representing extra-urban. This part has a higher velocity to reach speeds as high as 120 km/h. The distance of NEDC cycle is 11007 m in a time period of 1180 s. This cycle has an average speed of 34 km/h. The main characteristics of the NEDC in comparison to other certification cycles are provided in Table 2.4.

Table 2.4: Comparison the key characteristics of selected driving cycles (Weiss et al., 2011)

<table>
<thead>
<tr>
<th>Region</th>
<th>NEDC</th>
<th>ECE-15</th>
<th>US FTP-75</th>
<th>JTC 10-15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trip durations(s)</td>
<td>1180</td>
<td>780</td>
<td>1874</td>
<td>660</td>
</tr>
<tr>
<td>Trip distance (km)</td>
<td>11.007</td>
<td>4.052</td>
<td>17.77</td>
<td>4.16</td>
</tr>
<tr>
<td>Average speed (km/h)</td>
<td>33.6</td>
<td>18.7</td>
<td>34.1</td>
<td>22.7</td>
</tr>
<tr>
<td>Maximum speed (km/h)</td>
<td>120</td>
<td>50</td>
<td>91</td>
<td>70</td>
</tr>
<tr>
<td>Share (%)</td>
<td>-idling</td>
<td>24</td>
<td>30</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>-Low speed &gt;0≤50 km/h</td>
<td>55</td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>-medium speed &gt;50-90 km/h</td>
<td>14</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>-high speed &gt;90 km/h</td>
<td>7</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Weiss et al. (2011) follows the NEDC driving cycle to measure the emission. The study was conducted by using light duty vehicles and does on dynamometer test. According to this research, before doing tests on vehicles, it takes at least 6 hours to do a soak at temperature of 20-30 °C.
2.3.3 Japanese driving cycles

There are three types of driving cycle that have been produced in Japanese. It starts with 10 mode cycle in 1983, and follows the 10-15 modes cycle and newest JC08 test cycle. The three cycles is used to study the emission for light vehicles in urban city. In addition to testing emission it is used in the study of fuel consumption, but only for mode 10-15 modes and JC08 test cycle only.

Figure 2.4 shows 10 modes cycle for one segment to simulate for urban driving conditions. This segment cover a distance of 0.644 km at an average speed of 17.7 km/h. Based on figure, last cycle is 135 s and maximum speed is 40 km/h.

![Image: 10 modes cycle](www.dieselnet.com/standards/cycles)

The cycle for 10-15 is shown in Figure 2.5. There are two segments in this cycle, i.e. 10 modes and 10-15 modes. There are two main segments in this cycle, i.e. 10 modes consist of three segments and 15 modes for one segment. Maximum speed for 15 modes is 70 km/h and the distance of the cycle is 4.16 km, average speed 22.7 km/h and duration 660s.
The JC08 test cycle is the latest and completed in the year 2011. It represents driving pattern in the city and have the characteristics of the parameters such as idling periods, acceleration and deceleration. The JC08 driving schedule is shown in Figure 2.6. Parameters for this cycle are as follows; (1) Duration: 1204 s; (2) Total distance: 8.171 km; (3) Average speed: 24.4 km/h; and (4) Maximum speed: 81.6 km/h.
2.4 City specific driving models

In addition to the standard driving cycle such as United States, Europe and Japan, there are also other countries that have developed driving cycle to their countries. This cycle is developed to study the emission and fuel consumption as well as comparing results obtained with existing standards driving cycle. The cycle was discussed below.

2.4.1 Brasov City driving cycle

There are two types of driving cycle that have been developed which is modal driving cycle (Figure 2.7) and transient driving cycle (Figure 2.8). The modal driving cycle is developed based on many changes in speed while for transient driving cycle depend on longest period with constant speed. C. Dinu et al. (2009) have developed driving cycle using GPS equipment, data (speed and acceleration) collected on the same routes. Vehicles that have been used in this study are different in each route.

To develop modal driving cycle, the author C. Dinu et al. (2009) uses the concept of driving pulses. The parameters studied such as average speed, maximum speed, duration, and distance used is the same at all pulses. The next step, analysts use statistical methods to produce modal driving cycle.

To get transient driving cycle, calculation of parameters is done with complete driving cycle. The data analysis starts with the mono and bi-parametric probability density function for all the parameters. This diagram produced by the method of Computer Added Design (CAD) application. The parameters of driving cycle in the Brasov city are as follows:

- Durations: 710 second;
- Length: 4.44 km;
- Average speed: 22.5 km/h;
- Maximum speed: 73 km/h.
2.4.2 Dhaka city driving cycle

Adnan et al. (2011) developed the driving cycle for vehicular emission estimation in Dhaka city (Figure 2.9). The speed time data was computed by the GPS at traffic peak and non-peak and using the different types of vehicles. The selected of route is
the main road that take into account factors such as shops, construction materials, and dustbins. All these factors will affect the results. Four parameters were used for analysing micro-trips i.e. acceleration, deceleration, cruise and idle time percentage (%). It shows a total 25.4% idling, 33.6% acceleration, 32.0% deceleration and 9.0% cruising time. According the result, total cycle duration is 2050 seconds, average distance 7.2 km and average speed 12.7 km/hr. The data was analysed and also compared to other driving cycles such as the FTP-75. Result show that, FTP-75 driving cycle is not suitable to predict the emission standard of Dhaka city because occurring the rapid change in speed is more frequent than that of FTP-75.

![Figure 2.9: Dhaka city driving cycle (Adnan et al., 2011)](image)

2.4.3 ARTEMIS Driving cycle

This cycle is used for passenger cars and it represents driving pattern in Europe. It was developed within the European research project ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems). There are three parts in ARTEMIS driving cycle, urban, rural (i.e. extra-urban) and highway based on three main characteristics (average speed, stop frequency and duration) (M.Andr et al., 2004). Figure 2.10 shows the driving cycle in three different categories of roads (urban, rural secondary road and motorway).
Based on figure, it clearly shows significant differences in the three patterns produced. For urban driving cycle, there are 21 stops and average speed around 17.5 km/h. The running speed is 24.4 km/h. The road driving of the road cycle is running speed 63 km/h, with 2 stops representing, one stop for 7 km travelled. An average speed of motorway driving is about 120 km/h and no stop in cycle. The overall speed of the driving cycle is about 1000 km/h.

Figure 2.10: The ARTEMIS driving cycle (M. Andr et al., 2004)
2.4.4 Bangkok Driving cycles

Tamsanya et al. (2006) developed the driving cycle using micro trip technique for studying the exhaust emissions and fuel consumption in Bangkok (Figure 2.11). According to authors, driving cycle used for the exhaust emission for new car registered in Thailand is based on standard drive cycles of the European driving cycle (ECE). The fact is driving cycle developed in Europe is not realistic for Thailand because it has different traffic. Therefore, the need for developed of driving cycle is important in Bangkok to analysed emission and fuel consumption assessment.

Analysis selection based on three steps: first step start with analysis of the traffic flow data, second the selection of some road based on parameters such as means and variance to represent entire road in Bangkok. The routes selected will represent the entire road in Bangkok. According to the author, for choosing whole route in Bangkok it is difficult.

The speed-time data in this study were collected during the morning peak period between 7:00 a.m. and 9:00 am using real time logging system. The selections of the morning peak period are important because it has a higher traffic flow. With a high traffic flow it will affect the result for the emission and fuel consumption. As a result, the highest exhaust emissions and fuel consumption were reported during this period. The data of each road route was carried out for two weeks.

\[ V_{\text{max}} = 62 \text{ km/h}; \quad Acc_{\text{max}} = 2.7 \text{ m/s}^2; \quad Dcc_{\text{max}} = -3.3 \text{ m/s}^2; \quad \text{length} = 1160\text{s}; \quad \text{distance} = 5.71 \]

Figure 2.11: Bangkok driving cycle (Tamsanya et al., 2006)
2.4.5 Tehran driving cycle

Naghizadeh (2003) developed the driving cycle for simulation of vehicle exhaust gas emissions and fuel economy in the city of Tehran (Figure 2.12). The method used to develop driving cycle is the concept of micro trip which uses two parameters, namely, average speed and idle time percentage. In this study the authors use four traffic condition for the purpose of collecting data, congested urban condition, urban condition, extra urban condition and highway as shown Table 2.5

Table 2.5: Classification of traffic condition (Naghizadeh, 2003)

<table>
<thead>
<tr>
<th></th>
<th>Congested</th>
<th>Urban</th>
<th>Extra Urban</th>
<th>Highway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Speed (km/h)</td>
<td>0-10</td>
<td>10-25</td>
<td>25-40</td>
<td>&gt;40</td>
</tr>
<tr>
<td>Idle time (%)</td>
<td>0-100</td>
<td>&lt;60</td>
<td>&lt;24</td>
<td>&lt;13</td>
</tr>
</tbody>
</table>

The next step is calculated the duration at each traffic condition using the following formula:

\[
t_i = \frac{t_{\text{drive cycle}}}{t_{\text{overall}}} \sum_{j=1}^{n} t_{ij}
\]  

(2.1)

Where:
\( t_i \) is duration of category number \( i \) (\( i = 1, 2, 3, 4 \)) in the cycle,
\( t \) drive cycle is duration of the final drive cycle,
\( t \) overall is duration of all recorded data,
\( t_{ij} \) is the time of microtrip number \( j \) in category number \( i \),
\( n_i \) is the total number of microtrips within category number \( i \).
From the result, the Tehran car driving cycle has greater maximum acceleration and deceleration but smaller average acceleration and deceleration, than the FTP cycle, the lower emissions and lower fuel consumptions.

Figure 2.12: Tehran driving cycle (Naghizadeh 2003)

2.5 Motorcycle driving cycle

Other vehicles such as cars and trucks, motorcycles are also used in the study to produce driving cycle. The cycle will be discussed including Edinburgh Scotland driving cycle, Khon kaen city Thailand driving cycle and Makassar city, Indonesia driving cycle.

2.5.1 Edinburgh and Delhi driving cycle

This study involves two cities which are Edinburgh and Delhi as a case study (Saleh et al., 2010). The method used to developed cycle is micro trip technique where data
was collected from trip in urban and rural routes. A data collection was selected at the target vehicle and installs the data acquisition.

Figure 2.13 shows driving cycles for Delhi driving cycle (DMDC) for urban while Figure 2.14 shows driving cycles for Edinburg driving cycle (EMDC) for rural. The results show that EDMC has the acceleration and deceleration rates higher than DMDC. The study was done using 44 trips for both the routes and used the 12 parameter. Then, the parameters need to be estimated for each trip using the mean value, standard deviation (SD) and coefficient of variations (COV). A filtering cycle drive is done by calculating the total absolute relative error (Sj) for each parameter using this formula;

\[ \Delta k = \frac{P_{ij} - P_{ijn}}{P} \times 100 \]  

\( k \) is assessment parameter (k varies from 1 to 12)
\( \Delta k \) is the value of the relative error for parameter \( k \)
P is overall mean value of parameter
\( p_{ijn} \) is a parameter with a value of routes \( i \) and \( j \) route category and \( n \) (number of test runs for each vehicle)

The selection of driving cycle is dependent on a minimum value of absolute relative error through the following formula;

\[ S_j = \sum_{k=1}^{12} \Delta k \]  

\( S_j \) = total absolute relative error
Figure 2.13: Driving cycle DMDC (urban) (Saleh et al., 2010)

Figure 2.14: Driving cycle EMDC (rural) (Saleh et al., 2010)
2.5.2 Khon Kaen City, Thailand

P.Khumla et al., (2010) construct driving cycle to fuel consumption and emission of motorcycle using data logger during weekend, weekend and weekday-weekend periods by the statistical method. For developed driving cycle, it collecting data using micro-trip technique and generated nine target parameter such as average speed, average running speed, time spent in acceleration, time spent in deceleration, time spent at idle, time spent at cruise, average acceleration, average deceleration and positive acceleration kinetic energy. There are four steps that involved in methodology; (1) road selection, (2) collection of speed time data, (3) data analysis and, (4) generation of driving cycle. The resulting of the cycle is 7.647 km in length, maximum velocity 70 km/h, maximum acceleration 3.6 m/s\(^2\), maximum deceleration -2.22 m/s\(^2\), and 1145 s in time duration and involves 6 intermediate stops as shown in (Figure 2.15)

Figure 2.15: Khon Kaen driving cycle (P.Khumla et al., 2010)
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