Driving Cycle Analysis for Fuel Economy and Emissions in Kuala Terengganu During Peak Time

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***Abstract*—Number of vehicles grows rapidly in Kuala Terengganu by year. This increment is troubled by the performance of the vehicle regarding pollutants generated. Plug-in hybrid electric vehicles (PHEV) are widely considered to be the most promising vehicles instead of the traditional engine vehicles to reduce fuel consumption and exhaust gas emission. The objectives of this paper are to develop driving cycle of Kuala Terengganu and to analyse the fuel economy and emissions in Kuala Terengganu during peak time. Driving cycle is where PHEV is used as the main apparatus to determine the driving cycle data. In this study, the on-road measurement method is used to collect the data, along with the global positioning system. This technique involves recording speed-time dataset in the real-world driving cycle. Three main methods to identify the best driving cycle are route selection, data collection and data analysis. The data were analysed to get the best driving cycle using a computer program, which is Mathematical Laboratory (MATLAB), along with validated parameters.**

***Index Terms*—Driving Cycle; Micro-Trip; Exhaust Emission; Fuel Consumption.**

I. INTRODUCTION

The increment prices of gasoline, the level of an alarming pollutant and the effects that will affect this problem in future, it should be concerned. This pollutant comes from exhaust emission of vehicles, erroneous technique of road users and unwary of traffic users. For pioneering vehicle emission models and powertrain input, the development of driving cycle is important [1]. According to [2], there are several factors which affected the emission levels which are vehicle-related factors such as model, size, fuel type, technology level and mileage, and also 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. Traffic engineer, researcher, and technologist are brainstorming to overcome this problem by producing the hybrid car. In production, a hybrid car, the main core needed is a driving cycle and powertrain [3]. Driving cycle involves recording a set of real-world speed-time data, where the vehicle speed concerning time will be recorded [4] or driving cycle is a speed-time profile which represents driving patterns in region or city [5]. In general, a driving cycle is made up of a few micro-trips, where micro-trip is defined as the trip made between two idling periods [5].

II. DC CHARACTERIZATION AND DEVELOPMENT

The flowchart in Figure 1 shows the research activities and methodology in finding the best driving cycle for Kuala Terengganu (KT). The inputs of KT driving cycle are second-by-second speed and location. The data are first will be collected at peak hour which is 8.30 a.m. with 15 runs of data. The route for route-to-work (RTW) is selected based on the population of traffic users in Kuala Terengganu. The data then will be analysed using Mathematical Laboratory (MATLAB) in order to develop the best driving cycle in KT.

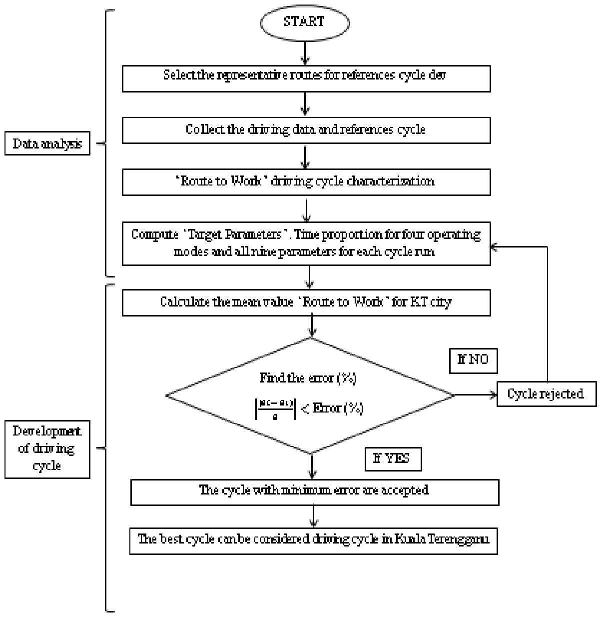

Figure 1: Flowchart of driving cycle development

Figure 2 highlights the selected route for KT driving cycle from Kampung Wakaf Tembesu to Wisma Persekutuan. This research took 15 days for one time which is at 8.30 am since this time is the peak hour for RTW and this data collection is taken on weekdays only. The data is taken throughout the time of 8.30 a.m. for 15 days on April 2017.

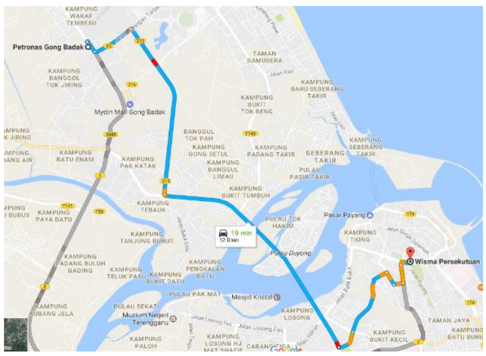

Figure 2: Selected route of KT driving cycle.

After the route is selected, the test run is handled to compute all the nine parameters as listed in Table 1. Those parameters are average speed, average running speed, average acceleration of all acceleration phases, average deceleration of all deceleration phases, time proportion of idling, time proportion of acceleration, time proportion of cruise, time proportion of deceleration, average number of acceleration-deceleration changes within one driving period and root mean square of acceleration. After the entire 15 runs are computed, the mean value and the percentage error are calculated.

Table 1
Assessment of Nine Parameters

No	Variable	Unit	Formula
1	Average Speed, v_1	km/h	$v\_avg = 3.6\frac{dist}{T_{total}}$
2	Average Running Speed, v_2	km/h	$v\_run = 3.6\frac{dist}{T_{drive}}$
3	Average Acceleration, a	m/s²	$a\_avg = \left(\sum_{i=1}^{n}\begin{cases}1 (a_i > 0)\\ 0 \text{ (else)}\end{cases}\right)^{-1}\sum_{i=1}^{n}\begin{matrix}1 & (a_i > 0)\\ 0 & \text{(else)}\end{matrix}$
4	Average Deceleration, d	m/s²	$d\_avg = \left(\sum_{i=1}^{n}\begin{cases}1 (a_i < 0)\\ 0 \text{ (else)}\end{cases}\right)^{-1}\sum_{i=1}^{n}\begin{matrix}1 & (a_i < 0)\\ 0 & \text{(else)}\end{matrix}$
5	Time Proportion of Idling, P_i	%	$\%drive = \frac{T_{drive}}{T_{total}}$
6	Time Proportion of Cruise, P_c	%	$\%cruise = \frac{T_{cruise}}{T_{total}}$
7	Time Proportion of Acceleration, p_a	%	$\%acc = \frac{T_{acc}}{T_{total}}$
8	Time Proportion of Deceleration, P_d	%	$\%dec = \frac{T_{dec}}{T_{total}}$
9	Root Mean Square of Acceleration, RMS	m/s²	$RMS = \sqrt{\frac{1}{T_{total}}\sum_{i=1}^{n}a_i^2}$

This research is conducted to analyses the route for 8.30 a.m. KT driving cycle. This activity is as part of an initiative to reduce air pollution and gas emission using the plug-in hybrid car in KT area because driving cycle is the main core to build plug-in hybrid electric vehicle (PHEV) powertrain.

In order to produce the driving cycle, three major cores should be done which are route selection, data collection and drive cycle development. Two methods that can be employed to collect the speed-time data are chase vehicle method and onboard technique method using global positioning system (GPS).

A. Route Selection

This route as in Figure 2 was chosen since it is the most used route by local people for RTW in KT. In this study, speed-time data is collected by using GPS based on onboard measurement method along the selected route starting from Kampung Wakaf Tembesu to Wisma Persekutuan. Kampung Wakaf Tembesu as the starting point is chosen due to its population. Whereas, Wisma Persekutuan as the end point is chosen because most of the government sectors located in the Wisma Persekutuan and it is nearby.

B. Data Collection

Data was collected at peak hour which is 8.30 am along the selected road. There are three types of techniques or ways to collect the data which are chase car technique, onboard measurement technique and the combination of onboard measurement and circulation driving. Chase car technique is when instrumented vehicle record the second-by-second speed data as it follows the target vehicles. Meanwhile, the onboard measurement technique is when speed-time data collections were carried out using a real-time logging system equipped in the selected vehicle along the predetermined route. Lastly, a combination of onboard measurement and circulation driving, also known as the hybrid method, is the combination of the two techniques. A major limitation of chase car technique is that it is difficult to chase a car when driving behaviours are aggressive. Thus, KT driving cycle is using onboard measurement technique for the data collection since it is more suitable for KT drivers' irregular behaviour and to avoid risks such as accident and sudden loss of control.

C. Generation of Micro trips

The development of a drive cycle is based on micro-trips. Micro-trip is a trip between two successive time points at which the vehicle velocity is zero [8]. Each micro trip starts with an idle phase and ends with a decelerating phase which reduces to zero. This measure of motion involves of acceleration, cruise and deceleration modes. A period of rest is at the beginning and end of a micro-trip. The whole data has to be separated into a number of micro-trips. A large number of micro-trips can be acquired after this process for all collected data. Then, group the micro-trips according to its driving situation. Generated micro-trips will be spliced to develop a driving cycle in the future steps.

D. Selection of Assessment Measures

Performance measures or assessment measures is a critical step and defines the quality of developed cycles. It represents the trend and characteristics of the complete driving dataset. A set of measures have been selected in the existing. Different methodologies used different forms of these parameters. Speed parameters include average speed, maximum speed minimum speed and root mean square speed. Acceleration and deceleration parameters used average acceleration, average deceleration and an average number of acceleration and deceleration changes. A portion of driving mode includes time proportion of idling mode, time proportion of acceleration, time proportion of cruising and time proportion of deceleration are also used as parameters [6].

E. Development of Driving Cycles

Micro trip-based development method is mostly used in the current development of driving cycles. The common processes in the development of driving cycles as stated in above steps which are route selection, data collection, generation of micro-trips and lastly, the development of driving cycles. To develop the best driving cycle for RTW in KT, the speed-time data has to be divided into several driving segments or micro-trips [9]. The micro-trips then will be grouped into several bins according to their driving situation. Thus, the mean values of the parameter for each category will be calculated and will be set as target values. After that, several micro-trips are randomly picked with a total of 900-1300s of driving time and combine them as a candidate drive cycle. The nine parameters are calculated from the candidates to drive cycle, and then, the absolute difference is calculated relative to the target values. The candidate driving cycle with the minimum values of difference relative to target values is directly chosen as the actual driving cycle.

The selection of assessment measures and the development method conclude the quality of final driving cycles. Present methodologies and practices vary for the use of variable and development method. Other than that, the variable measurement used in the existing driving cycle included the measurement of fuel consumption and exhaust emission.

In current methodology for developing driving cycles, the indicated limitations are considered. This is for the minimisation of an error and to eliminate the problem that may arise in selecting the final driving cycle by a random selection.

III. RESULT AND DISCUSSION

Figure 3 shows the result of the proposed KT driving cycle for RTW at 8.30 am. The result is obtained after 15 sets of data is collected using onboard measurement method. The data then were divided into micro-trips using Mathematical Laboratory (MATLAB) program, and they were grouped or clustered into several groups according to the driving situation. In this research, the group is based on the average speed which is between 0 to 15 km/h, 16 to 30 km/h, 31 to 45 km/h, 46 to 60 km/h and 61 to 75 km/h. The mean values of the nine parameters are then calculated and set as target values. The maximum and minimum value of time is set depending on the number of micro-trips acquired for the actual KT driving cycle. In this research, the micro-trips acquired is 8 micro-trips and minimum and maximum total time are set as 900 to 1300 s. After the time has been set, several micro-trips has randomly picked with a total time of 900 to 1300 s and combined them as a candidate drive cycle. The nine driving parameters of the all-candidate drive cycles are then calculated. The percentage or absolute difference between target values and the candidate drive cycles are calculated. Thus, the minimum percentage error is selected which is 5.33% and the proposed driving cycle for KT at 8.30 am is obtained as in Figure 3 with eight micro-trips and total time of 1254 s.

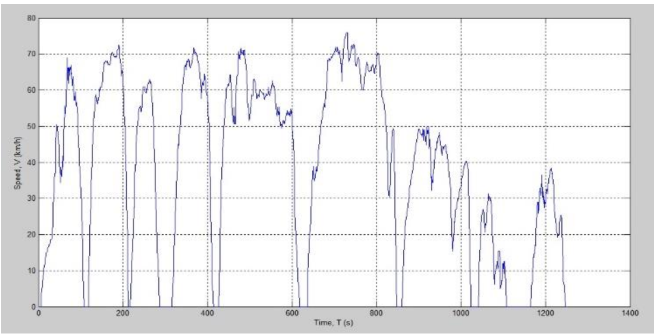

Figure 3: The proposed KT driving cycle

All the parameters for the proposed KT driving cycle are shown in Table 2. From the Table 2, it is shown that the average speed is 62.86 km/h and the average running speed is 73.74 km/h. Based on the results, it shows that the speed of the selected route and time is moderate and this condition indicates that the traffic is also clear. The time spent by the car in different operating mode is 14.75 % for the time proportion of idling, 22.46% for time proportion of idling, 39.19 % time proportion of acceleration and 32.16 % time proportion of deceleration. The rate for acceleration and deceleration is 0.77 m/s and 0.93 m/s respectively. The root mean square of acceleration is 0.94 m/s^2. The value of mean length of the driving period is 1254s. The mean length of the driving period is high it indicates that the path is good and clear without any obstacles.

Table 2
Parameter Assessment for Proposed Driving Cycle

Parameters	Value
V_{avg} (km/h)	62.86
V_{RS} (km/h)	73.74
a (m/s^2)	0.77
d (m/s^2)	0.93
P_i (%)	14.75
P_c (%)	22.46
P_a (%)	39.19
P_d (%)	32.16
RMS (m/s^2)	0.94

The emission developed from KT Driving cycle is shown in Figure 4. There are four types of gas such as carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_X) and particulate matter (PM) are measured in both mass and the number of particles.

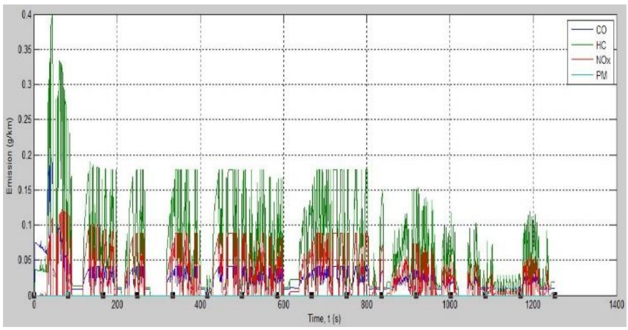

Figure 4: The emission developed from KT Driving cycle

HC and CO are produced on proposed KT driving cycle for 8.30 a.m. are 0.974 grams/mile and 1.265 grams/ mile respectively. This number of HC and CO are not an alarming number of exhausted gases. The number of NOx and PM are 0.326 grams/mile and 0 grams/miles respectively. These results are expected as the emissions of HC, CO and NOx for the most part that will emit more emissions prior to 'light off'. Each run took around 1100 to 1400 seconds to complete. Data were collected and analysed to be separated into each parameter with a specific computer program which is Advance Vehicle Simulator (ADVISOR). The graph of emission developed was conducted using ADVISOR as shown in Figure 5. Exhaust emission can be reduced by using this KT driving cycle for the period of 8.30 a.m.

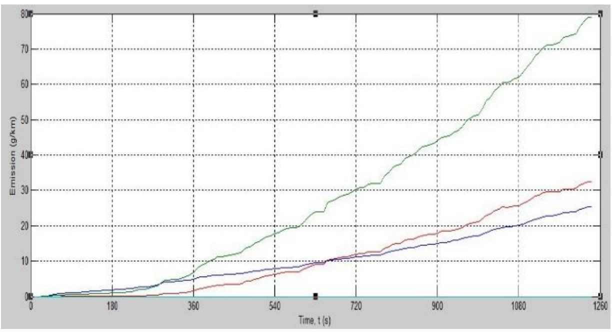

Figure 5: Emission development during proposed KT driving cycle

The fuel consumption for KT driving cycle is fluctuating as shown in Figure 6. As the graph increase, the economy of fuel increasing correspondingly. This explains the economical for fuel in the proposed driving cycle.

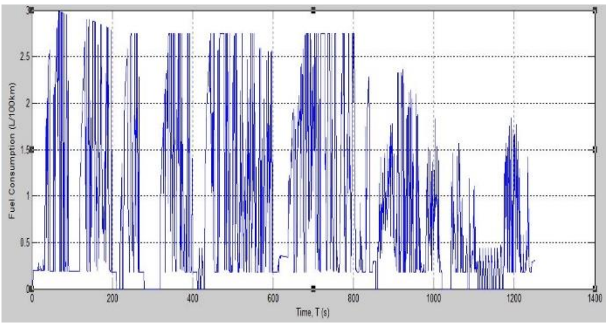

Figure 6: The fuel consumption for best KT driving cycle

Figure 7 is a fuel economy during proposed KT driving cycle. The graph shows an increasing graph gradually. Fuel consumption is measured using the carbon balance method, which produces a figure for CO. This graph was extracted from the proposed driving cycle for RTW KT at 8.30 a.m. data collection. The graph shows that the driving cycle is economic.

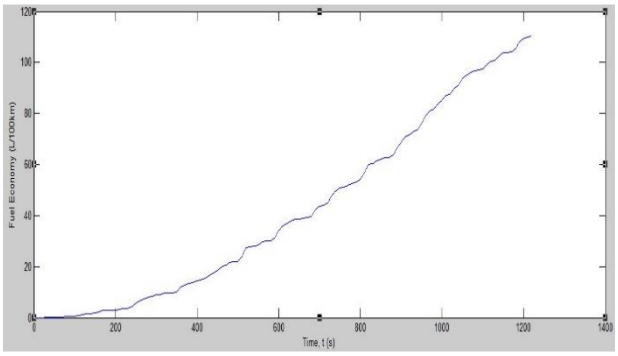

Figure 7: Fuel economy during proposed KT driving cycle

Compared to the other number of data, the data for the proposed driving cycle is the best driving cycle corresponding number of exhaust emission and fuel consumption. The fuel consumption decreasing fluctuates respectively with time.

This advanced vehicle simulator (ADVISOR) results in Table 3 for KT shows that the proposed driving cycle is the best driving cycle for KT because of the reducing number of gas throughout the time and the smallest percentage error which is 5.33%.

Table 3
Result of Advisor KT Driving Cycle

Fuel Consumption (L/100km)	Emission (grams/miles)			
	HC	CO	NO_x	PM
7	0.45	0.678	0.257	0.000

IV. Conclusion

The development of KT driving cycle is done using micro-trips–based. The data are collected from predetermined initial location to final location along a selected route at peak hour which is 8.30 am. The KT driving cycle is successfully obtained with minimum percentage error which is 5.33% and can be concluded that the proposed method is possible to generate a KT driving cycle for PHEV powertrain to overcome exhaust emission and fuel consumption problems.

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