Development of Kuala Lumpur driving cycle for the estimation of fuel consumption and vehicular emission

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Abstract. Driving cycles is a series of data points representing the speed of vehicle verses time sequence profile developed for certain road, route, specific area or city. Generally, driving cycle is used to estimate the fuel consumption (FC) and vehicular exhaust emission. The common factors that affected the FC and exhaust emission are the engine operating conditions such as cold start, low engine loads and high engine loads which are found during actual driving. The research presents the measurement and analysis of engine conditions based on actual driving behaviours in an attempt to formulate representative driving cycle for Kuala Lumpur. The methodology used for this research is adapted from the Worldwide Harmonized Light-duty Test Cycle (WLTC) introduced by the working party on pollution and energy (GRPE) under the United Nations Economic Commission for Europe (UNECE). This research covered a wide area of paved road in Kuala Lumpur, about 62.34% by surveying the road condition on the eight selected routes. The used of On-board Diagnostic (OBD) and Global Positioning System (GPS) equipment are used to record the vehicle travel speed during data collection activity. The driving characteristics are then analysed from speed profile and its target statistic parameters are defined to develop representative driving cycle. The characteristics of the newly developed driving cycle are compared to the European driving cycle which is currently being used in Malaysia for new vehicle certification and registration. Therefore, the correlation of FC is derived to indicate the impacts of real-world driving conditions relative to domestic conditions.

1.0 Introduction
Due to the evolution of automotive industry in Malaysia, the rapid increase of number of passenger vehicles as well as the very limited control strategies of emission, motor vehicles are alleged to be one of the main source of air pollution. According to a report, Malaysia’s Biennial Update Report (BUR), submitted to United Nations Framework Convention on Climate Change (UNFCCC) in 2015, road transport sector is accounted to be significant source of carbon emission, estimated to be the second largest sector following the industry sector which ranked at the first place [1]. Committed to reduce the emission level, Malaysia need to be very critical in developing the strategies in controlling the level of emission. Thus, Malaysia Automotive, Robotics and IoT Institute (MARii) is spearheading the initiative in addressing the vehicle emission level by conducting a study in estimating the fuel consumption based on driving behaviour. The study is to develop a representative Kuala Lumpur Driving Cycle (KLDC) for light-duty passenger vehicle. The idea is that, this driving cycle will directly reflect the actual fuel
consumption and carbon emitted by the light-duty passenger vehicle based on actual local driving characteristics (road conditions, driver’s behaviour, weather, etc).

Driving cycle is a representative plot of vehicle speed versus time obtained from real-world driving natures in a specific region or road network. Driving cycle also is defined to consists of sequence of several operating modes such as idling, cruising, acceleration and deceleration [2]. Generally, driving cycle derived from actual driving natures precisely represents a typical driving pattern for a particular population or region [3]. Thus, different region will result to different driving cycle due to dissimilarities of actual driving characteristics and regional traffic congestion level as well [4].

The fuel consumption is derived from carbon balance method which directly correlated with the emitted exhaust emission from a motor vehicle. The emission factors in turn depend on several other factors such as type of fuel, type of engine, driving attributes, utilization of equipment and weather condition. In short, it can be concluded that a driving cycle is directly related with the fuel consumption and exhaust emission. Thus, a representative of regional driving cycle is crucial in determining accurate estimations fuel consumption and emission model.

2.0 Methodology

By using the concept of Deming cycle; the Plan-Check-Do-Action (PDCA), the reasearch methodology is constructed accordingly in conducting the research. Basically, the Deming cycle is being used to ensure the project can run smoothly in order to achieve all the objectives. Figure 1 depicts systematic methodology process flow adapted from the PDCA cycle that had been used for this study.

![Figure 1. Research methodology.](image-url)
3.0 Data Collection and Cycle Development

Prior to the data collection, considered as the key element in developing a driving cycle, route selection phase is very critical. It is because, the relationship between the routes selected and the driving behaviour is directly proportional. In that sense, it is important to ensure that selected routes of high utilization are included. In order to achieve that, there are few factors need to be accounted during the selection such as traffic density and peak periods. For this study, the traffic density and Level of Service (LOS) for a particular road network is assessed through two salient sources. A set of database provided by the Ministry of Work Malaysia namely RTVM 2015 is used as the prime source [5]. At the same time, live data on traffic density is extracted from the online platform, Google Traffic. Both data sources are used to obtain the most desired road conditions. Thus, it is important to ensure data are collected on the routes are representative of network-wide conditions instead of any few particular routes. Figure 2 illustrates the definition of LOS based on the RTVM 2015.

![LOS A](image1.png)
**LOS — A**
No congestion, Free flow with low traffic volumes and high speeds.

![LOS B](image2.png)
**LOS — B**
No congestion, Reasonably free flow, but speed depends on traffic flow.

![LOS C](image3.png)
**LOS — C**
Minimum congestion, Stable flow zone, but with drivers less able to travel at their own chosen speed.

![LOS D](image4.png)
**LOS — D**
Moderate congestion, Unstable flow, Restricted drivers chosen speed.

![LOS E](image5.png)
**LOS — E**
Severe congestion, Very unstable flow, possible short stoppages.

![LOS F](image6.png)
**LOS — F**
Extreme congestion, Unacceptable congestion; stop-and-go traffic, forced flow.

*Figure 2. Definition of LOS in the RTVM 2015.*

The choice of data collection methods (chase-car, instrumented vehicle with OBD and hybrid method combining with driving circulation) is based on suitability and appropriateness for the driving conditions. The salient considerations are data types and quality. Hence, considering to establish a driving cycle that will be used nationwide, the hybrid approach joined up with driving circulation will be used. It is because this method is superior in term of quality and accuracy compared to other methods. However, a few problems may arise from the GPS data which include loss of signal, stuck speed and false zero speed as well as correction during post-processed phase for filtering GPS data. With respect to eliminate this error, the data derived from OBD acts as the prime source for this study.
Driving conditions are analysed through the speed-time profile, generated from the road data measurement. For this purpose, the kinematic segments, known as microtrips are defined within the overall driving test. Typically, the microtrips are described by their idling duration and cross-contribution of the instantaneous speeds and accelerations. Correspondence analysis and clustering tools are used to classify the microtrips according to their speed-acceleration relation. The principle in assessing the relation is to group microtrips that are similar or close to each other and to differentiate groups that contrasted from each other. The unified speed profile obtained is set as the reference database. The homogeneity of the microtrips justify the class of each groups in order to describe the class through overall parameters. The parameters to be measured are including the average speed, average acceleration and deceleration, percentage of idling, percentage of cruising as well as number of stops. Therefore, the analysis makes it possible to develop a typology of local driving conditions into speed classes (i.e. low, medium, high) based on the speed profile characteristics.

For the cycle development, the selected microtrips are merged together into a set of trial driving cycle. The selection of the individual microtrips to be merged is done automatically by using clustering tool. Then, the Speed Acceleration Frequency Distribution (SAFD) is developed. The SAFD is used to illustrate the relationship of speed and acceleration in graphical manner. Generally, the bubble chart gives an idea on the driving pattern based on the real-world driving conditions. Once the trial driving cycle is constructed, it is then to be compared with the unified reference database. Then, statistical approach is used to compare the representativeness of the driving cycle with the reference database. An analysis named chi-square analysis is performed to analyse the similarity of the driving cycle to the reference database. In that sense, the final cycle shall replicate Kuala Lumpur actual driving behaviour constituting various driving operations like accelerating, cruising and idling. Figure 3 shows the example of SAFD to illustrates the relationship between speed and acceleration correspondence with the driving operations.

![SAFD](image)

**Figure 3.** SAFD developed to determine the relationship of vehicle operations and driving behaviour.

### 4.0 Conclusions and Recommendation

The present research is attempted to establish a representative driving cycle for Kuala Lumpur territory. The methodology used is adopting the approach introduced by the GRPE under the UNECE for the development of WLTC. However, in order to ensure the novelty of this research, the method of route selection is a bit different in order to replicate the real-world driving behaviour based on domestic conditions. Google Traffic data is used to validate the current level of congestion by comparing the extracted data from RTVM 2015. By using the data from both traffic census as well as online platform,
the assumption made for deciding the peak and off-peak periods could be justified by comparing both data.

To reflect the actual driving behaviour and fuel consumption for each vehicle category across nationwide, further study needs to be done in regions other than central, namely North, South, East Coast, Sabah and Sarawak. With the availability of the driving data nationwide, it is expected that the results will be more accurate and the assessment of emission as well as fuel consumption will be more stringent. Thus, it can be concluded that, better assessment for vehicular exhaust emission can be done with the driving behaviour data that are obtained from various regions across Malaysia.

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