Development of Driving Cycle for Passenger Car under Real World Driving Conditions in Kuala Lumpur, Malaysia

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Abstract. The traffic condition becomes the main reason of pollutants in the developing countries. The exhaust emission and fuel consumption can be determined by constructing a driving cycle with its analyzed target parameters. The developed driving cycles are not same as other countries or cities due to its different traffic conditions. The methodology includes, route selection, data collection and cycle construction. The driving cycle was constructed from data collected from different routes of Kuala Lumpur during peak and off-peak hours. Micro-trip method was used to develop a complete KL cycle. A variety of parameters were studied and analyzed to determine and compare its driving pattern with other candidate cycles. The lowest percentage of overall error of candidate cycles was selected as KL cycle. The KL cycle was developed successfully with 17 numbers of micro-trips and a total time of 1219s. Then, the proposed driving cycle was compared with other existing cycles. From the comparison, it shows that, the KL driving cycle is similar to Beijing cycle with its driving parameters, except for the percentage of time taken in cruise mode.

1. Introduction

Driving cycle is a collection of data points that generate speed versus time graph which obtained from the real-world driving situation. It is usually developed from the data collected in a specific area or city, certain roads and routes [1]. The data collected mostly will represent the congested area to the free flow area during the peak hours, so that a typical driving pattern of the population of a place or city can be easily obtained. The definition of the driving cycle also can be referred to the operating conditions such as the idle state, acceleration, cruising, deceleration and steady state to show the type of pattern in an area of the city.

Subsequently, the operating conditions of a vehicle traveling in traffic are rarely available, its emissions and fuel consumption are often estimated from the design parameters, presumably operating under some selected average conditions [2]. This emission model is often represented by emission
factors and are normally expressed in terms of grams of pollutants per unit of distance traveled. With the aid of driving cycle, we are able to estimate fuel consumption and emissions of vehicles within respective urban areas.

The driving cycle was categorized into legislative and non-legislative cycle. The higher authorities of road traffics will control the emissions from motor vehicles for legislative cycle so that it not exceed the statutory emission standard [3]. US 75 cycle, ECE cycle and Japan 10-15 mode cycle is the cycles that are implementing this legislative cycle to control the vehicle emissions. Non-legislative cycles are the cycle used to estimate the carbon emission and fuel consumption. The Melbourne peak cycle and Perth cycle, are some of the examples. Therefore, driving cycles has been developed for different cities to determine their driving characteristics as shown in Table 1.

The development of driving cycle includes route selection, data collection, and cycle construction. Route selection is usually done before data collection to ensure the targeted route are suitable to collect data according to the traffic conditions during peak hours. Data can be collected by using a chase-car method or on-board measurement to capture each second of travelling speed of a vehicle driven on selected routes [4]. The cycle can be constructed by extracting the collected speed data and separating it into micro-trips, and developing a driving cycle by generating a graph of speed versus time with the combined micro-trips and idle duration according to the assessment criteria. In this study, the objective is to develop a more sensible driving cycle to determine fuel consumption and exhaust emission for the Kuala Lumpur city. The use of real time data collection done to ensure the preciseness of developed driving cycle. Besides, the proposed methods can be a guideline for others to develop the driving cycle of other cities with other types of vehicle.

| Driving cycle       | Route selection                  | Data collection          | Assessment criteria                                    | Construction method                               |
|---------------------|----------------------------------|--------------------------|-------------------------------------------------------|---------------------------------------------------|
| FTP72               | -Home-to-work trips              | On-board measurement     | Stop per distance                                     | Select the whole trip best fit the overall survey data |
| FTP75               |                                  |                          | Average speed                                         |                                                   |
|                     |                                  |                          | Maximum speed                                         |                                                   |
|                     |                                  |                          | Number of stops                                        |                                                   |
|                     |                                  |                          | SAPD                                                  |                                                   |
|                     |                                  |                          | Speed / acceleration matrix                           |                                                   |
| Sydney cycle        | -Road classification             | Chase car method         | Average speed                                         | Random selection of 2-min driving segment          |
|                     | -High emission                   |                          | Percentage of idle                                    |                                                   |
|                     | -Traffic density                 |                          |                                                       |                                                   |
| Melbourne peak cycle| -Central business area           | Chase car method         | Average speed                                         | Random selection of 100m driving segment           |
|                     | -Arterials                       |                          | Root mean square speed                                 |                                                   |
|                     | -Highways                        |                          | Root mean square acceleration                         |                                                   |
|                     |                                  |                          | Positive kinetic energy                               |                                                   |
|                     |                                  |                          | Percentage idle speed                                 |                                                   |
|                     |                                  |                          | Speed / acceleration probability                      |                                                   |
|                     |                                  |                          | density function                                       |                                                   |
| Perth cycle         | -Geographic area                 | Chase car method         | Average speed                                         | Knight tour algorithm                              |
|                     |                                  |                          | Stop per distance                                     |                                                   |
|                     |                                  |                          | Positive kinetic energy                               |                                                   |
|                     |                                  |                          | Percentage of idle                                    |                                                   |
|                     |                                  |                          | Speed distribution                                     |                                                   |

2. Methodology

2.1. Route selection

In constructing of local driving cycle, the road route selection is crucial to identify and categorize the level of traffic flow condition from a congested zone to a free flow zone. The information can be
extracted from Road Traffic Volume Malaysia (RTVM) and referred as Level of Service (LOS). The traffic volume survey was done to determine the number of vehicles that passes through the area of interest in the region of Kuala Lumpur. Therefore, Road Traffic Volume Malaysia (RTVM) which is yearly statistic of transport report was referred to get the traffic volume of each route according to the percentage of the vehicles passed through the traffic census station. The traffic volume data were taken from 5 census station along the Kuala Lumpur region [5].

Since the number of census point in RTVM for KL was not adequate, pre-route selection was done to determine the congested area in the region of Kuala Lumpur. Pre-route selection was carried out by referring to the Goggle Map’s live traffic where to determine the congested route and its peak hour helps in comparing the condition of the routes from time to time. The factors that need to be considered and influenced in route selection and data collection are construction activities that take place along the roadside, heavy rain and other factors such public holidays causes data variabilities when compared to the data collected on normal days.

2.2. On-road driving data collection
The speed-time data was collected using a chase-car technique. Chase-car method is a method where the drivers will randomly select a car and chase it along their route to collect the data. This technique should be repeated to obtain a huge number of data to construct a precise driving cycle [6]. Each equipment was calibrated before starting the data collection. The data were collected during the peak hours, off peak hours, weekends, and also at highway to categorize it according to its Level of Service (LOS) where the traffic flow can be determined from its travelling speed. Eight routes were selected to collect data during the peak hours, off peak hours and weekend while four routes were selected to collect data at highway which will differentiate the data from high speed to low speed data. To improve the efficiency and accuracy in data collection, each route was separated into two directions and the data was collected in each direction.

2.3. Generation of micro-trips
The driving cycle will be developed based on generated micro-trips which defined as driving activity between adjacent stop covers each “stop-go” condition. It may consist of acceleration, cruise and deceleration modes [7]. The micro-trips will be separated from the whole speed data that have been extracted from the recorded data.

2.4. Data analysis
The target parameters were defined and calculated based on the speed-time data obtained from on-roads data collection. The velocity, acceleration (or deceleration) and displacement in every second throughout the speed-time data are calculated. The assessment criteria used in developing the KL driving cycle to determine the driving pattern are as shown in Table 2 [8]. The driving modes of the vehicles were defined. Then, the micro-trips were arranged according to its specific speed range and the percentage number of micro-trips (%Nm) and percentage of time spent in micro-trips (%Tm) were calculated to be compare with the candidate cycles [9].

| Table 2. Kuala Lumpur driving characteristics |
|------------------------------------------------|
| No. | Parameters | Condition |
|-----|------------|-----------|
| 1   | Average speed, $V_{avg}$ (km/h) | Speed = 0, Acc = 0 |
| 2   | Average running speed, $V_{1\text{avg}}$ (km/h) | Speed > 0, Acc = 0 |
| 3   | Average acceleration, $\text{Acc}_{avg}$ (m/s$^2$) | Acc > 0 |
| 4   | Average deceleration, $\text{Dec}_{avg}$ (m/s$^2$) | Acc < 0 |
| 5   | Percentage of idle, %Idle | Speed = 0, Acc = 0 |
| 6   | Percentage of cruise, %Cruise | Speed > 0, Acc = 0 |
| 7   | Percentage of acceleration, %Acc | Acc > 0 |
| 8   | Percentage of deceleration, %Dec | Acc < 0 |
| 9   | Number of stops per km, Stops/km | |
| 10  | Positive kinetic energy, PKE (m/s$^2$) | |
2.5. **Construction of driving cycle**

A random selection of micro-trip was categorized depend on its speed range. The time taken to complete a driving cycle was set to 1200 seconds based on the time necessary to analyze the gas according to its samples [10]. A tolerance limit of 5% under-estimation and 15% over-estimation was considered in choosing the micro-trip to develop a better emission purpose driving cycle. Once the random selection of micro-trip was done, it’s followed by calculating the driving parameters, percentage number of micro-trips (%Nm) and percentage of time spent in micro-trips (%Tm). A various number of candidate cycles were developed to compare between each other and to select the driving cycle with the lowest error as a KL driving cycle.

3. **Result and discussion**

The driving cycle construction with the procedure discussed above were applied to the data collected from the selected routes. Ten candidate cycle was proposed in order to get the best candidate cycle with a less overall percentage of error. The KL 10 candidate cycle was selected as a KL driving cycle with less error was recorded among the other developed candidate cycle as shown in Table 3. The developed KL driving cycle with its driving parameters are closely related to the target parameters is shown in Figure 1. Micro-trips become longer at the high speed range data against time taken. The developed KL driving cycle has completed a distance of 7.86 kilometers in 1219 seconds with a total of 17 intermediate stops between micro-trips.

|               | KL1 | KL2 | KL3 | KL4 | KL5 | KL6 | KL7 | KL8 | KL9 | KL10 |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| E1(%)         | 55.10 | 54.98 | 54.41 | 63.18 | 43.48 | 53.32 | 58.30 | 66.39 | 51.56 | 32.03 |
| E2(%)         | 35.69 | 35.69 | 35.69 | 39.61 | 39.61 | 40.91 | 32.66 | 32.66 | 32.67 | 32.66 |
| E2(%)         | 2.45  | 2.42  | 2.78  | 1.97  | 1.98  | 2.25  | 2.43  | 2.43  | 2.19  | 2.20  |
| Sum of errors (%) | 37.08  | 37.02  | 36.82  | 41.99  | 32.14  | 37.45  | 37.92  | 41.97  | 34.49  | 24.73  |

**Table 3.** Sum of errors of constructed candidate cycles

![KL 10](image)

**Figure 1.** Developed driving cycle for passenger cars
The following observations are made from the developed driving cycle:

1. Speed range below 10 km/h was dominant. This is due to congested road or heavy traffic condition which lead to have more stop-go condition.

2. 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 move at higher speed range with less frequent stop due to less traffic condition.

3. A 23.21 km/h average speed was recorded in the developed KL 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 takes place during that period due to frequent stop along the road.

To evaluate the developed KL cycle, a comparison was made between the existing international cycles as shown in Table 4. The driving cycle for passenger car was compared with US driving cycles such UDDS and LA92 which developed for emission purpose. Besides, it was also compared with the driving cycles of cities in China such Beijing driving cycle and Shanghai driving cycle and together with Hong Kong driving cycle.

For the average speed data, it shows that Beijing cycle is closely related to the KL driving cycle while the average speed for other driving cycles are a bit far from the developed KL cycle. The comparison for the average running speed is nearly correlated to the Beijing cycle. The average acceleration and average deceleration were the lowest than those mandatory cycles. The percentage of time spent in acceleration and deceleration is among the highest but closely related to the UDDS cycle. The percentage time spent in idle is similar to Hong Kong cycle, but the highest was Shanghai cycle. It has the lowest percentage of time spent in cruise mode compared to other existing cycle. Concerning the potential acceleration kinetic energy (PKE), the other cycles are generally larger than the developed KL cycle.

On overall consideration, it can be concluded that the traffic in Kuala Lumpur and Beijing is closely related to each other and the traffic condition in Kuala Lumpur is more congested compared to other existing driving cycles. Therefore, high fuel consumption and emission will be obtained from the tested vehicle using the KL driving cycle. Other than that, there are huge number of micro-trips found in the low range speed data than the high range speed data. It shows a high percentage of frequent stop of vehicles happen and causes traffic problems.

Table 4. Comparison of KL cycle with existing international cycles.

| Driving Parameters | KL | Beijing | Shanghai | Hong Kong | UDDS | LA92 |
|--------------------|----|---------|----------|-----------|------|------|
| V_{avg} (km/h)     | 23.21 | 23.00   | 34.00    | 25.00     | 31.40 | 39.40|
| V_{I_avg} (km/h)   | 28.73 | 28.00   | 42.00    | 30.40     | 38.60 | 47.00|
| Acc_{avg} (m/s^2)  | 0.37  | 0.52    | 0.54     | 0.59      | 0.50  | 0.67 |
| Dec_{avg} (m/s^2)  | -0.38 | -0.55   | -0.68    | -0.59     | -0.57 | -0.75|
| %Acc (%)           | 39.87 | 36.00   | 39.00    | 34.50     | 39.70 | 38.30|
| %Dec (%)           | 39.29 | 34.00   | 31.00    | 34.20     | 34.70 | 34.10|
| %Idle (%)          | 17.80 | 16.00   | 19.00    | 17.80     | 17.60 | 15.10|
| %Cruise (%)        | 3.04  | 10.00   | 11.00    | 12.00     | 8.00  | 12.50|
| PKE (m/s^2)        | 0.32  | 0.43    | 0.46     | 0.39      | 0.38  | 0.40 |
4. CONCLUSION
The objective of this paper is to develop a driving cycle to determine fuel consumption and emissions from vehicles. Due to data variation in constructing driving cycle, most of the developing countries’ city routes having different driving cycle which are not same as one another.

A practical method was used to develop the driving cycle by using micro-trip method from real-world driving data. The driving parameters include average speed (Vavg), average running speed (V1avg), average acceleration (Accavg), average deceleration (Decavg), percentage of idle (%Idle), percentage of cruise (%Cruise), percentage of acceleration (%Acc), percentage of deceleration (%Dec), number of stops per kilometer travelled (Stops/km) and positive kinetic energy (PKE) were considered when constructing the driving cycle. The developed driving cycle was compared with other existing cycle, thus focuses the variety of traffic condition in Kuala Lumpur city.

There are some limitations found in this study. One of the limitation is, the high speed data from the highway data collection is less, which gives a less variety of choice to choose the micro-trip during the random selection of micro-trip to construct the driving cycle. Thus, it should be increased to improve the accuracy in selecting the microtrip. Besides, the inconsistency in driving behavior is not considered in this research. Other than that, the developed driving cycle mostly refers to Kuala Lumpur city and may not be suitable to use for other cities. This research can be used as a reference and further the studies to determine the fuel consumption and emission.

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