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# DEVELOPMENT AND CHARACTERIZATION OF UMT PHEM DRIVING CYCLE

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## ABSTRACT

This paper presents the development of a Universiti Malaysia Terengganu Plug-in Hybrid Electric Motorcycle (UMT PHEM) driving cycle. The real world speed-time data for UMT PHEM driving cycle is collected using global positioning system. The route is selected based on daily traffic of UMT PHEM. The developed driving cycle consist of 299 s, with a distance of 1.27 km, and an average speed and a maximum speed of 12.68 km/h and 15.46 km/h, respectively. The results obtained from this analysis are within reasonable range and satisfactory.

**Keywords:** driving cycle, UMT PHEM, power train, fuel economy, emissions.

## INTRODUCTION

Nowadays, air pollution has become a global concern among researcher and academician because it contrary effect towards the world ecosystem and human being. In general, mobile sources, stationary sources and open burning sources contributes towards air pollution. According to [1] emission from mobile sources is the major source of air pollution in Malaysia. The proportion of emission from motor vehicle account for at least 70-75% of the total air pollution in Malaysia. In 1996, a staggering figure of 82% of air pollution are caused by motor vehicles (Department of the Environment, 1996). The driving cycle of electric vehicle is needed to reduce the air pollution. The applications of driving cycle have been implemented in motorcycle and car manufacturing. The method of driving cycle is a common sight around the globe such as America, Europe, Australia and Asia [2]. Conducting a driving cycle analysis using data trip collection from vehicles in real life manoeuvre is interesting whereas its data analysis is very perplexing. Successful driving cycle analysis on the other hand can greatly benefit technology. Driving cycle is an important core for inventive vehicle emission models and power train input [3]. The widespread of application of driving cycle have caught the attention of researcher, academician, engineer and environmentalist. In the automotive sector, driving cycle is used to produce a long term vital for design, parts and automotive components. Traffic engineers can reconstruct the traffic to ensure it is smoother and improve traffic flow. Environmentalist need driving cycle data to analyse the vehicles exhaust emission and fuel consumption [4]. A set of speed-time data is called a driving cycle in particular area or city. It is broadly used to determining fuel consumption pattern and estimate vehicle air pollutant emissions for a vehicle in specific place. Driving cycle consist of four sequence of vehicle operating condition, which are idle, acceleration, cruise and deceleration.

Motorcycle is the second main conveyance after car in Universiti Malaysia Terengganu (UMT). Student tends to use motorcycle than car since it save more time and can avoid rush-hour traffic rather than car. The driving cycle in UMT is not exist, so the purpose of this study is to obtain a better understanding of driving characteristics for UMT route such as average speed, running speed, acceleration, deceleration, mean length, time proportion of idling, acceleration and deceleration, root mean square of acceleration and deceleration, and acceleration energy per kilometre. In addition driving cycle can be used to produce the component sizing for UMT Plug-in Hybrid Electric Motorcycle (UMT PHEM) as displayed in Figure-1.

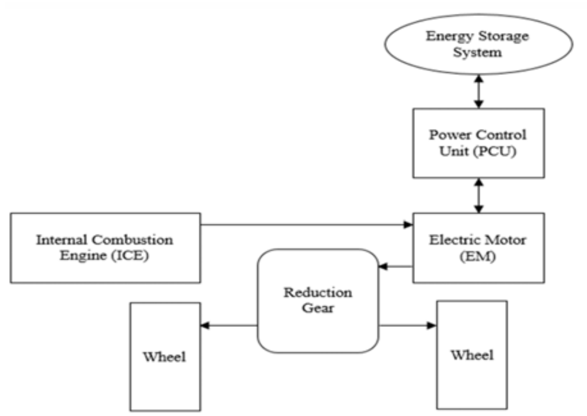


**Figure-1.** Schematic of proposed UMT PHEM power train.

## UMT PHEM DRIVING CYCLE DEVELOPMENT

In order to produce the driving cycle, three major task should be tackled namely route selection, data collection and drive cycle construction. There are two method that can be employed to collect the speed-time data which are chase vehicle method and on board technique by using global positioning system (GPS). For the purpose of this study at UMT, the second method was adopted to avoid a risk such as accident and sudden loss of control. Therefore, the on board method is applied where GPS and data logger is used. This technique involves recording a set of real world speed-time data, where the motorcycle speed with respect to time will be recorded. This process will be repeated, in order to obtain large amount of data.

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According to [5-6] Wang *et al*., (2012) and Barlow *et al*., (2009), 11 variables are used to analyse and characterize UMT PHEM driving cycle speed-time data as listed in Table-I. Figure-2 presents the flowchart with reference to the stages of data analysis and development of driving cycle. Three main routes have been selected as the research setting that represents the most congested traffic in UMT. In this study, speed-time data is collected for 50 days on weekdays, during peak hour. The selected route for UMT PHEM driving cycle development is illustrated in Figure-3, Figure-4, and Figure-5.

**Table-1.** Variables used in UMT PHEM driving cycle analysis.

| 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 | $a\_avg = \left(\sum_{i=1}^{n}\begin{cases}1\,(a_i > 0)\\0\text{ (else)}\end{cases}\right)^{-1}\sum_{i=1}^{n}\begin{matrix}1 & (\mathrm{a_i} > 0)\\0 & \text{(else)}\end{matrix}$ |
| 4 | Average Deceleration, $d$ | m/s² | $d\_avg = \left(\sum_{i=1}^{n}\begin{cases}1\,(a_i < 0)\\0\text{ (else)}\end{cases}\right)^{-1}\sum_{i=1}^{n}\begin{matrix}1 & (\mathrm{a_i} < 0)\\0 & \text{(else)}\end{matrix}$ |
| 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 | Average number of acceleration-deceleration changes within one driving period, $M$ | | - |
| 10 | Root Mean Square of Acceleration, $RMS$ | m/s² | $RMS = \sqrt{\frac{1}{T_{total}}\sum_{i=1}^{n}a_i^2}$ |
| 11 | Acceleration Energy per Kilometer, $KPE$ | m/s² | $PKE = \frac{1}{dist}\sum_{i=2}^{n}\begin{cases}{v_i}^2 - v_{i-1}^2 & (v_i > v_{i-1})\\ & (else)\end{cases}$ |

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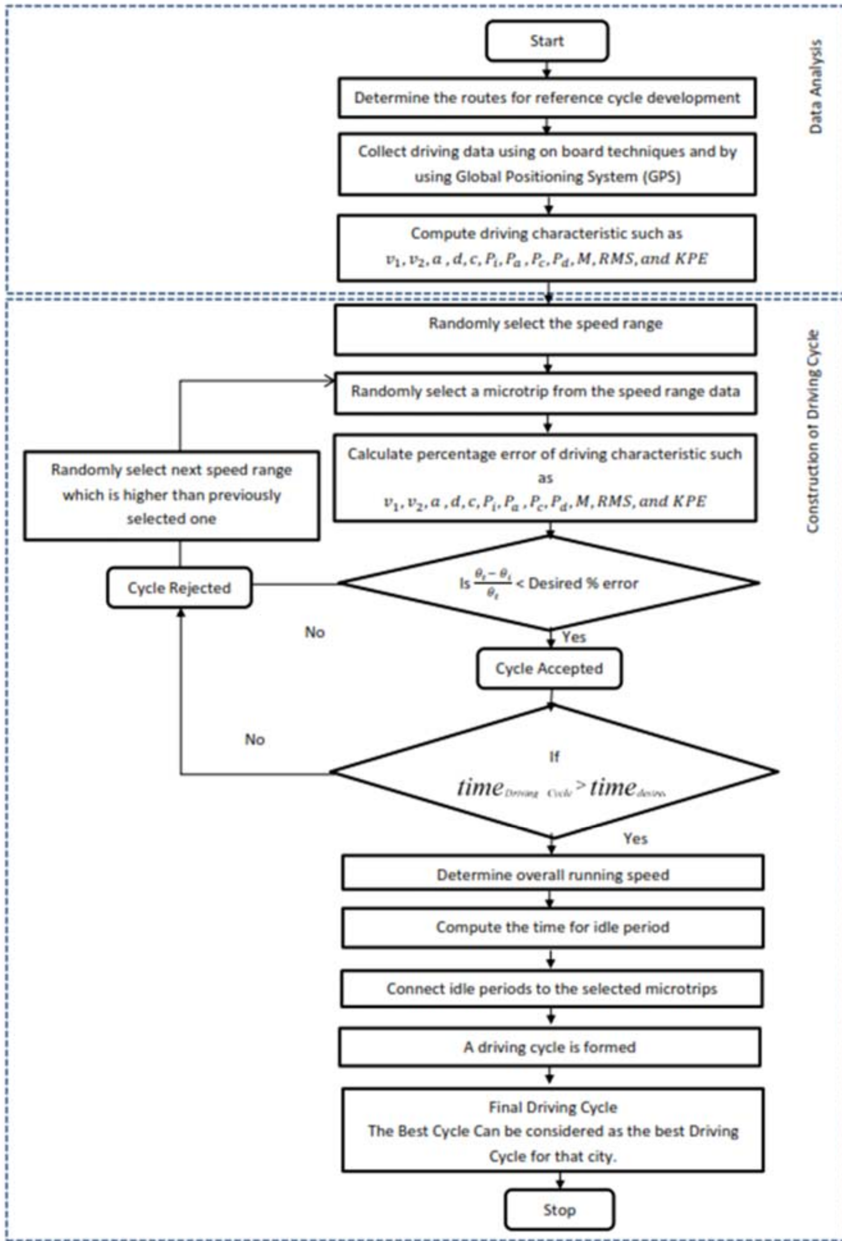


**Figure-2.** Flow chart of UMT PHEM driving cycle development.

**Figure-3.** Route 1.

**Figure-4**. Route 2.

**Figure-5.** Route 3.

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The distance of Route 1 is 4.75 km shown in Figure-3. This route starts from the main gate, then to the graduate school building; later pass through the school of ocean engineering. Moving on to the aquatrop hatchery, microprocessor labs, lecture complex and finally circulate the hostel. Thus, Route 2 is almost similar to Route 1 but passed through Library, and includes the route perpendicular to chancellery building and Dewan Sultan Mizan Hall. The distance of this route is 3.25 km shown in Figure-4. Figure-5 shown Route 3.Route 3 has shortest distance which is 1.57 km. Despite being the shortest, these routes cover the busiest area and junction which is highly congested during peak hours. This route also passed through the Sultan Mahmud Islamic Centre and the sports centre.

## DATA ANALYSIS

The speed-time data of UMT is collected during the period of 10:00-12:00p.m for 50 days on February and March 2015. Data is collected around 5:00-6:00p.m which is peak hour for student, lecturers and staff to leave the campus. Only one set of speed-time data is collected for one day. Total speed-time data collected is 50 set. Speed-Time data is collected by using global positioning system and data logger along the selected route around UMT. The value of 11 data variables are shown in Table-2. The mean values in Table-3 are obtained from Table-2. After the mean value is gained, the percentage error for all run is calculated in Table-4. The smallest percentage error is considered as the best UMT PHEM driving cycle in Table-5. The average speed for UMT PHEM driving cycle is 12.68 km/h and the average running speed is 13.86 km/h. The results indicated that the speed is very slow. For complete circulation at UMT PHEM driving cycle, the rate for acceleration and deceleration is equal which is 0.46 and 0.48 $m/s^2$ .The four vehicle operating modes is calculated. The time proportion of idling, time proportion of cruising, time proportion of acceleration and time proportion of deceleration are 9.12, 4.73, 44.41 and 42.03 respectively. The Root Mean Square for this run is 0.65 and the Acceleration Energy per Kilometre is 0.36. The best UMT PHEM driving cycle is constructed as presented in Figure-4 that is run 105 from route 3.

**Table-2.** UMT PHEM driving cycle data analysis.

| Criterion | $v_1$ (km/h) | $v_2$ (km/h) | $a$ ($m/s^2$) | $d$ ($m/s^2$) | $P_i$ (%) | $P_c$ (%) | $p_a$ (%) | $P_d$ (%) | M | $RMS$ ($m/s^2$) | $KPE$ ($m/s^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| J | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Run 1 | 18.49 | 19.1 | 0.41 | 0.42 | 3.49 | 3 | 47.83 | 45.83 | 0.94 | 0.54 | 0.12 |
| Run 2 | 18.01 | 18.56 | 0.42 | 0.42 | 3.23 | 4.68 | 46.12 | 46.12 | 0.92 | 0.56 | 0.21 |
| Run 3 | 18.48 | 18.99 | 0.4 | 0.42 | 2.99 | 3.65 | 48.17 | 45.35 | 0.93 | 0.52 | 0.14 |
| Run ….. | ….. | ….. | ….. | ….. | ….. | ….. | ….. | ….. | ….. | ….. | ….. |
| Run 50 | 17.21 | 18.14 | 0.29 | 0.33 | 5.43 | 1.86 | 49.07 | 43.79 | 0.93 | 0.42 | 0.22 |
| Run 51 | 19.82 | 20.77 | 0.78 | 0.81 | 5.53 | 1.01 | 48.99 | 46.97 | 0.95 | 1.13 | 0.18 |
| Run 52 | 19.94 | 20.45 | 0.71 | 0.77 | 3.7 | 0.62 | 50.93 | 46.58 | 0.97 | 1.01 | 0.24 |
| Run ….. | ….. | ….. | ….. | ….. | ….. | ….. | ….. | ….. | ….. | ….. | ….. |
| Run 100 | 15.91 | 16.77 | 0.35 | 0.34 | 5.52 | 0 | 46.95 | 47.71 | 0.94 | 0.48 | 0.27 |
| Run 101 | 10.57 | 13.34 | 0.42 | 0.42 | 21.2 | 0.29 | 40.23 | 39.08 | 0.79 | 0.59 | 0.25 |
| Run 102 | 13.96 | 14.78 | 0.46 | 0.46 | 6.38 | 8.94 | 46.15 | 38.89 | 0.85 | 0.62 | 0.27 |
| Run ….. | ….. | ….. | ….. | ….. | ….. | ….. | ….. | ….. | ….. | ….. | ….. |
| Run 148 | 12.75 | 13.35 | 0.36 | 0.37 | 5.17 | 1.72 | 47.06 | 46.37 | 0.93 | 0.47 | 0.29 |
| Run 149 | 11.47 | 13.72 | 0.48 | 0.45 | 16.87 | 9.94 | 35.35 | 38.07 | 0.73 | 0.66 | 0.32 |
| Run 150 | 9.24 | 14.91 | 0.54 | 0.54 | 38.38 | 1.62 | 30.08 | 30.08 | 0.6 | 0.68 | 0.41 |

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**Table-3.** Mean values of the assessment parameters of grouped run.

| Criterion | $v_1$ (km/h) | $v_2$ (km/h) | $a$ (m/s²) | $d$ (m/s²) | $P_i$ (%) | $P_c$ (%) | $p_a$ (%) | $P_d$ (%) | M | $RMS$ (m/s²) | $KPE$ (m/s²) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| J | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Mean value (Route 1) | 7.35 | 17.35 | 0.38 | 0.17 | 5.19 | 4.62 | 47.57 | 42.67 | 0.90 | 0.54 | 0.22 |
| Mean value (Route 2) | 16.69 | 17.76 | 0.49 | 0.52 | 6.70 | 2.58 | 47.00 | 44.01 | 0.91 | 0.69 | 0.37 |
| Mean value (Route 3) | 11.92 | 13.78 | 0.45 | 0.45 | 14.15 | 4.16 | 41.23 | 40.81 | 0.82 | 0.61 | 0.34 |
| Mean value | 11.99 | 16.30 | 0.44 | 0.38 | 8.68 | 3.78 | 45.27 | 42.40 | 0.88 | 0.62 | 0.16 |

**Table-4.** Percentage difference relative to target summary statistic.

| Criterion | $v_1$ (km/h) | $v_2$ (km/h) | $a$ (m/s²) | $d$ (m/s²) | $P_i$ (%) | $P_c$ (%) | $p_a$ (%) | $P_d$ (%) | M | $RMS$ (m/s²) | $KPE$ (m/s²) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| J | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Mean value | 11.99 | 16.30 | 0.44 | 0.38 | 8.68 | 3.78 | 45.27 | 42.50 | 0.88 | 0.62 | 0.16 |
| Run 3 | 18.48 | 18.99 | 0.40 | 0.42 | 2.99 | 3.65 | 48.17 | 45.35 | 0.93 | 0.52 | 0.31 |
| Run 23 | 16.15 | 17.52 | 0.30 | 0.36 | 8.12 | 3.25 | 48.37 | 40.38 | 0.89 | 0.46 | 0.23 |
| Run 27 | 14.22 | 16.13 | 0.36 | 0.39 | 12.03 | 3.75 | 43.52 | 40.80 | 0.84 | 0.49 | 0.29 |
| Run 30 | 15.47 | 16.67 | 0.29 | 0.31 | 7.45 | 3.80 | 46.06 | 42.82 | 0.89 | 0.41 | 0.21 |
| Run 32 | 15.72 | 16.82 | 0.35 | 0.37 | 6.84 | 2.56 | 46.50 | 44.22 | 0.91 | 0.51 | 0.27 |
| Run 87 | 14.19 | 15.99 | 0.32 | 0.34 | 11.56 | 4.76 | 42.93 | 40.89 | 0.84 | 0.46 | 0.24 |
| Run 91 | 15.59 | 16.80 | 0.41 | 0.40 | 7.55 | 2.39 | 44.62 | 45.62 | 0.90 | 0.59 | 0.31 |
| Run 105 | 12.68 | 13.86 | 0.46 | 0.48 | 9.12 | 4.73 | 44.41 | 42.03 | 0.86 | 0.65 | 0.36 |
| Run 106 | 12.68 | 13.86 | 0.46 | 0.48 | 9.12 | 4.73 | 44.41 | 42.03 | 0.86 | 0.65 | 0.36 |
| Run 108 | 13.19 | 13.85 | 0.46 | 0.43 | 5.46 | 5.46 | 43.15 | 46.23 | 0.89 | 0.61 | 0.34 |

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

| Criterion | $v_1$ (km/h) | $v_2$ (km/h) | $a$ (m/s²) | $d$ (m/s²) | $P_i$ (%) | $P_c$ (%) | $p_a$ (%) | $P_d$ (%) | M | $RMS$ (m/s²) | $KPE$ (m/s²) | Total error (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| j | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | |
| Run 3 | 54.16 | 16.52 | 8.33 | 10.31 | 65.55 | 3.56 | 6.41 | 6.72 | 6.28 | 15.52 | 14.84 | 208.2 |
| Run 23 | 34.72 | 7.5 | 31.25 | 5.44 | 6.44 | 14.13 | 6.85 | 4.98 | 1.72 | 25.27 | 39.9 | 178.2 |
| Run 27 | 18.62 | 1.03 | 17.49 | 2.43 | 38.61 | 0.92 | 3.86 | 3.99 | 4.01 | 20.39 | 76.4 | 187.75 |
| Run 30 | 29.05 | 2.28 | 33.54 | 18.58 | 14.16 | 0.4 | 1.75 | 0.76 | 1.71 | 33.39 | 27.74 | 163.36 |
| Run 32 | 31.13 | 3.2 | 19.79 | 2.82 | 21.19 | 32.36 | 2.72 | 4.06 | 3.99 | 17.14 | 64.23 | 202.63 |
| Run 87 | 18.37 | 1.89 | 26.66 | 10.7 | 33.2 | 25.76 | 5.16 | 3.78 | 4.01 | 25.27 | 45.99 | 200.79 |
| Run 91 | 30.05 | 3.08 | 6.04 | 5.06 | 13.01 | 36.85 | 1.43 | 7.35 | 2.85 | 4.15 | 88.56 | 198.43 |
| Run 105 | 5.77 | 14.96 | 5.42 | 25.07 | 5.08 | 24.97 | 1.89 | 1.1 | 1.72 | 5.6 | 55.15 | 146.73 |
| Run 106 | 5.77 | 14.96 | 5.42 | 26.07 | 5.08 | 24.97 | 1.89 | 1.1 | 1.72 | 5.6 | 58.15 | 150.73 |
| Run 108 | 10.03 | 15.02 | 5.42 | 12.94 | 37.09 | 44.26 | 4.68 | 8.79 | 1.71 | 0.9 | 45.99 | 186.83 |

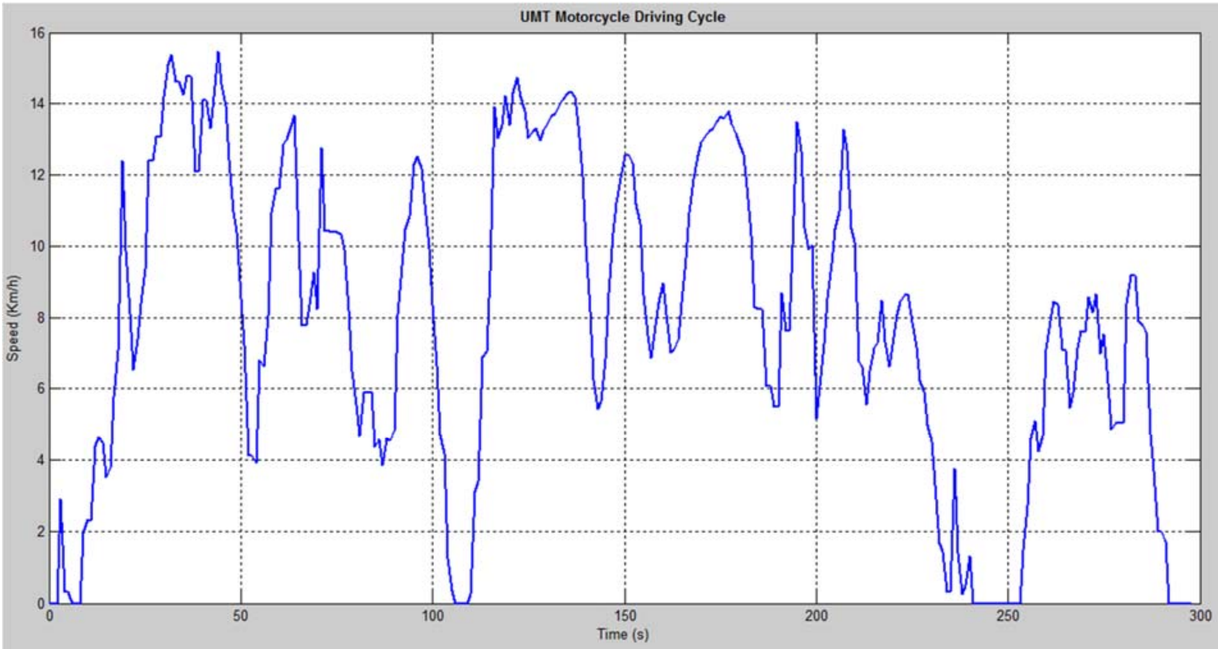


**Figure-6.** The UMT PHEM driving cycle.

## CONCLUSIONS

Based on the results of this study, it can be concluded that the proposed method is possible to generate a UMT PHEM driving cycle was proved by the tabulate data above in order to measure fuel economy and emissions.

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