Journal of Engineering Science and Technology
Vol. 14, No. 6 (2019) 3143 - 3157

DRIVING CYCLE ANALYSIS FOR FUEL RATE AND EMISSIONS IN KUALA TERENGGANU CITY DURING GO-TO-WORK TIME

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Abstract

One of the major contributions of air pollution is the vehicle's exhaust gas emission. Unfortunately, day by day, the vehicles demanding keep increasing. This increment, however, will affect the vehicle's performance in terms of pollutant generated. Thus, plug-in hybrid electric vehicle (PHEV) is introduced as one of the most promising vehicles to reduce fuel consumption and exhaust gas emission instead of conventional engine vehicles. In order to analyse the fuel rate and emissions, the driving cycle is a very important element. Driving cycle is a speed-time data set and as an important input for vehicle emission models. The objectives of this paper are to characterize and develop driving cycle of Kuala Terengganu city during Go-to-Work time, which is 7.30 a.m. along five different routes using k-means method, to analyse fuel rate and emissions using the driving cycle developed and to compare the fuel rate and emissions with conventional engine vehicles, Hybrid Electric Vehicle (HEV) and Plug-in Hybrid Electric Vehicle (PHEV). The methodology involves three major steps, which are route selection, data collection using on-road measurement method and driving cycle development using the k-means method. MATLAB software has been used as the computer program platform in order to produce the driving cycle and Vehicle System Simulation Tool Development (AUTONOMIE) software has been used to analyse fuel rate and gas emission. Based on the findings, it can be concluded that real-world driving cycle can be designed with reduced energy consumption thereby minimizing the impact on the environment and economy.

Keywords: Driving cycle, Fuel rate, Gas emissions, K-means, PHEV.

1. Introduction

The increment prices of gasoline and the level of alarming pollutant should be concerned. This pollutant comes from exhaust emission of vehicles, the wrong technique of road users and unwary of traffic users. As reported by the Department of Statistics Malaysia in 2016, motor vehicles are the major sources of air pollution in Malaysia, which is 70% as illustrated in Fig. 1 [1]. According to Barlow et al. [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 a hybrid car.

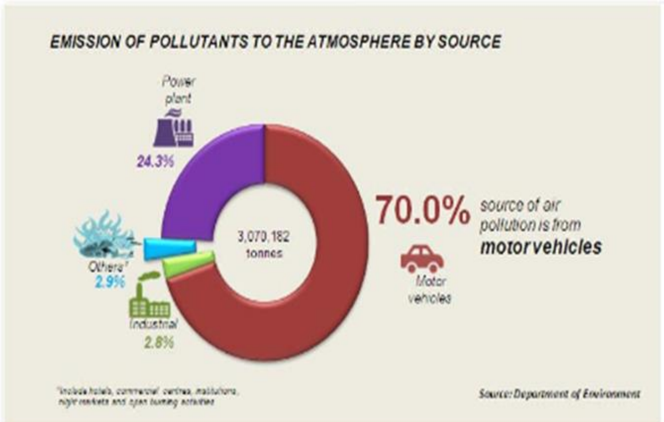

Fig. 1. Malaysia emission of pollutants report [1].

The hybrid vehicle is the most promising vehicle to reduce fuel consumption and exhaust gas emission [3]. There are a few types of hybrid vehicle such as Hybrid Electric Vehicle (HEV), Battery Electric Vehicle (BEV), Full Electric Vehicle (EV) and Plug-in Hybrid Vehicle (PHEV). The main focus of this paper is PHEV. PHEV is a rechargeable HEV that is equipped with charging connector, typically in-board charger. However, before producing a vehicle, pioneering vehicle emission models and powertrain input, a driving cycle is needed [4, 5].

Driving cycle is a representative speed-time profile of driving behaviour of a specific region or city [6]. The driving cycle also characterizes the behaviour of vehicle on the road by a series of acceleration, deceleration, idling, and cruising events, and have a wide range of users, from designing traffic control systems to determining the performance of vehicles. More importantly, it is used in the emission testing of vehicles for certification of emission norms [7].

The construction of the driving cycle starts with the data collection of the actual driving cycle of the vehicle. In recent years, several methods were proposed for the development of the driving cycle such as micro-trip based cycle construction, segment-based cycle construction, pattern classification cycle construction and modal cycle construction. According to Kamble et al. [8], Pune driving cycle was developed using micro-trips approach. Micro-trip is a trip between two consecutive time points at which, the speed of the vehicle is zero. The whole Pune driving data are separated into a number of micro-tips and binned into *n* numbers of segments of different modes of vehicle operation.

Likewise as mentioned by Fotouhi and Montazeri-Gh [9], the Tehran driving cycle also developed using micro-trips based approach, however, the micro-trips are clustered using *k*-means approach. For this work, the same approach is chosen since there are a lot of pros by using this *k*-means technique such as cluster centres can minimize conditional variance, which can give a good representation of data, simple and fast method, and easy to implement. The differences between Tehran work and this work are the value of *k* is different regarding the traffic condition and style of driving, and the focus area and routes also different.

As presented by Kin and Mao [10], Jiang et al. [11], Seers et al. [12] and Zhang et al. [13, 14], the characteristic parameters such as average speed, average driving speed, average acceleration and deceleration, percentage of idle, cruise, acceleration, and deceleration are used as a guideline for characterizing the complete driving cycle. For this work, nine parameters will be used as the guideline since they are the fundamental assessment in order to characterize the driving cycle.

The objectives of this paper are to characterize and develop driving cycle of Kuala Terengganu city at 7.30 a.m. along five different routes using the *k*-means method, to analyse fuel economy and emissions using the driving cycle developed and to compare the fuel rate and emissions with conventional engine vehicles, HEV and PHEV. In this paper, the development of Kuala Terengganu along five routes will be discussed. In Section 2, the methodology including the route selection, data collection, driving cycle development, which is by using micro-trips and k-means approach also will be discussed. Later, in Section 3, the analysis of the fuel rate and emissions of PHEV are compared with the analysis of the other vehicles powertrain using Vehicle System Simulation Tool Development (AUTONOMIE) software.

2. Methods

Figure 2 shows the flow chart and research activities on how to develop a driving cycle in Kuala Terengganu (KT) along five different routes, which are Routes A, B, C, D and E during Go-to-Work time in Kuala Terengganu city, which is 7.30 a.m. The inputs of the KT driving cycle are second-by-second speed. The data are collected at Go-to-Work (GTW) time, which is 7.30 a.m. since 7.30 a.m. is the most people in Kuala Terengganu go to work with 10 runs of data. All five routes have been chosen as selected routes based on its traffic volume in Kuala Terengganu. In this research, the on-board measurement method will be used using a Global Positioning System (GPS). The data gathered then will be divided into several micro-trips and from each micro-trip, the features such as average speed and percentage of idle will be calculated. The clustering of the micro-trips using *k*-means method will take place in order to find the final driving cycle of Kuala Terengganu along Routes A, B, C, D and E at 7.30 a.m. Then, using the final driving cycle of Kuala Terengganu, the fuel economy and emissions will be analysed using AUTONOMIE software and will be compared to other vehicles' powertrain such as conventional engine vehicle, HEV, and PHEV.

Table 1 shows the assessment parameters in order to characterize the driving data. The parameters chosen are average speed, average driving speed, average acceleration and deceleration, time proportion of idling, cruising, acceleration and deceleration and root mean square of acceleration.

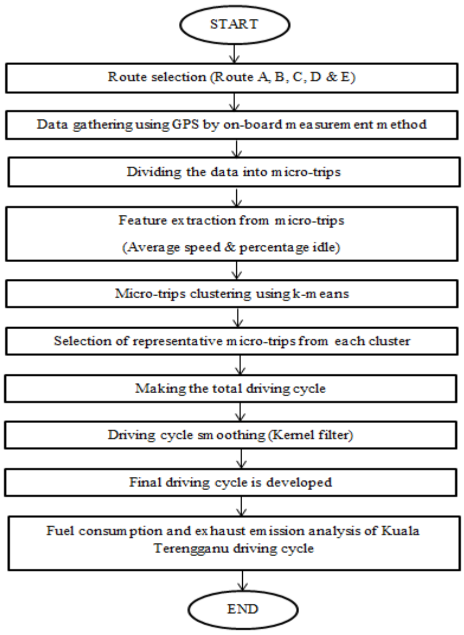

Fig. 2. Flow chart of driving cycle development.

Table 1. KT driving cycle assessment parameters.

Parameters	Unit	Equation
Average speed of whole driving cycle	Km/h	$V_1 = 3.6\frac{dist}{T_{total}}$
Average running speed	Km/h	$V_2 = 3.6\frac{dist}{T_{drive}}$
Average acceleration of all acceleration phase	m/s^2	$a = \left(\sum_{i=1}^{n} \begin{cases} 1 & (a_i > 0) \\ 0 & (else) \end{cases}\right)^{-1} \left(\sum_{i=1}^{n} \begin{cases} a_i & (a_i > 0) \\ 0 & (else) \end{cases}\right)$
Average deceleration of all deceleration phase	m/s^2	$d = \left(\sum_{i=1}^{n} \begin{cases} 1 & (a_i < 0) \\ 0 & (else) \end{cases}\right)^{-1} \left(\sum_{i=1}^{n} \begin{cases} a_i & (a_i < 0) \\ 0 & (else) \end{cases}\right)$
Time proportion of idling	%	$\%\ idle = \frac{T_{idle}}{T_{total}}$
Time proportion of cruising	%	$\%\ cruise = \frac{T_{cruise}}{T_{total}}$
Time proportion of acceleration	%	$\%\ acceleration = \frac{T_{acc}}{T_{total}}$
Time proportion of deceleration	%	$\%\ deceleration = \frac{T_{dec}}{T_{total}}$
Root mean square acceleration	m/s^2	$RMS = \sqrt{\frac{1}{T}\int_0^T (a)^2 dt}$

2.1. Route selection

Figure 3 highlights the selected routes for KT driving cycle from Kampung Wakaf Tembesu to Wisma Persekutuan named as Routes A, B, C, D and E. According to Ministry of Works Malaysia, these five routes are the most frequent routes used by Kuala Terengganu citizen as 'route-to-work' routes [15]. In this study, speed-time data are 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 endpoint is chosen because most of the government sectors located in the Wisma Persekutuan and it is nearby.

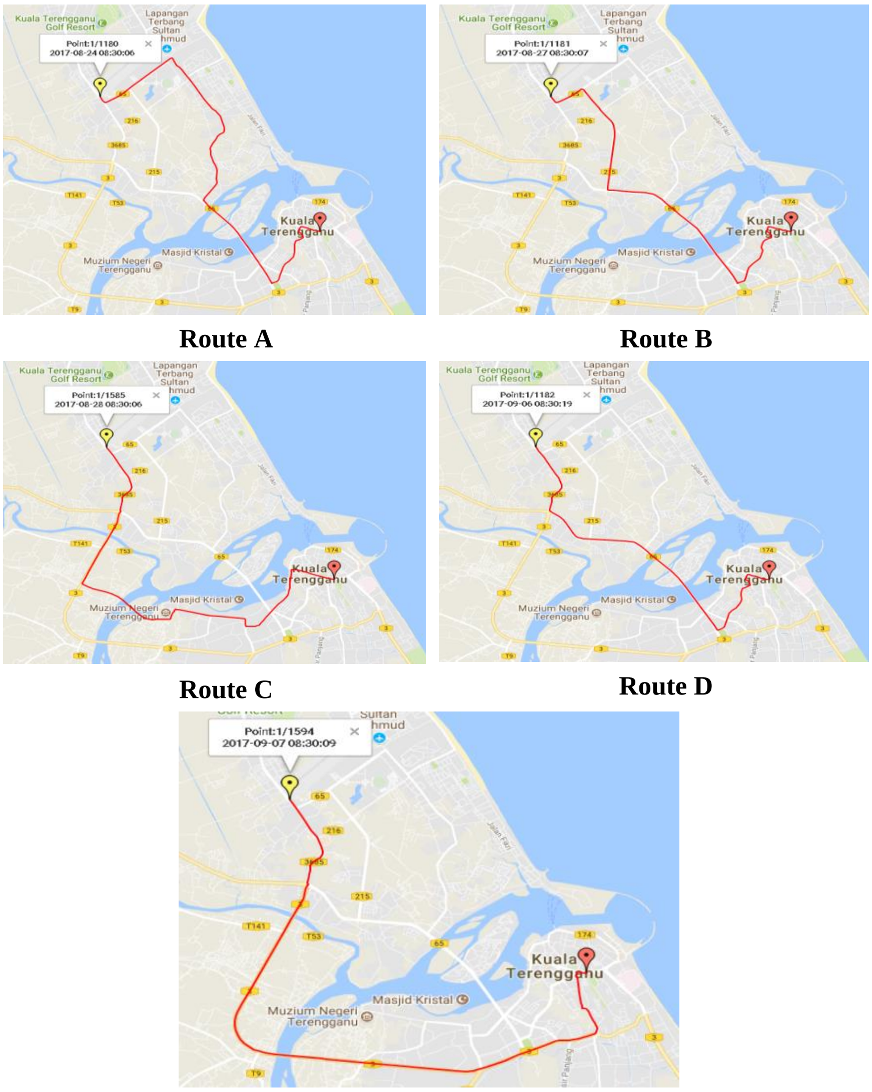

Fig. 3. Selected routes: Routes A, B, C, D and E.

2.2. Data collection and micro-trips definition

Data was collected at GTW time, which is 7.30 a.m. along the selected road with 10 runs. There are three types of techniques or ways to collect the data, which are chase car technique, on-board measurement technique and combination of on-board measurement and circulation driving. Chase car technique is when instrumented vehicle record the second-by-second speed data as it follows the target vehicles. While on-board measurement technique is when speed-time data collections were carried out using a real-time logging system equipped on a selected vehicle along the predetermined route. Lastly, a combination of on-board measurement and circulation driving also known as a hybrid method is the combination of the two techniques [16]. For KT driving cycle, on-board measurement technique will be used for the data collection since it is more suitable for KT drivers' irregular behaviour to avoid a risk such as accident and sudden loss of control.

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 [17]. Each micro trip starts with an idle phase and ends with a decelerating phase, which reduces to zero. This measure of motion involves acceleration, cruise and deceleration modes. 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, the micro-trips are clustered into several groups depending on the traffic situations such as congested traffic flow, medium traffic flow and clear traffic flow. *K*-means approach will be using in order to cluster the micro-trips.

2.3. *K*-means clustering method

As mentioned earlier, in this study, the *k*-means approach will be used in order to cluster the micro-trips. *K*-means is one of the simplest unsupervised learning algorithms that solve the clustering problem. The procedure follows a simple and easy way to classify a given data set through a certain number of clusters (assume *k* clusters) fixed a priori. The steps of the *k*-means algorithms are described briefly as follows [18]:

Step 1: Decide on a value for *k*. In this study, the value of *k* is based on traffic condition.

Step 2: Initialize the *k* cluster centres (randomly, if necessary)

Step 3: Decide the class memberships of the total data, N by assigning them to the nearest cluster centre.

Step 4: Re-estimate the *k*-cluster centres, by assuming the memberships found above are correct.

Step 5: If none of the N data changed memberships in the last iteration, exit. Otherwise, go to Step 3.

2.4. Feature extraction and micro-trips clustering

The proposed approach in developing the driving cycle is by micro-trips clustering. In order to cluster the micro-trips, driving features must be extracted first. There are a lot of driving features that can be extracted from the micro-trips as mentioned earlier in Table 1. However, for this purpose, only two features will be used, which are average speed and also the percentage of idle. These two features have been chosen since they will give the greatest effect on the emission [9]. After the extraction of the parameters, the average speed and percentage of idle are plotted in 2-dimensional feature space as in Fig. 3. As shown in Fig. 4, it can be proved that there is a relation between average speed and percentage of idle. When the average speed is high, the percentage of idle will be low and vice versa.

Figure 5 shows the micro-trips are clustered into 3 clusters using the *k*-means clustering method. According to Shen et al. [19], clustering with 3 clusters, will divide the clusters clearly and properly. As for this reason, the clustering result with 3 clusters is selected in this study. Each cluster has its own characteristics and stands for different traffic condition. Cluster 1 stands for clear traffic condition, cluster 2 stands for medium traffic condition and lastly, cluster 3 stands for congested traffic condition.

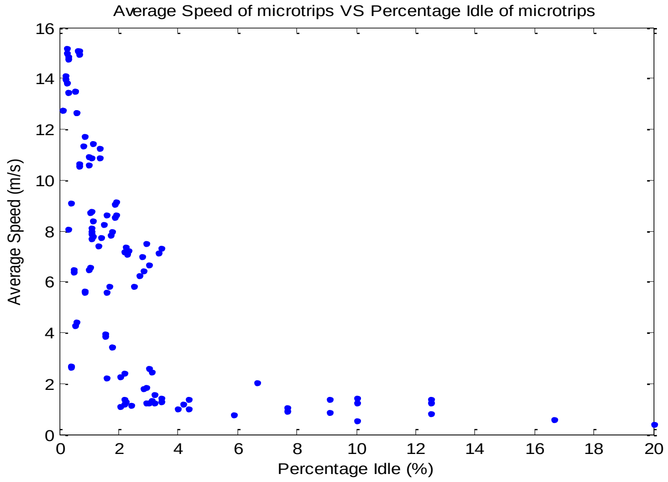

Fig. 4. Average speed of micro-trips vs. percentage idle of micro-trips.

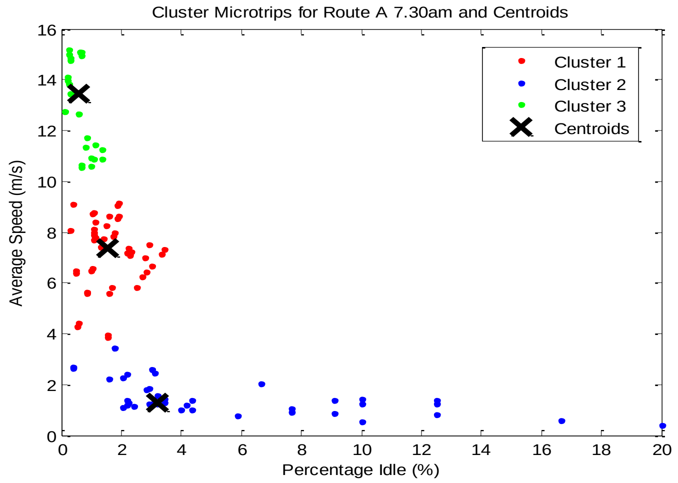

Fig. 5. Clustering of micro-trips.

2.5. KT driving cycle development

In the previous section, the micro-trips have been clustered into three groups. Whereas, in this section, the representatives of micro-trips are determined in order to produce the driving cycle for each cluster. The closest micro-trips to the cluster centre will consider as the representative micro-trips. The selected micro-trips for each group are presented as in Figs. 6 to 8. The micro-trips then will be combined in order to produce the final driving cycle of Kuala Terengganu along Routes A, B, C, D and E at 7.30 a.m.

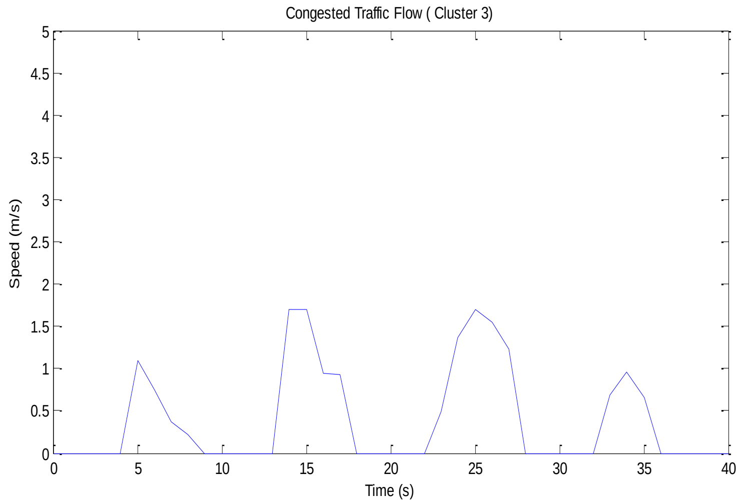

Fig. 6. Congested traffic condition.

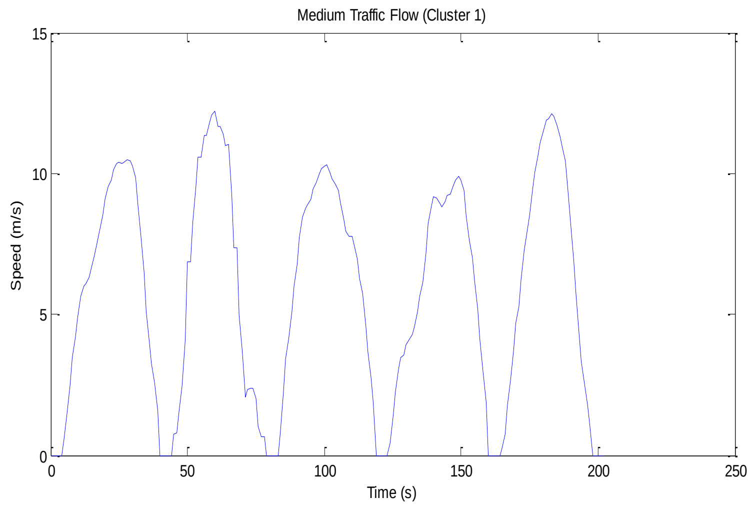

Fig. 7. Medium traffic condition.

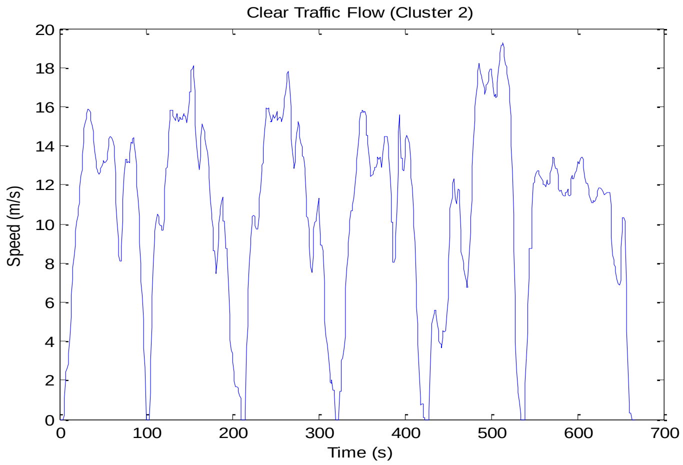

Fig. 8. Clear traffic condition.

3. Results and Discussion

In this section, the results of the development of the driving cycle will be analysed and discussed. In addition, the analysis of the fuel rate and gas emission will be determined and the comparison between KT driving cycle with other vehicle powertrain such as the conventional vehicle, HEV and PHEV will also be discussed.

3.1. KT driving cycle analysis

Figures 9 to 13 show the final proposed Kuala Terengganu driving cycle along Route A, B, C, D, and E at 7.30 a.m. As in the figure, it shows that every route presents different pattern of driving cycle. This is due to other external factors such as traffic light, road conditions, drivers' behaviour and environmental factors [20].

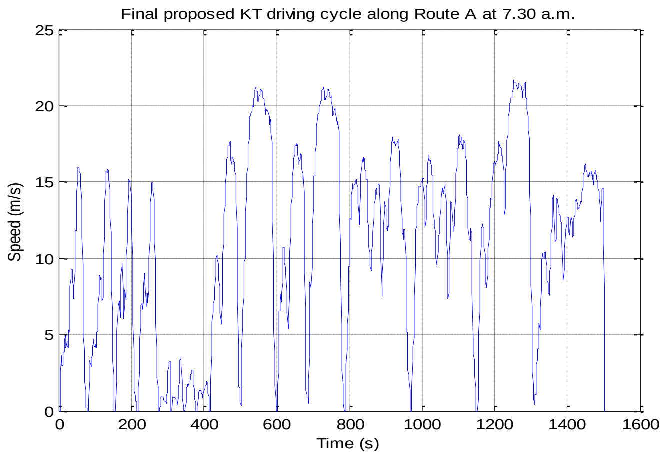

Fig. 9. Final proposed of KT driving cycle along Route A.

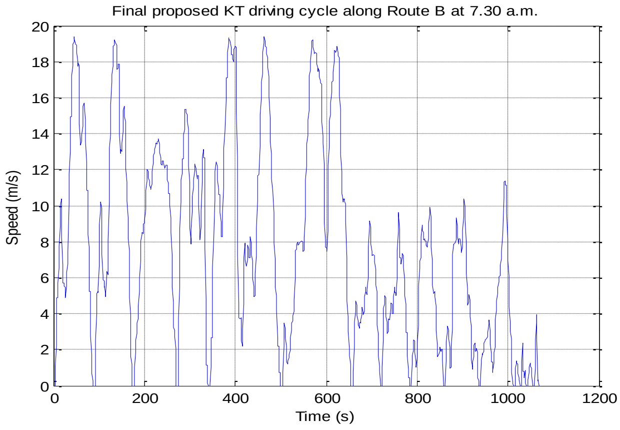

Fig. 10. Final proposed of KT driving cycle along Route B.

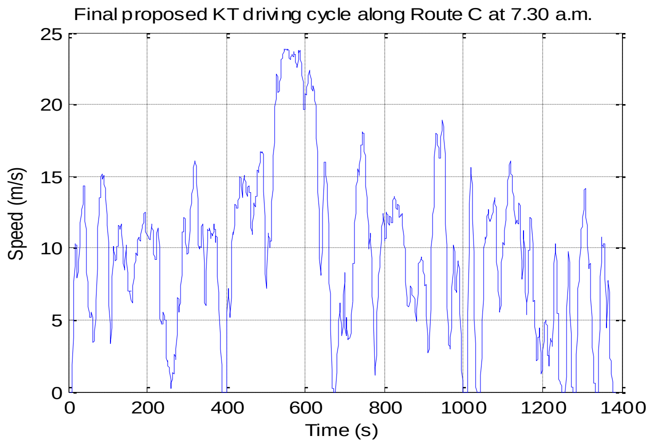

Fig. 11. Final proposed of KT driving cycle along Route C.

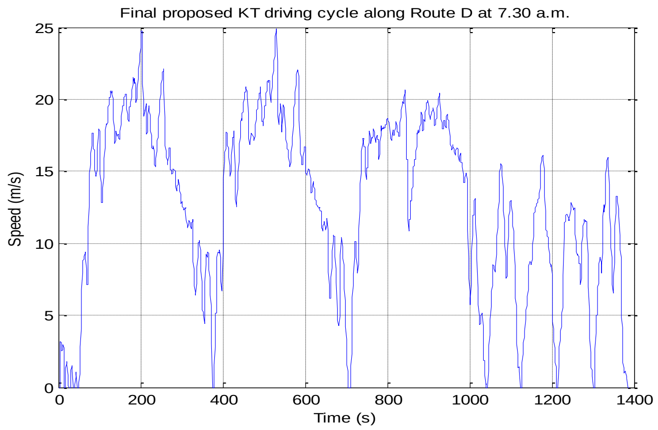

Fig. 12. Final proposed of KT driving cycle along Route D.

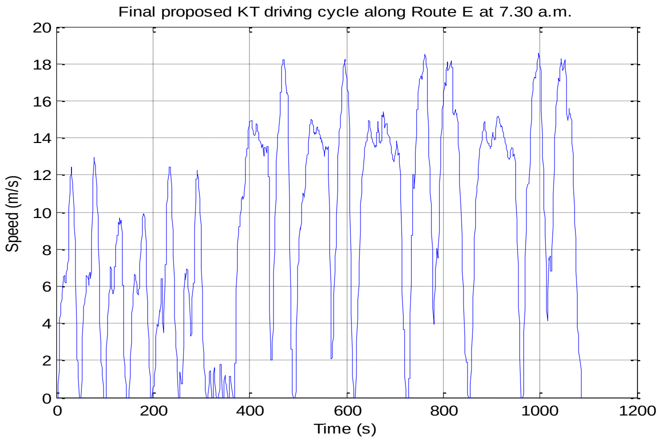

Fig. 13. Final proposed of KT driving cycle along Route E.

Table 2 shows the characteristics of KT driving cycle along Routes A, B, C, D and E in terms of 9 parameters such as average speed, average driving speed, average acceleration and deceleration, time proportion of idling, cruising, acceleration and deceleration and root mean square of acceleration. From the table, it shows that the speed range above 10 km/h was dominant. This is due to the busy and medium traffic condition of KT 'route-to-work' routes. The micro-trips at the higher speed range are longer compared to the micro-trips at lower speed range. This is because the vehicle experiencing a free flow moves at a higher speed range with less frequent stop due to less traffic condition. The low average speed was recorded in the developed KT driving cycle shows the vehicles are moving at lower speed and more micro-trips are found below the average speed. Therefore, more fuel consumption and emission take place during that period due to frequent stop along the road.

Table 2. Assessment parameters of KT driving cycle along Routes A, B, C, D and E.

Parameters	Route A	Route B	Route C	Route D	Route E
Distance travelled (km)	16.37	8.25	9.71	17.74	10.07
Total time (s)	1507	1072	1391	1388	1089
Final micro-trips	13	15	9	11	17
Average speed (km/h)	39.10	27.71	34.75	46.00	33.27
Average running speed (km/h)	41.00	29.94	37.07	48.08	36.27
Average acceleration (m/s^2)	0.47	0.55	0.58	0.43	0.53
Average deceleration (m/s^2)	0.51	0.54	0.55	0.48	0.56
RMS (m/s^2)	0.69	0.70	0.70	0.60	0.72
Percentage idle (%)	3.78	6.06	5.69	3.53	6.70
Percentage cruise (%)	5.37	6.06	11.24	7.27	4.68
Percentage acceleration (%)	47.28	43.34	40.42	47.01	45.78
Percentage deceleration (%)	43.57	44.55	42.65	42.19	42.84

3.2. Fuel rate and emissions analysis

After the driving cycle has been developed, the fuel rate such as fuel consumption and fuel economy, and emission can be determined using AUTONOMIE software version v1210. AUTONOMIE is a tool for automotive control system design, simulation and analysis [21]. It is mathematically-based forward simulation software based on MATLAB, with MATLAB data and configuration files and models built in Simulink. Each vehicle model in AUTONOMIE is modulized and can be divided into four major parts, Driver Controller, Vehicle Powertrain Controller, Vehicle Powertrain Architecture, and Environment as shown in Fig. 14. In this work, the vehicle model used in AUTONOMIE is a single split PHEV, which is PRIUS MY04.

Table 3 shows the fuel rate and emissions of KT driving cycle for Route A, B, C, D, and E using PHEV powertrain. From the result in Table 3, it can be concluded that Route E produces the lowest value of fuel consumption, which is 0.44 l/100 km, the highest value of fuel economy, which is 227.55 km/l and the lowest value of CO_2 emission, which is 10.38 g/km. While, Route B gives the highest value of fuel consumption and emission, which are 1.76 l/100 km and 41.49 g/km respectively, with the lowest value of fuel economy, which 56.93 km/l. Note that, the results are not only affected by the distance, but also affected by other factors such as the number of ‘stop-go’ conditions, road conditions, and many more.

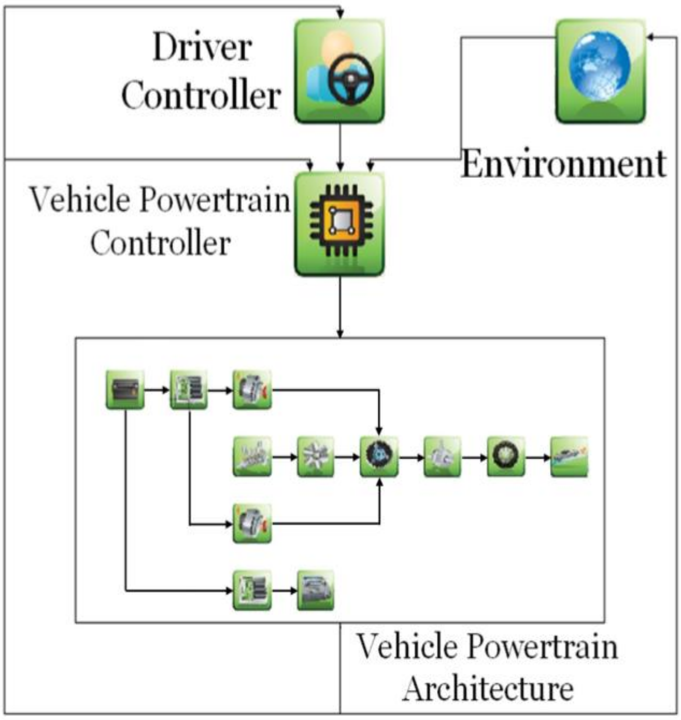

Fig. 14. Layout of vehicle models in AUTONOMIE [21].

Table 3. Fuel rate and emissions of KT driving cycle.

Route	Fuel consumption (l/100km)	Fuel economy (km/l)	CO_2 Emission (g/km)
A	0.76	131.89	17.91
B	1.76	56.93	41.49
C	0.79	126.34	18.69
D	0.90	110.83	21.31
E	0.44	227.55	10.38

In order to prove that PHEV powertrain gives the lowest value of fuel consumption and CO_2 emission, and the highest value of fuel economy, the comparison between conventional engine vehicle, HEV and PHEV have been made using Route E driving cycle and tabulated in Table 4. From the table, it clearly shows that PHEV is the best powertrain compared to conventional engine vehicle and HEV with the lowest value of fuel consumption and emission, and the highest value of fuel economy. It is because PHEVs start in 'all-electric' mode runs on electricity and when the batteries are low in charge, it calls on the Internal Combustion Engine (ICE) to provide a boost or to charge up the battery pack. The ICE is used here to extend the range. PHEVs can charge their batteries directly from the grid (which HEVs cannot); they also have the facility to utilize regenerative braking. As mentioned by Un-Noor et al. [22], PHEVs' ability to run solely on electricity for most of the time makes its carbon footprint smaller than the HEVs. They consume less fuel as well and thus, reduce the associated cost.

Table 4. Comparison between PHEV, HEV and conventional vehicle.

	PHEV	HEV	Conventional
Fuel economy (km/l)	227.55	25.19	14.03
Fuel consumption (l/100km)	0.44	3.97	7.13
CO_2 emission (g/km)	10.38	93.75	168.62

4. Conclusions

The development of KT driving cycle is done using micro-trips clustering by the *k*-means method. The data are collected from predetermined initial location to final location along Routes A, B, C, D and E at Go-to-Work time, which is 7.30 am. The KT driving cycle is successfully obtained 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 economy problems. Further study regarding the driving cycle in the Kuala Terengganu city will be made. A special Internet of Things (IoT) application or device that will help the citizens about the routes, fuel rate and emissions will be developed in the future.

Acknowledgement

The authors would like to be obliged to Ministry of Education Malaysia for providing financial assistance under FRGS (59435) grant and School of Ocean Engineering, UMT for all their technical and research support for this work to be successfully completed.

Nomenclatures

a	Average acceleration of all acceleration phase
d	Average deceleration of all deceleration phase
V_1	Average speed of whole driving cycle
V_2	Average running speed

Abbreviations

AUTONOMIE	Vehicle System Simulation Tool Development
BEV	Battery Electric Vehicle
EV	Electric Vehicle
GPS	Global Positioning System
GTW	Go-to-Work
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Energy
KT	Kuala Terengganu
MATLAB	Matrix Laboratory
PHEV	Plug-in Hybrid Electric Vehicle
RMS	Root Mean Square

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