# DEVELOPMENT OF LOCALISED DRIVE CYCLE UNDER REAL TRAFFIC CONDITION 

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## DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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## STATEMENT 1

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## NOMENCLATURE

| NEDC | New European Driving Cycle |
| :--- | :--- |
| GPS | Global Positioning System |
| WLTP | Worldwide harmonized Light vehicles Test Procedure |
| FTP-75 | EPA Federal Test Procedure |
| OBD | On Board Diagnostic |
| SDC | Singapore Driving Cycle |


#### Abstract

ABSTRAK

Satu kitaran memandu adalah satu siri titik data yang mewakili kelajuan kenderaan terhadap masa. Ia adalah digunakan secara meluas untuk digunakan kepada pengeluar kenderaan, pakar alam sekitar dan jurutera lalu lintas. Kitaran memandu kereta memainkan peranan penting dalam penggunaan bahan api. Beberapa tahun yang lalu, statistik jualan bagi kereta penumpang di Malaysia telah meningkat secara beransuransur. Kitaran memandu mewakili keadaan memandu di dunia sebenar telah dicadangkan dan penggunaan bahan api kenderaan yang dianggarkan telah dibandingkan dengan keputusan yang diukur. Tujuan kajian ini adalah untuk menghasilkan satu kitaran pemanduan setempat dalam keadaan lalu lintas yang sebenar. Tambahan pula, kajian itu perlu menganggarkan penggunaan bahan api kereta. Pembangunan kitaran pemanduan kenderaan melibatkan tiga langkah: ujian pemilihan laluan, pengumpulan data, dan penghasilan kitaran memandu. Pertama, pemilihan laluan juga telah dijalankan. Kitaran memandu telah ditubuhkan bagi kawasan bandar dan juga untuk kawasan lebuhraya. Kajian yang digunakan di atas meter pengukuran dengan menggunakan aplikasi dari telefon pintar yang membantu untuk mengumpul kelajuan kenderaan sepanjang jalan dan akan menghasilkan profil kelajuan-masa. Bahagian kedua projek ini adalah untuk menganggarkan penggunaan bahan api dari kereta yang sama dengan menggunakan data dari atas meter kereta membandingkan dengan pengiraan yang dihasilkan oleh kitaran memandu. Parameter yang boleh membuat perbandingan adalah tempoh masa, jumlah jarak perjalanan, kelajuan maksimum dan kelajuan purata. Data rujukan boleh dari data NEDC. Kaedah ini adalah mesra pengguna dan juga boleh digunakan dalam kehidupan seharian. Penggunaan bahan api kereta itu dihasilkan dalam bentuk satu liter bagi setiap 100km. Keputusan adalah yang baik dengan nilai anggaran. Kitaran memandu setempat mempunyai corak mereka yang mewakili keadaan ujian jalan raya tersebut. Ia bukan sebenar untuk diikuti oleh negara yang berlainan, walaupun NEDC atau WLTP.


#### Abstract

A drive cycle is a series of data points representing the speed of a vehicle against time. It is widely used for vehicle manufacturers, environmentalists and traffic engineers. The drive cycle of cars plays important roles in fuel consumption. A few years ago, the sales statistic for passenger cars in Malaysia was increased gradually[4]. Drive cycle that represents the real-world driving conditions had been proposed and estimation vehicle fuel consumption was compared with measured results. The purpose of this study is to develop a localised drive cycle in a real traffic condition. Furthermore, the study needs to estimate the fuel consumption of the car. The development of the drive cycle of the vehicle involves three steps: test route selection, data collection, and drive cycle development. Firstly, the selection of the routes also was conducted. The driving cycle was established for the urban area and also for the extra-urban area. The study used the on board measurement method which is by using the application from the smart phone that can help to collect the speed of the vehicle along the road and produce the speed-time profile. The second part of the project was to estimate the fuel consumption of the same car using the data from on board meter of the car compare with the sample calculation that produced by drive cycle. The parameters that can compare are duration, total distance travelled, maximum speed and average speed. The reference data is from the NEDC data. The method is userfriendly. The fuel consumption of the car was produced in term of litre per 100 km . The results are in a good fit to the estimated values. The localised drive cycle has their patterns that represent the behavior of the road test. So this drive cycle cannot be comparing with others country.


## 1. Chapter 1: Introduction

### 1.1. Overview

The drive cycle of cars plays important roles in fuel consumption and trade issue. The lab based methods have been highly criticised due to their being far from reality as well as easily manipulated. This study will combine real driving experiments which are urban driving cycle and extra urban driving cycle. In addition, the results of fuel consumption from experiments that will be calculated will be compared with the value that stated on the board of the car.

From 2011 until 2015, the sales statistic for passenger cars in Malaysia was increased gradually [4]. Perodua brand was $1^{\text {st }}$ ranking in Malaysia vehicle sales data for July 2015 [5]. So that, this study will focuses to the most popular vehicle model in Malaysia which is Perodua Myvi SE 1.5 (automatic). This paper intends to develop a localised drive cycle under real traffic condition.

A drive cycle is a set of data points that representing of vehicle speed versus time and also representing about how the vehicle is driven [6]. By using Geo Tracker application on a smart phone, it will record the speed along the road and the time taken from one point to another point will record. Besides that, this drive cycle has a relation with fuel consumption of the vehicles. In the event that another drive cycle energizes distinctive area or even unique excitation in a similar area, different exhaust gas emissions and fuel consumptions are acquired, what's more, accordingly if the drive cycle is not delegated, the streamlining on a single drive cycle, will be a problematic answer for real-world driving [7].

### 1.2. Problem Statement

In Malaysia, there is no drive cycle that has been developed before this [8] but last year there was one drive cycle that has been developed for a car. But there was not enough for our country that every year our automotive section industry always grows. So that this study would like to develop a second drive cycle in Malaysia even though using same model which is Perodua Myvi.

Furthermore, by referring this drive cycle will help our automotive industry become stronger and can challenge others automotive industry from different countries. This drive cycle will show the fuel consumption of the car. Thus, it can help users to buy a better car by comparing the fuel consumption of the different cars.

In addition, it also can help the users to fill up a fuel in a tank more easily or more suitable for your car. By using a better ways to fill up the fuel, the user can manage their journey and also by helping from the drive cycle. So that, this paper can help our production of the automotive industry and also can make user become more trust to buy our country product.

### 1.3. Objective

The objectives of this study, which are:-
i. To develop localised drive cycle in a real traffic condition
ii. To estimate the fuel consumption of the car.

### 1.4. Scope of the Project

The scopes of this project mainly focus on the localised drive cycle that plays important roles in fuel consumption and fuel economy of the car (Perodua Myvi). This drive cycle represents the activities of the road test which are in a city (urban cycle) and highways (extra-urban cycle).

Furthermore, by having a certain checkpoint to stop was to compare the pattern of the drive cycle and fuel consumption of the car. The road test was run three times in the clockwise and three times in the counter clockwise.

Lastly, from the drive cycle of each test will be compared to their pattern, fuel consumption and fuel economy by using a simple calculation. Moreover, drive cycle will be compared with the other countries, for example New European Driving cycle (NEDC), Worldwide harmonized Light vehicles Test Procedure (WLTP) and EPA Federal Test Procedure (FTP-75.

### 1.5. Flow chart



Figure 1.1: Flow chart of the project

### 1.6. Outline Paper

In this paper consists of five chapters that explained the overall information and details from the introduction to the conclusion of this project. Chapter 1 is the introduction of the project to the research background, problem statement, objectives, flow chart and scope of the project.

While, for Chapter 2 is about the literature review from others researcher or related to this project from the past journal, articles, books and webpages as references.

In chapter 3 which is the methodology, where the procedure, experiment and calculations will be explained briefly on how they conducted and needed to be included in the project.

Chapter 4 is discussed about the results and the discussions have been obtained. Lastly, the chapter 5 is the conclusion of the project. The summary of the project implementation and achievement are included.

## 2. Chapter 2: Literature Review

### 2.1. Definition of a drive cycle

First of all, what is a drive cycle? A drive cycle is a series of data points representing the speed of a vehicle against time [9]. From the others researches the meaning for a drive cycle was a speed time sequenced profile developed for certain road, route, specific area or city [10]. Besides that, a drive cycle is a represented speed-time profile for a study area within which a vehicle can be idling, accelerating, decelerating or cruising [2]. In conclusion, the meaning of the drive cycle is a profile that representing the activities in a road test in term of speed-time profile.

### 2.2. The function of the drive cycle

The main function of the drive cycle was to determine the activities of the road test by analysing the speed-time profile. Every venue or city has a different drive cycle, even though in a same country. In this regards, this project to be done by producing a localised drive cycle around Parit Buntar, Nibong Tebal and Bandar Bharu.

Besides that, the US EPA uses 5 standard test cycles based on Dynamometers in laboratory conditions to provide point estimates of vehicle fuel economy to consumers [11]. Furthermore, the used of the drive cycle also can help the users to choose their vehicles. The figure 2.1 below shows the conceptual framework of the user that interested in purchasing the conventional vehicles. First of all, the users need to know the more precise information about the fuel consumption from the customised drive cycle.

Then, from the information, they need to make a decision with type of car that they want to buy. Depending on the income levels people may also change their decision. Lastly, from their decision, it will be reflected in energy use, emission and vehicle travelled[11].


Figure 2.1: Conceptual framework: strategies, behaviour, and outcomes [11].
Other than that, the used of drive cycle also can obtain the pollutant emission of the vehicle level by referring from a vehicle characteristic, operating conditions, level of maintenance, temperature, fuel characteristics, altitude and humidity as presented in Table 2.1 below.

Table 2.1: Factors that affect the pollutant emissions of vehicles [1].

| Characteristics | Description |
| :---: | :---: |
| Vehicle | - Engine type and technology-diesel, two strokes, four strokes, Otto, types of transmission system. <br> - Exhaust, crankcase and evaporative emission control system <br> - Engine mechanical condition and adequacy of maintenance. <br> - Air conditional, trailer towing and adequacy of maintenance. |
| Fuel | - Fuel properties, quality and alternative fuel. |
| Fleet | - Vehicle mix (number and type of vehicle use). <br> - Vehicle utilization (kilometres per vehicle per year) <br> - Age profile of the vehicle fleet and clean fuels program. <br> - Traffic mix and choice of mode for passengers. |
| Operating | - Altitude, temperature, humidity (for $\mathrm{NO}_{\mathrm{x}}$ emissions) <br> - Vehicle sews pattern - number and length of trips, number of cold starts, speed, loading, aggressiveness of driver <br> - Degree of traffic congestion, capacity and quality of road infrastructure and traffic control system. |

### 2.3. Data collection

The literature review shows that the data collection can be categorised into three methods which are chase-car method, on board measurements method and combined method of chase-car, on-board measurement and circulation driving [12].

### 2.3.1. Chase car method

The first method which is a chase car method is involving a random selection of the target vehicle in the traffic stream and the chase car will follow that vehicle while keeps a constant distance during the test [13]. In the United States, their drive cycle has been done by using a chase-car method [14]. The selection of target vehicle needs to be selected that followed the road rules.

### 2.3.2. On-board measurement

Then, the on-board measurement method is considered as instrumented vehicle. For example, by using the Global Positioning System (GPS), it can record the longitude and the latitude or position of the vehicle for every second. Besides that, onboard diagnostic reader (OBD II) that extracts vehicle data including OBD speed, coolant temperature, engine load and engine speed during the recorded runs conducted over a period of three days while the Delhi instrumented vehicles made four runs per day for six days a week [15].

Furthermore, at Hong Kong, their collection data for the drive cycle was using optical sensor pointing to the axle of the vehicle [16]. By using the infrared photoelectric sensor and pulse converter, the rotation of the wheel was measured. Then, the data that produced will be displayed in the micro-computer. But the latest Hong Kong drive cycle in 2007 used different device which is using GPS loggers [17]. But nowadays the application on smart phone can collect the data speed that's needed to produce a drive cycle.

### 2.3.3. Cycle construction

This method of cycle construction varies with the purpose of driving cycle, estimation of fuel consumption, estimation of emission inventories, or for traffic engineering purpose [18].

This is because when the country has a low air temperature the cold start needs to be considered when developing the drive cycle for fuel consumption or emission estimation. The surrounding temperature will affect the fuel consumption and emission of the car so that it must to be monitored consistently [19]. Four major drive cycle construction methods were micro-trip based cycle construction, pattern classification cycle construction, modal cycle construction and segment based cycle construction.

For the micro-trip based cycle construction, it can be defined as driving activities along a road test even though in an idle period [19]. For example, in this project were divided into two parts which are urban driving and extra-urban driving. This method was a better approach for fuel consumption and emissions of the vehicle.


Figure 2.2: Micro-trip assignments derived from the target drive cycle [20].

Then, for segment-based cycle construction, it is similar to the micro-trip based cycle construction but the roadway type is considered when selecting the route. For a drive cycle for traffic engineering purpose, this method was the most suitable to followed [21].

### 2.4. Others countries drive cycle

### 2.4.1. USA drive cycle (FTP-75)

The United State drive cycle also known as Federal Test Procedure (FTP-75) used for emission certification testing of cars and light duty trucks. The FTP-75 cycle that shows in figure 2.3 was obtained from FTP-72 as shown figure 2.4. This drive cycle divides into three phases.

For phase 1, it is known as cold transient with distance 5.8 km and the temperature about $20-30^{\circ} \mathrm{C}$ and duration about 505 s . While for the phase 2 that known as cold stabilized, the distance was 6.3 km and the duration about 505 s . For the third phase which is hot start phase with distance 5.8 km and the duration also 505 s . All the data were recorded in table 2.2 below.

Table 2.2: The main characteristic of FTP 72 and 75 drive cycles [2].

| Cycle <br> name | Total <br> time <br> $(\mathbf{s})$ | Distance <br> $(\mathbf{m})$ | Cruise <br> period <br> $(\%)$ | Accelerating <br> period (\%) | Average <br> speed <br> $(\mathbf{k m} / \mathbf{h})$ | Positive <br> Kinetic <br> Energy (m/s $\mathbf{2}^{2}$ |
| :--- | :---: | :---: | :---: | :--- | :--- | :--- |
| FTP-72 | 1369 | 11996.85 | 18.04 | 36.96 | 31.6 | 4.307 |
| FTP-75 | 1874 | 17786.59 | 20.06 | 36.45 | 34.2 | 4.197 |



Figure 2.3: US EPA Urban Dynamometer Driving Schedule (FTP-75) [2].


Figure 2.4: Urban dynamometer driving schedule (FTP-72) [2].

### 2.4.2. Worldwide harmonized Light vehicles Test Procedure (WLTP)

The worldwide harmonized light vehicles test procedure (WLTP) is a global harmonized standard for determining the levels of pollutants, emissions, fuel consumption and electric range for the passenger car. This is an improvement of the NEDC. However this WLTC cycles are still unrealistic for the Western Europe area. The figure 2.5 below shows the WLTC for the passenger car. The maximum for this drive cycle was $131.3 \mathrm{~km} / \mathrm{h}$ and for the average speed along the road test was $53.5 \mathrm{~km} / \mathrm{h}$. The duration and distance for the WLTP was quite higher compare to the NEDC.


Figure 2.5: The WLTC for class 3 (passenger car).

### 2.4.3. New European drive cycle (NEDC)

For the new European drive cycle (NEDC), it consists of two types of cycle which are urban driving cycle (UDC) and extra-urban driving cycle (EUDC). This project is following this type of drive cycle so that the result can be compared. For ECE-15 cycle, the cycle was repeated 4 times of 195 s while for the EUDC, the duration of the cycle was 400 s. Figure 2.6 below shows the ew European drive cycle.


Figure 2.6: New European driving cycle (NEDC) [22].

For the first part which is an urban driving cycle, the characteristics of this section were low engine load, low vehicle speeds and low exhaust temperature. On the other hand, the EUDC has a higher velocity which is $120 \mathrm{~km} / \mathrm{h}$. The table 2.3 below show the comparison the characteristics of the NEDC, WLTP, and FTP-75.

Table 2.3: comparison the characteristics of NEDC, WLTP, and FTP-75 [3].

| Parameter | NEDC | WLTP | FTP-75 |
| :--- | :--- | :--- | :--- |
| Duration | 19 min 40 s | 30 min | 31 min 15 s |
| Distance (km) | 10.90 | 23.30 | 17.80 |
| Stop duration (\%) | 23.70 | 12.60 | 17.90 |
| Max. speed $(\mathbf{k m} / \mathbf{h})$ | 120 | 131.30 | 91.20 |
| Average speed $\mathbf{( k m / h})$ | 33.40 | 46.50 | 34.10 |
| Max. acceleration $\left(\mathbf{m} / \mathbf{s}^{\mathbf{2}}\right.$ ) | 1.06 | 1.67 | 1.47 |
| Min. acceleration $\left(\mathbf{m} / \mathbf{s}^{\mathbf{2}}\right.$ ) | -1.39 | -1.50 | -1.48 |

### 2.4.4. Dublin city drive cycle

For the Dublin city drive cycle, it has been developed only for the urban drive cycle. On road test, the data collection was on-board diagnostic tool and saved into a data acquisition. Figure 2.7 shows the routes that used for the Dublin city drive cycle.


Figure 2.7: Routes that were employed during the tests [15].

Figure 2.8 shows the example of the Dublin drive cycle that has been developed. The duration of the test was around 15 minutes and the maximum speed up to $55 \mathrm{~km} / \mathrm{h}$.


Figure 2.8: Dublin Drive cycle (DDC) [15].

### 2.4.5. Singapore driving cycle (SDC)

This Singapore driving cycle chose a combining method data collection, which is chase car method, instrumented vehicle with on-board measurement and hybrid method of the chase car, instrumented vehicle and circulation driving. The figure 2.9 below shows the route that has been chosen for developing a Singapore driving cycle.


Figure 2.9: Inner ring and outer ring road systems in Singapore for circulation driving[13].
The speed-time profile that shows in figure 2.10 below was the finalized driving cycle that compared with the NEDC. The figure shows the difference on the maximum speed of the both drive cycles. In conclusion, Singapore has a lot of urban area because the figure below shows the maximum speed was quite low.


Figure 2.10: Finalised Singapore driving cycle (SDC) and NEDC [13].

## 3. Chapter 3: Methodology

This study only does experimental part which is doing the road test around Parit Buntar, Nibong Tebal and Bandar Bharu. The vehicle that has been chosen was Perodua Myvi 1.5 se as shown in figure 3.1 below. The data collection that was used in this project was on-board measurement by using a Geo tracker application on the smart phone.


Figure 3.1: The Perodua Myvi 1.5 se.

Before that, the route for drive cycle has been set. I chose this route as shows in appendices, figure 7.6 because this route includes the urban driving and also extraurban driving. By using the same route, the experiment will conduct two types of flow which are counter clockwise and clockwise. Then, the result of these two types of flow will be compared. Furthermore, by having a certain checkpoint, the data for each checkpoint will be compared and will be analyse.

The experiment started at a petrol station to full fill up the tank with petrol fuel RON95 by using method one click only (it will stop automatically when the petrol inside the tank touch the nozzle) and at medium flow rate. Before refilling the petrol, the car will be stay without starting the engine for a one minutes to make sure the petrol inside the tank not stirred up. This is because when the petrol not in static, it will affect the volume of the petrol. The nozzle will stop filling the petrol when the petrol inside the tank touches the nozzle. So that by applying the single click on the medium speed of the petrol, it can ensure that the petrol will fully fill up.

Then, the experiment will run by driving a car along a route and will stop at certain checkpoints to differentiate between urban driving and extra-urban driving. During the experiment, there are no other passengers. Thus, the load of the car will be same each of the tests. The load of the car will affect the fuel consumption and fuel economy of the car. Moreover, the experiment will undergo with the air conditioner turned on. The air conditioner itself can affect the fuel consumption and fuel economy of the car. Thus, to develop the localised drive cycles under a real traffic condition, this study need to follow the usual people do while driving their car.

Before starting the engine of the car, the ODO meter (Trip A) and the fuel economy metre on the board of the car that was shown in figure 3.2 was set up to zero. Then, the car was started and the application from the smart phone which is Geo Tracker application will start. The time taken from starting until the end will be recorded by using the application and also will be recorded by referring the time from that display on the monitor of the car. The speed of the car will follow the speed limit of the certain area and also the experiment must flow like other users on the road.


Figure 3.2: Car board Perodua Myvi
After reaching at a checkpoint, the car will stop and change the gear to the neutral and pull the hand-brake. Then, the time and also the value of the ODO meter will be recorded. For the precautionary step, the checkpoints that have been chosen are around the petrol station and at the large space that can a car stop. The checkpoints were placed at strategic places, for example, before entering the highways (extraurban). This is because the result can be divided into two categories which are city (urban) and highway (extra-urban).

During the experiment at extra urban driving, the limit speeds at the area only $110 \mathrm{~km} / \mathrm{h}$ but needs to achieve $120 \mathrm{~km} / \mathrm{h}$ for 1 km because want to compare with the New European Driving Cycle (NEDC). The all result will be compared with the other countries of drive cycle.

The experiment must follow the road rule for example stop at the traffic lights, cannot take over a car at double line section and also the speed limit. This is because to ensure that a safety of the people on the road itself. The data can see the differences because of these factors.

After complete one road test, the car once again will full fill up the petrol to determine the fuel that was consumed during the test. The same petrol station and also the same petrol pump were chosen to get a better result. After the engine was turned off, the time taken to complete a cycle was taken and also the value of ODO metre was recorded that represent the length of the road that has been travelled. The same method was used at the beginning of the test which is letting the car stay at an ideal condition without starting the engine and a single click at a medium speed.

Furthermore, by using Geo Tracker application, it can record the speed of the car. Thus, it can produce a graph of speed against time for example in Appendix. The disadvantage of this application was when the car was stopping the speed in the application not show $0 \mathrm{~km} / \mathrm{h}$. But from the graph itself it showed the pattern was ideal but not at $0 \mathrm{~km} / \mathrm{h}$.

On the other hand, the test of idle time will be undergoing. The car will be full filled up with petrol then park the car near to the petrol pump for an hour or more. Then, calculate the fuel consume for every second by using a formula.

After complete all the road test, the speed data from the application was recorded in Microsoft Excel to produce a drive cycle. Then, a simple calculation to calculate the fuel consumption and fuel economy of the car was calculated by the equation (1) and (2) below.

Lastly, from the drive cycle that was produced will be compared with the NEDC. The characteristics that will be compared were maximum speed, the distance and the duration to complete one cycle. The reason NEDC was chose for comparing the data was in Malaysia, the road user used extra urban area and urban area quite similar with the NEDC.

## 4. Chapter 4: Results and Discussion

### 4.1. Overview

In Malaysia, our road users always use urban area and also an extra urban area every day. The microtrips for this localised drive cycle divide into four parts. Two microtrips for extra urban drive cycle and another two were for the urban drive cycle. For the extra-urban drive cycle, the maximum speed was $110 \mathrm{~km} / \mathrm{h}$ but extra urban divide into three types, which are high speed $(110 \mathrm{~km} / \mathrm{h})$, medium speed $(90 \mathrm{~km} / \mathrm{h})$, and slow speed $(70 \mathrm{~km} / \mathrm{h})$. While for the urban drive cycle the maximum speed was $60 \mathrm{~km} / \mathrm{h}$. The equations used in data analysis and developers of the drive cycle were shown below:
a) $S_{\text {avg }}=\frac{d(\mathrm{~km})}{t(\mathrm{~s})}$
b) $F C(l / 100 \mathrm{~km})=\frac{1}{F E(\mathrm{~km} / \mathrm{l})} \times \frac{1}{\frac{1 \mathrm{~km}}{100 \mathrm{~km}}}$
c) $F E(k m / l)=\frac{d(k m)}{F(l)}$
d) $\%$ difference $=\frac{\mid \text { reference value-actual value } \mid}{\text { reference value }} \times 100 \%$

Where $S_{\text {avg }}$ is the average speed of a microtrip, $d$ is the distance travelled, $t$ is the microtrip duration, FC is fuel consumption, FE is a fuel economy and F is fuel use in microtrip.

### 4.2. Localised drive cycle

For the localised drive cycle which is around Parit Buntar, Nibong Tebal and Bandar Bharu, the speed profile for the clockwise route which is set 1 , set 2 and set 3 while for anti-clockwise is set 4 , set 5 , and set 6 was shows in figure 4.1 . For the set 1 , the duration was 57 minutes and 22 second to complete one cycle which is 39.59 km . The maximum speed was $118 \mathrm{~km} / \mathrm{h}$ and for the average speed was $41 \mathrm{~km} / \mathrm{h}$. The drive cycle for set 1 was shown below.


Figure 4.1: Drive cycle for set 1.

Then for the set 2 that shown in figure 4.2, the time taken to complete one cycle which is 39.63 km was 60 minutes and 41 second. The maximum speed that was driven in this cycle was $118 \mathrm{~km} / \mathrm{h}$ and the average speed was $39 \mathrm{~km} / \mathrm{h}$.


Figure 4.2: Drive cycle for set 2.

For the third set in a clockwise route that shown in figure 4.3 below, the duration to complete one cycle was 52 minutes 12 seconds with a distance 40.27 km . The maximum speed was $122 \mathrm{~km} / \mathrm{h}$ while the average speed was $46 \mathrm{~km} / \mathrm{h}$ ).


Figure 4.3: Drive cycle for set 3.
In conclusion for this route, it's shown that the three of them not much difference of data but each of them has their own drive cycle because each of the cycles has their own activities. Furthermore, in comparison to the desired cycle which is set 1 , the resultant duration differs by $6.9 \%$ from set 2 and $8.8 \%$ for the set 3 . Hence, the resultant cycle is accepted as the localised drive cycle. While for the counterclockwise route which is set 4 , the time taken to travel 40.26 km was 50 minutes. The maximum speed of this cycle was $121 \mathrm{~km} / \mathrm{h}$ and the average speed was $48 \mathrm{~km} / \mathrm{h}$.


Figure 4.4: Drive cycle for set 4.

Next for the set 5 drive cycle, the duration was 50 minutes and 7 seconds. Then, the distance from the initial position to final position was 40.38 km . The maximum speed was $121 \mathrm{~km} / \mathrm{h}$ and the average speed of this cycle was $48 \mathrm{~km} / \mathrm{h}$. The drive cycle for set 5 was shown in figure 4.5 below.


Figure 4.5: Drive cycle for set 5 .

For the set 6 drive cycle, the duration was 49 minutes and 19 second to complete 40.29 km from the initial position until the final position. Then, the maximum speed was $122 \mathrm{~km} / \mathrm{h}$ and the average speed was $48 \mathrm{~km} / \mathrm{h}$.


Figure 4.6: Drive cycle for set 6.

### 4.3. Estimation of passenger car's fuel consumption and fuel economy

The table 4.1 below showed the result of fuel consumption and fuel economy of the passenger cars from the on board metre of the car and the calculation for each cycle. For each cycle, their own fuel economy and fuel consumption will show their activities of the road.

The relationship between fuel economy and fuel consumption was inversely proportional. When the fuel economy was higher, the fuel consumption was lower. As the table below shows, the highest percentage difference was the set 1 . The possible error that occurs at set 1 was a delay of the petrol pump sensor that not stops filled up the petrol immediately when the petrol already touches the nozzle.

Furthermore, the fuel that consumes when idle time of 4760 seconds was 1.46 liter. This result has an error which is there has a distance travelled around 50 to 80 meters only. This can be ignored because the fuel that consume for 50 to 80 meters was not so high. Thus, the fuel consumption per unit second was 0.000308 litres per second. So that the fuel consumption and the fuel economy that has shown in table 4.1 was including the ideal time of the car.

The on board data will act as a reference value because users will always look at the on board metre. The all result of percentage difference was less than $10 \%$. Thus, as conclusion, the result was accepted for a localised drive cycle. It will help the users to plan their journey without worried.

Table 4.1: The difference between on board and calculation data.

| Set | Total Fuel economy (km/l) |  |  | Total Fuel consumption (I/100km) |  |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
|  | On <br> board | Calculation | \% difference <br> $(\%)$ | On <br> board | Calculation | \% difference <br> $(\%)$ |
| $\mathbf{1}$ | 16.8 | 15.46 | 7.9 | 5.95 | 6.47 | 8.7 |
| $\mathbf{2}$ | 15.8 | 16.51 | 4.4 | 6.33 | 6.06 | 4.2 |
| $\mathbf{3}$ | 17.5 | 18.30 | 4.6 | 5.71 | 5.46 | 4.4 |
| $\mathbf{4}$ | 16.7 | 16.72 | 0.1 | 5.99 | 5.98 | 0.2 |
| $\mathbf{5}$ | 16.8 | 16.42 | 2.3 | 5.95 | 6.09 | 2.4 |
| $\mathbf{6}$ | 16.5 | 16.31 | 1.2 | 6.06 | 6.13 | 1.2 |

### 4.4. Real road representative

### 4.4.1. Checkpoint/microtrip A

The figure 4.7 shows, each of the cycles has their own pattern or the most accurate term is activities or behaviour of the road condition. This drive cycle is an urban drive cycle. The initial pattern of the drive cycle for set 1 and set 3 is quite similar compared with the set 2 because at the area have a junction. The initial phase of set 2 , road condition is lighter so that a car can move freely but suddenly the road condition quite heavier compared with the others. The smoothest pattern of speed-time profile is set 2 because the car does not stop too much.




Figure 4.7: The difference drive cycle at checkpoint A.

### 4.4.2. Checkpoint/microtrip B

For this area, the drive cycle is extra-urban drive cycle which is the high speed highway. As the figure 4.8 shows, the smoothest pattern of drive cycle is set 2 because the pattern does not have a much of fluctuate. For the set 3, the pattern was the roughest due to heavy road condition. The road condition for set 1 was the medium condition among three of its. The maximum speed for this three drive cycle was around $120 \mathrm{~km} / \mathrm{h}$ but only for 1 km because our maximum speed rule was $110 \mathrm{~km} / \mathrm{h}$.



Figure 4.8: The difference drive cycle at checkpoint B.

