Abstract. Driving cycles were identified as one of the core sources that contribute to develop the powertrain for vehicle. Plug-in hybrid electric vehicles (PHEVs) are the future transport for next generation. Compared to conventional internal combustion engine vehicle, hybrid and electric vehicle can improve fuel economy and reduce greenhouse gases. This paper describes a development of Kuala Terengganu driving cycle for Universiti Malaysia Terengganu PHEV. Car speed-time data along the two selected fixed route is obtained by using on-board technique which is Global Positioning System, GPS. The developed driving cycle contains a 1050s speed time series, with a distance of 2.17 km, and an average and a maximum speed of 20.67 km/h and 61.47 km/h, respectively. The results obtained from this analysis are within reasonable range and satisfactory.

1. Introduction
The significant growth of world population had led to an increased use of transportation resulting in pollution and other serious environmental problem. The urge for more efficient and greener vehicle is greatly on demand for modern cities. Proactive measures should be taken to minimize these emissions. Nowadays, the automotive industry move their sight from producing internal combustion engine (ICE) vehicles to more efficient and eco-friendly hybrid electric vehicles. Plug-in hybrid electric vehicle (PHEV) is a vehicle which uses two or more kinds of propulsion. This paper introduces a method of developing Kuala Terengganu (KT) driving cycle for Universiti Malaysia Terengganu (UMT) PHEV. Figure 1 shows a schematic illustration of the UMT PHEV powertrain. The UMT PHEV has only one electric machine (EM) which functions as either a motor or generator at a time and powered by batteries and ultracapacitors packs. Driving cycle for car had been developed in several parts of the world including America, Europe, Australia and Asia [1]. The purpose of a driving cycle is to simulate actual driving characteristics on the road, in order to measure the vehicle exhaust emission and fuel consumption [2]. Actual driving cycle, are the cycle derived from the movement of test vehicle on the road under real traffic conditions [3]. The driving cycle for different country have various set of parameters.

2. Driving cycle development
Basically, developing a driving cycle includes of recording the driving condition using one or several instrumented vehicles, which are usually driven for normal purposes [4]. Data will be recorded as the image of the traffic conditions. Then, all data will be analyzed in order to subsequently describe or characterized this condition. To produce a driving cycle, the research tackles three major tasks, which
are data collection, route selection and cycle construction. In this paper, on-board measurement technique will be conducted to collect vehicle speed data. The data are obtained using on-board measurement techniques, which is global positioning system (GPS) to collect car speed-time data along the selected route. The flowchart for KT driving cycle is illustrated in figure 2.

![Figure 1. Schematic illustration of UMT PHEV powertrain.](image)

![Figure 2. Flowchart for KT driving cycle development.](image)
Two different routes were selected in KT city are shown in figures 3 and 4, due to the level of congestion. The 12 sets of relevant variable parameters were adopted in the development of a car’s driving cycle construction. Table 1 lists the variable used in a KT driving cycle development.

Figure 3. Selected route 1.  
Figure 4. Selected route 2.

Table 1. Variables used in KT driving cycle construction [4].

| No | Variable                                      | Unit       | Formula                                      |
|----|-----------------------------------------------|------------|----------------------------------------------|
| 1  | Average speed,                               | km/h       | $v_{avg} = \frac{3.6 \text{dist}}{T_{total}}$ |
| 2  | Average running speed, $v_2$                 | km/h       | $v_{run} = \frac{3.6 \text{dist}}{T_{drive}}$ |
| 3  | Average acceleration of all acceleration phases, $a$ | m/s²       | $a_{avg} = \frac{\sum_{i=1}^{n} 1(a_i>0)}{n} - \frac{\sum_{i=1}^{n} 1(a_i<0)}{n}$ |
| 4  | Average deceleration of all deceleration phases, $d$ | m/s²       | $d_{avg} = \frac{\sum_{i=1}^{n} 1(a_i<0)}{n} - \frac{\sum_{i=1}^{n} 1(a_i>0)}{n}$ |
| 5  | Mean length of a driving period, $c$         | s          | -                                             |
| 6  | Time proportion of idling, $P_i$             | %          | $P_i = \frac{T_{drive}}{T_{total}}$            |
| 7  | Time proportion of acceleration, $P_a$       | %          | $P_a = \frac{T_{acc}}{T_{total}}$              |
| 8  | Time proportion of cruise, $P_c$             | %          | $P_c = \frac{T_{cruise}}{T_{total}}$           |
After the route is selected, the test run is handled to compute all the 12 parameters, which 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, root mean square of acceleration and acceleration energy per kilometer. After all 40 runs are computed, the mean value and the percentage error for both road are calculated.

3. Results and discussions

Speed-time data was collected by using GPS within two selected road. The data was collected at a peak hour ranging from 5:00 - 7:00 p.m for 40 days on November and December 2014. The assessment parameters derived from the test run are shown in tables 2 and 3. There were 40 tests run for both selected routes. There are significant differences between runs 1 - 20 and 21- 40. The road pattern is different in KT city and 20 assessments for each selected KT road is calculated and the mean value is listed in table 4. After the mean value is calculated, percentage difference relative to target summary statistics is calculated and the result is illustrated in table 5. Minimum percentage error of the assessment parameters of grouped runs is shown in table 6 and the KT driving cycle is selected based on the lowest percentage error. The lowest percentage error for run 20 in route 1 is selected as the best KT driving cycle. The driving pattern shows that the recommended KT driving cycle, as shown in figure 5 has an average speed of 20.67 km/h and the running speed is 23.54 km/h with idling. The maximum speed for KT driving cycle is 61.47 km/h. The rate of acceleration and deceleration is 0.39. The mean length of driving period is low, which is 131.25. It shows that the route is full of obstacle and the car has to stop for several times. The root mean square for this run is 0.55 m/s\(^2\) and 0.32 m/s\(^2\). The best KT driving cycle is constructed as presented in figure 5.

| Criterions | \(v_1\) (km/h) | \(v_2\) (km/h) | \(a\) (m/s\(^2\)) | \(d\) (m/s\(^2\)) | \(c\) (s) | \(P_i\) (%) | \(P_c\) (%) | \(P_a\) (%) | \(P_d\) (%) | \(M\) | \(RMS\) (m/s\(^2\)) | \(KPE\) (m/s\(^2\)) |
|------------|----------------|----------------|-------------------|-------------------|--------|-----------|-----------|-----------|-----------|-----|-----------------|---------------|
| Run 1      | 21.09          | 27.58          | 0.71              | 0.67              | 52.31  | 23.5      | 4.0       | 35.3      | 37.1      | 9   | 10              | 11.03         |
| Run 2      | 21.61          | 23.03          | 0.34              | 0.37              | 167.6  | 6.16      | 8.4       | 44.3      | 41.0      | 446.4| 1               | 0.45          |
| Run …      | ...            | ...            | ...               | ...               | ...    | ...       | ...       | ...       | ...       | ... | ...             | ...           |
| Run …      | ...            | ...            | ...               | ...               | ...    | ...       | ...       | ...       | ...       | ... | ...             | ...           |

Table 2. Analysis data for route 1.
Table 3. Analysis data for route 2.

| Criterion | $v_1$ (km/h) | $v_2$ (km/h) | $a$ (m/s$^2$) | $d$ (m/s$^2$) | $c$ (s) | $P_i$ (%) | $P_c$ (%) | $P_a$ (%) | $P_d$ (%) | $M$ | RMS (m/s$^2$) | KPE (m/s$^2$) |
|-----------|--------------|--------------|---------------|--------------|--------|-----------|-----------|-----------|-----------|-----|--------------|--------------|
| j         | 1            | 2            | 3             | 4            | 5      | 6         | 7         | 8         | 9         | 10  | 11           | 12           |
| Run 21    | 25.81        | 27.17        | 0.32          | 0.36         | 2.06   | 5.00      | 11.67     | 44.34     | 44.34     | 372.39| 0.45         | 0.24         |
| Run 22    | 20.66        | 22.31        | 0.28          | 0.32         | 17.40  | 7.38      | 11.97     | 39.98     | 37.68     | 449.38| 0.40         | 0.22         |
| Run ...   | ...          | ...          | ...           | ...          | ...    | ...       | ...       | ...       | ...       | ...  | ...          | ...          |
| Run ...   | ...          | ...          | ...           | ...          | ...    | ...       | ...       | ...       | ...       | ...  | ...          | ...          |
| Run ...   | ...          | ...          | ...           | ...          | ...    | ...       | ...       | ...       | ...       | ...  | ...          | ...          |
| Run 39    | 19.06        | 21.34        | 0.24          | 0.33         | 7.9    | 10.67     | 51.86     | 37.92     | 573.38    | 0.45 | 0.27         | ...
| Run 40    | 18.61        | 20.79        | 0.28          | 0.33         | 70.12  | 10.52     | 48.88     | 40.95     | 548.41    | 0.44 | 0.25         | ...

Table 4. Mean values of the assessment parameters of grouped runs.

| Criterion | $v_1$ (km/h) | $v_2$ (km/h) | $a$ (m/s$^2$) | $d$ (m/s$^2$) | $c$ (s) | $P_i$ (%) | $P_c$ (%) | $P_a$ (%) | $P_d$ (%) | $M$ | RMS (m/s$^2$) | KPE (m/s$^2$) |
|-----------|--------------|--------------|---------------|--------------|--------|-----------|-----------|-----------|-----------|-----|--------------|--------------|
| j         | 1            | 2            | 3             | 4            | 5      | 6         | 7         | 8         | 9         | 10  | 11           | 12           |
| Route 1 (run 1 – run 20) | 20.4 | 23.97 | 0.49 | 0.49 | 121. | 14. | 9.4 | 38. | 37. | 399. | 0.67 | 0.40 |
| Route 2 (run 21 – run 40) | 20.2 | 21.91 | 0.28 | 0.33 | 124. | 7.6 | 10. | 44. | 37. | 477. | 0.42 | 0.23 |
| Mean Value | 20.3 | 22.94 | 0.39 | 0.41 | 123. | 11. | 10. | 41. | 37. | 438. | 0.55 | 0.32 |

Table 5. Percentage difference relative to target summary statistics.

| Criterion | $V_1$ (km/h) | $V_2$ (km/h) | $a$ (m/s$^2$) | $d$ (m/s$^2$) | $c$ (s) | $P_i$ (%) | $P_c$ (%) | $P_a$ (%) | $P_d$ (%) | $M$ | RMS (m/s$^2$) | KPE (m/s$^2$) | Total Error |
|-----------|--------------|--------------|---------------|--------------|--------|-----------|-----------|-----------|-----------|-----|--------------|--------------|-------------|
| j         | 1            | 2            | 3             | 4            | 5      | 6         | 7         | 8         | 9         | 10  | 11           | 12           | ...
| Mean Value | 20.3 | 22.9 | 0.39 | 0.41 | 123. | 11.2 | 10. | 41.3 | 37.7 | 438. | 0.55 | 0.32 | 666.1 |
| Run 1     | 3.53        | 3.53        | 0.39          | 0.41         | 123. | 11.2 | 10.0 | 41.3 | 37.7 | 438. | 0.55 | 0.32 | 666.1 |
| Run 2     | 3.53        | 3.53        | 0.39          | 0.41         | 123. | 11.2 | 10.0 | 41.3 | 37.7 | 438. | 0.55 | 0.32 | 666.1 |
| ...       | ...          | ...          | ...           | ...          | ...    | ...       | ...       | ...       | ...       | ...  | ...          | ...          | ...
| ...       | ...          | ...          | ...           | ...          | ...    | ...       | ...       | ...       | ...       | ...  | ...          | ...          | ...

5
Table 6. Minimum percentage error of the assessment parameters of grouped runs.

| Criterion | $v_1$ (km/h) | $v_2$ (km/h) | $a$ (m/s$^2$) | $d$ (m/s$^2$) | $c$ (s) | $P_i$ (%) | $P_c$ (%) | $P_a$ (%) | $P_d$ (%) | $M$ | $RMS$ (m/s$^2$) | $KPE$ (m/s$^2$) | Total Error |
|-----------|--------------|--------------|---------------|---------------|--------|-----------|-----------|-----------|-----------|------|----------------|----------------|------------|
| Run 19    | 2.90         | 3.18         | 10.2          | 6             | 2.44   | 17.4      | 49.6      | 73.3      | 18.5      | 13.2 | 12.9           | 12.7           | 3.13       |
| Run 20    | 1.47         | 2.62         | 0             | 4.88          | 6.69   | 8.84      | 17.1      | 0.0       | 3.85      | 5.51 | 4.84           | 0              | 0          | 55.80     |
| Run 39    | 6.43         | 6.97         | 38.4          | 6             | 19.5   | 35.7      | 4.73      | 96.4      | 25.4      | 0.40 | 30.7           | 18.1           | 15.6       | 298.6     |
| Run 40    | 8.64         | 9.37         | 28.2          | 1             | 19.5   | 43.0      | 6.07      | 97.3      | 18.2      | 8.42 | 25.0           | 20.0           | 21.8       | 305.6     |
Figure 5. The recomended KT driving cycle.

4. Conclusions
Based on the results of this study, it can be concluded that the proposed method is possible to generate a recomended KT driving cycle that can be used for UMT PHEV powertrain, in order to measure fuel economy and emissions.

Acknowledgements
The authors would like to be obliged to Universiti Malaysia Terengganu and Ministry of Education Malaysia for providing financial assistance under project no. 59353.

References
[1] Hung W, Tong H, Lee C, Ha K, Pao L 2007 Transportation Research Part D: Transport and Environment 12 115-28
[2] Tong H Y, Hung, W.T., & Cheung, C.S 1999 Atmospheric Environment 33 2323-35
[3] Kamble S H, Mathew T V, Sharma G 2009 Transportation Research Part D: Transport and Environment 14 132-40
[4] BARLOW T J, Latham S, McCrae I, Boulter P 2009 A reference book of driving cycles for use in the measurement of road vehicle emissions