Driving cycle development methods: case study in Malaysia

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ABSTRACT

Over the years, many models have been created to estimate pollution inventories and fuel usage. These models can be divided into two types: travel-based and fuel-based. One of the most used travel-based models for estimating emission inventories is driving cycles. It can be used for a variety of different things, such as establishing pollution regulations, traffic control, and calculating journey time. For these goals, researchers have previously attempted to use easily available, well-established driving cycles. In many ways, however, the local environment differs greatly from that of the driving cycle's genesis. As a result, these cycles' applications have failed to provide high-quality results. This research aims to analyse the various approaches utilised for driving cycle construction in various locations of Malaysia under varied operational situations.

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1. INTRODUCTION

The transporation usage has been increased due to the significant growth of world population. This leads to an increase in airborne pollution levels and any other serious environmental issues, such as waste management [1]. The pollutant factors directly from vehicles' exhaust emissions, and exacerbated by poor technique from road users and unwary traffic users. Department of Environmental Malaysia (2017) has reported that 70.4% source of air pollution is from motor vehicles [2]. The modern cities are required to use more efficient and greener vehicles to avoid the environmental problems from continuing to occur.

Engineers, analyst and technologist are conceptualized an approach to overcome this issue by creating a hybrid car [3]. The hybrid vehicle is the foremost promising vehicle to decrease the fuel utilization and limit tailpipe emissions [4]. Driving cycle (DC) is a representative speed-time profile of driving conduct of a particular locale or city [5]-[7]. The driving cycle characterizes the conduct of the vehicle on the road and has a broad range of uses, from designing activity control frameworks to deciding the implementation of different vehicle types. It is additionally utilized within the emission testing of vehicles for certification of emission standards [8]. It is widely used of application for vehicle manufacturers, environmentalists and traffic engineers [9].

The worldwide harmonized light vehicle test cycle (WLTC) is one of the world's biggest driving cycle studies in the world, designed in 2012 with the goal of representing normal driving characteristics for light duty cars all over the world [10]. The WLTC collected the driving data across 14 countries in five different regions, including the United States, the European Union and Switzerland, Korea, Japan, and India.

The project also covered a variety of driving conditions including urban and highway routes, peak and off-peak hours and many for a conventional vehicle. Together with WLTC, new european drive cycle (NEDC), federal test procedure (FTP), and Japanese models are among the most well-known drive cycles. These DCs, like all type-approval DCs, are primarily used for calculating vehicle fuel consumption and mass emissions of pollutants, as well as for comparison and certification processes [11]. Europe, the United States, Japan, China, and India, are the main contributor in the global automotive sector. Other cities, such as Toronto, Canada [12], Iran [13], and Singapore [14] also have adopted local driving cycles. Local governments in Malaysia continue to use the NEDC for legislative purposes, as well as local manufacturers and suppliers for evaluation [15].

Nyberg *et al.* [16], driving cycles are important in vehicle design, and if vehicle manufacturers concentrate just on one driving cycle while building and designing a vehicle, the design may be optimised for that specific driving cycle, resulting in a design that is non-robust and sub-optimal for other driving cycles. It is also essential for the driving cycles to be updated frequently. The characteristics mentioned in the previous paragraph, change through the years within a city or area, as the road network is improved or updated the vehicles are changing in characteristics and number and drivers' behavior changes due to stress in a modern city [17]. There are few factors that effecting the driving cycle such as driving behaviour, driving conditions (road type, traffic condition, weather condition), and vehicle characteristics [18]. Eventhough the driving cycle used by Malaysian automotive manufactures is referring to WLTC, a local Malaysian drive cycle is still required to help with realistic fuel consumption estimates for Malaysian real-world driving.

2. METHOD

To construct a driving cycle, three stages were executed in this research which are route selection, data collection and drive cycle construction [19]. When constructing vehicle driving cycles, selecting a relevant test route that can capture real-world traffic circumstances in a city or region is crucial. The test route should take into account all local traffic factors, such as the distribution of road types, average velocity, traffic flow, topography, and so on [20].

There are three different methods of gathering data: the chase car method, onboard measurement method, and hybrid method [21]. Chase car technique is when a chase car follows the target vehicles, an instrumented vehicle records second-by-second speed data. Alternatively, the onboard measuring technique involves collecting speed-time data using a real-time logging device installed in the chosen vehicle over a predefined path [22]. Lastly, the hybrid method, is the combination of the two techniques, involves repeatedly sending a test car equipped with an instrument along the chosen routes during both peak and off-peak periods [23]. According to [24], The use of chase cars has a little impact on driver behaviour, resulting in more realistic driving data. The speed–time sequence is routinely collected using techniques such as chase–car, field survey questionnaires, and motorbike instrumentation.

The following steps are usually included in cycle construction methods: 1) real-world driving data collection, 2) segmentation, 3) cycle construction, and 4) evaluation and selection of the final cycle [25]. There is no universal or standard approach for creating a driving cycle. The micro-trips (MT) and Markov chains-Monte Carlo (MCMC) methods are the most frequent methodologies, as detailed in [26]. These approaches are essentially random; therefore, they are repeatable but not reproducible, which means that each time they are used, they produce a different driving cycle. The MCMC is used to build a driving cycle for electric vehicles to analyse private driving patterns, similar to the work provided by [27]. Driving data collecting, micro-trips division, characteristic parameter extraction, principal component analysis (PCA), and clustering algorithms are all part of the standard driving cycle development approach for passenger automobiles or special purpose vehicles [28]. However, this paper focuses on the development of DC in Malaysia only with different methods and focus area.

2.1. Kuala Lumpur driving cycle

Nearly all the Malaysia's researchers focus on Kuala Lumpur as the study area since Kuala Lumpur is the center of Malaysia. Since most Malaysians migrate to Kuala Lumpur to work for a living resulting Kuala Lumpur has the highest number of registered passenger vehicles in Malaysia, according to the ministry of transportation Malaysia [29]. As stated by Jamil *et al.* [30], in 2014, Kuala Lumpur and Johor has the largest number of vehicles on road with 2.3 million and 2.3 million respectively.

2.1.1. Development of Malaysian urban drive cycle using vehicle and engine parameters

As mentioned in Abas *et al.* [31], a KL driving cycle is developed together with engine specs and characteristics. As indicated in the paper, five roads with the most congested traffic during peak hours were chosen to represent the average urban driving conditions in Malaysia. The actual driving data collection was done using an instrumented passenger automobile during peak hours on the designated routes. The acquired data was then analysed by dividing the recorded travels into smaller micro-trips.

After that, the vehicle and engine parameters were simplified using principal component analysis, and the data was clustered using the TwoStep methodology. TwoStep cluster analysis determines clusters automatically and able to handle large datasets. Due to its ability to avoid the arbitrary nature of conventional clustering techniques, it is regarded as one of the most practical and objective selection criteria. As a result, it enables the identification of dataset segments that would not otherwise be obvious [32]. The target criterion for selecting suitable micro-trips as sub-cycles was the means of the created clusters. The sub-cycles were then arranged and built into the study's first Malaysian urban drive cycle. Finally, the initial drive cycle was validated by measuring fuel consumption on an engine bench test and comparing it to the actual driving results.

The drive cycle is made up of a succession of carefully chosen sequences that satisfy the target criterion. The percentage error of the parameters in each component and category is used to examine sequences at random. The cycle in each category was built using sequences with an inaccuracy of less than 10% from the target values. The cluster mean is utilised as the target value for each of the parameters in the appropriate categories. The assessment chose 17 sequences that had all of the parameters with an error rate of less than 10%. The selected sequences under its component are coupled with the acceleration component because the deceleration characteristic is within a cluster. The sub-cycles are grouped in order of ascending sequence duration, producing the beginning driving cycle, which covers vehicle speed, acceleration/deceleration, and engine characteristics from real-world Malaysian urban driving.

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

In order to develop a representative driving cycle for Kuala Lumpur, the research offers the measurement and analysis of engine conditions based on actual driving behaviours [33]. The study is to develop a representative Kuala Lumpur driving cycle (KLDC) for light-duty passenger vehicles. Eight selected routes based on road traffic volume Malaysia (RTVM) 2015 in the area Kuala Lumpur district were chosen as the area of study. Data collection method used was hybrid method which a combination of chase car method and on-board measurement method but on-board will be the prime source.

The methodology used is adopting the approach introduced by the working party on pollution and energy (GRPE) under the United Nations Economic Commissions for Europe (UNECE) for the development of WLTC. The selected micro-trips are combined into a set of trial driving cycles for cycle development. The clustering tool is used to automatically pick the individual micro-trips to be combined. After that, the speed acceleration frequency distribution (SAFD) is created. The SAFD is a graphical representation of the relationship between speed and acceleration. After constructing the trial driving cycle, it must be compared to the unified reference database. The representativeness of the driving cycle is then compared to the reference database using a statistical methodology. To determine the degree of similarity between the driving cycle and the reference database, a chi-square analysis is used. In this way, the final cycle will mimic Kuala Lumpur's actual driving behaviour, which is made up of numerous driving operations such as accelerating, cruising, and idling. However, the methodology used in this paper is same as the work presented by [34].

2.1.3. Development of driving cycle for passenger car under real world driving conditions in Kuala Lumpur, Malaysia

The goal of this study is to create a Kuala Lumpur city driving cycle to determine vehicle fuel consumption and emissions [35]. A chase-car strategy was used to acquire the speed-time data. Eight routes were chosen to gather data during peak and off-peak hours, and also during the weekends, while four routes were chosen to capture data on the highway, allowing the data to be differentiated between high and low speed data. The data then categorized based on the level of service (LOS) to determines the traffic flow based on the speed.

A practical approach was used to develop the driving cycle by utilising micro-trip methodologies and actual driving data. The micro-trips method is the most frequently used method to construct representative DC [36]. When designing the driving cycle, the following characteristics were taken into account: average speed, average running speed, average acceleration, average deceleration, percentage of idling, percentage of cruising, percentage of acceleration, percentage of deceleration, number of stops per kilometre travelled and positive kinetic energy (PKE). The designed driving cycle then was compared to other standard driving cycles, highlighting the city's diverse traffic conditions.

A random sample of micro-trips was grouped according to their speed range. The time it takes to complete a driving cycle was set at 1200 seconds to account for the time it takes to analyse the gas using its samples. To build a superior emission purpose driving cycle, a tolerance limit of 5% under-estimation and 15% over-estimation was considered when picking the micro-trip. Following the random selection of micro-trips, the driving parameters, percentage number of micro-trips and percentage of time spent in micro-trips are calculated. A number of candidate cycles were created to be compared and the driving cycle with the lowest inaccuracy was chosen as the KL driving cycle.

2.2. Terengganu driving cycle

Other state that is also became the choice of Malaysian's researchers as the area of study is Terengganu state. Terengganu is located in eastern Peninsular Malaysia. This section discussed a few works that developed a driving cycle in Terengganu.

2.2.1. Terengganu routes representation for development of Malaysia driving cycle: route selection methodology

This research focuses on route selection in Terengganu, one of the Malaysian states that contribute to the gathering of speed-time data for the Malaysia driving cycle (MDC) data collection effort [37]. The methods utilised for route selection, the selected routes, and the driving conditions for route data collecting in Terengganu are briefly described in this study. 11 routes in the Terengganu region have been chosen to submit speed-time data for the creation of MDC using technique used by the WLTC. The routes chosen include urban, rural, and highway roadways. When collecting samples for each route and direction, the driving conditions (peak, off-peak, weekend) are taken into account. The routes were chosen using RTVM data from 2015, which took into account the LOS and peak hour traffic flow for each route in Terengganu.

The route choice was double-checked, and the traffic conditions were verified using Google Maps. On the other side, Google Maps will be utilised to choose the start/end points and evaluate the road geography of the chosen routes. To ensure that the chosen routes are free of significant road construction and any road diversion, self-evaluation and route validation are necessary prior to the start of route data collecting. This article is primarily concerned with route selection in the Terengganu region, rather than the establishment of the Terengganu driving cycle. However, after all of the identified routes have been certified as eligible for route data gathering for future work, the speed-time data collecting can begin.

2.2.2. Driving cycle development for Kuala Terengganu city using k-means method

The purpose of this study is to characterise and create a driving cycle for Kuala Terengganu city at 8 a.m. using the k-means approach. To compare the fuel economy and emissions of conventional engine vehicles, parallel plug-in hybrid electric vehicles (PHEV), series PHEV, and single split-mode PHEV along five different routes while using the driving cycle that was created [38]. A PHEV is a rechargeable hybrid electric vehicle (HEV) with a charging connector, usually an in-board charger [39].

Route selection, data gathering using an on-road measuring approach, and driving cycle development using the k-means method are the three primary steps in the methodology. One of the most often used strategies for handling the clustering problem is the k-means clustering method [40]. The differences between this work and others are, the value of k is different regarding the traffic condition and style of driving, and the target route also different.

To create the optimal driving cycle, Matrix Laboratory software (MATLAB) was utilised as the computer programme platform, and vehicle system simulation tool development (AUTONOMIE) software was used to analyse fuel rate and gas emission. The AUTONOMIE programme offers an integrated environment and a set of procedures for maintaining, integrating, and connecting dynamic models of vehicle parts and subsystems in order to create and run multiphysics system simulations [41]. The methodology used in this paper was similar with work by [42] except it was corporated with one-step Markov modelling.

3. RESULTS AND DISCUSSION

3.1. Development of Malaysian urban drive cycle using vehicle and engine parameters

Figure 1 shows the driving cycle developed by Abas *et al.* [31]. On the engine test bench, the KL drive cycle was validated, and the recorded fuel consumption was compared to the NEDC and actual driving. Fuel efficiency measured using the KL urban drive cycle deviates by 8.5 percent from actual driving, compared to 43.1 percent using the NEDC. In comparison to the NEDC, the KL urban drive cycle is determined to be better at portraying Malaysian urban driving. Other states, on the other hand, need be taken into account in order to establish an accurate Malaysian driving cycle.

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

In Suhaimi *et al.* [33], there was no final developed driving cycle shown. However, Figure 2 depicts the SAFD example to demonstrate the relationship between speed and acceleration and driving activities. As such, the chart provides an overview of the driving style based on actual driving circumstances.

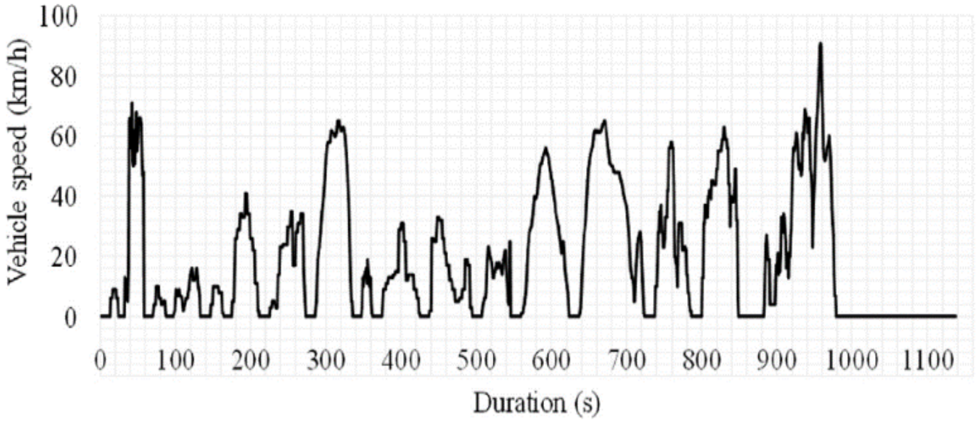

Figure 1. Kuala Lumpur urban drive cycle

3.3. Development of driving cycle for passenger car under real world driving conditions in Kuala Lumpur, Malaysia

Figure 3 depicts the created KL driving cycle and its driving parameters, which are closely related to the target parameters. When data is collected at rapid speeds, micro-trips become longer. With a total of 17 intermediate stops between micro-trips, the designed KL driving cycle travelled a distance of 7.86 kilometres in 1219 seconds [35].

There are certain limitations to this research. One of the constraints is that high-speed data from highway data gathering is less common, resulting in a smaller range of micro-trips to choose from when generating the driving cycle by random selection. As a result, it should be increased to improve micro-trip selection accuracy. Furthermore, the irregularity in driving behaviour is not taken into account in this study. Aside from that, the created driving cycle is primarily for Kuala Lumpur and may not be appropriate for other cities. However, this study can be utilised as a starting point for further research into fuel use and emissions.

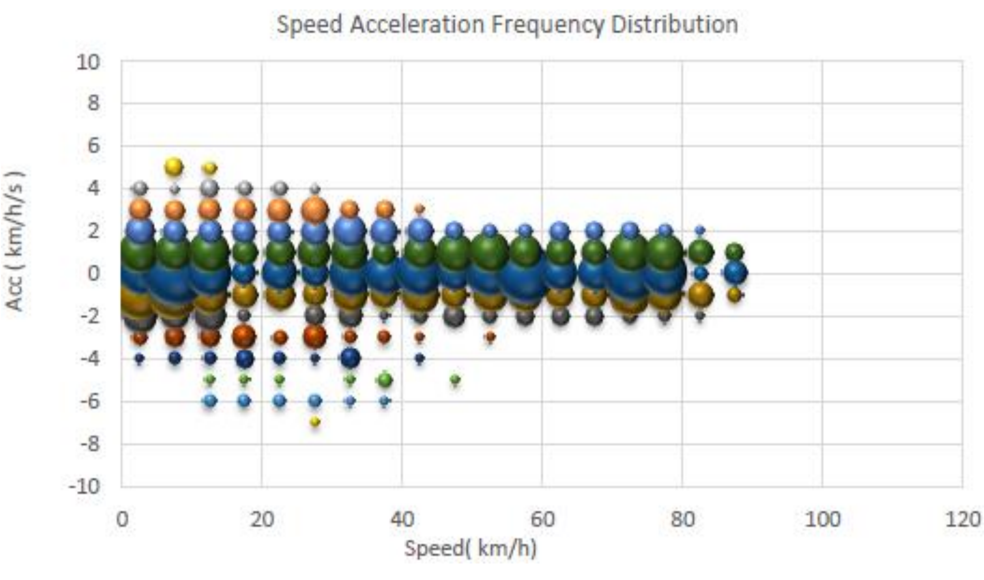

Figure 2. SAFD developed to determine the relationship of vehicle operations and driving behaviour

3.4. Driving cycle development for Kuala Terengganu city using k-means method

Figure 4 depicts the final Kuala Terengganu driving cycle along one of the routes that was examined. Micro-trips in the higher speed range are longer than micro-trips in the lower speed range, as seen in the diagram. This is because a vehicle in a free flow environment travel at a higher speed range with fewer stops due to less traffic congestion [38].

The fuel rate, such as fuel consumption and fuel efficiency, and emission can be determined using AUTONOMIE software version v1210 after the driving cycle has been constructed. The KT driving cycle was effectively achieved, indicating that the suggested method can be used to generate a KT driving cycle for PHEV powertrains in order to address exhaust emission and fuel economy issues. To acquire a realistic Terengganu driving cycle (TDC), more research needs to be done on other major roads in Terengganu.

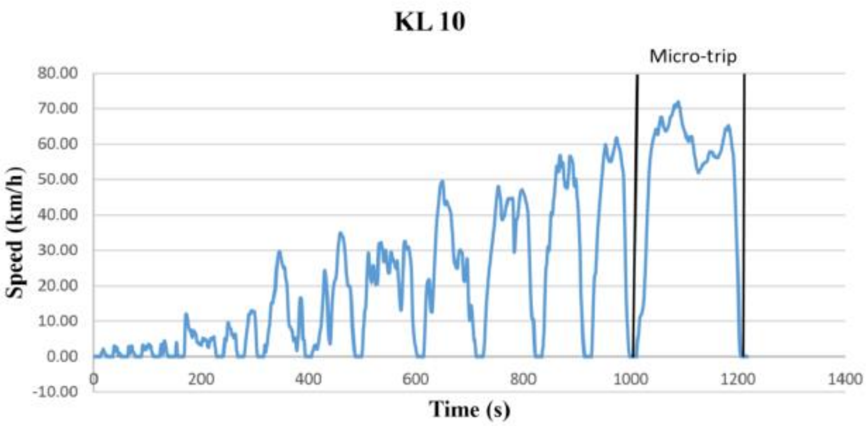

Figure 3. Developed driving cycle

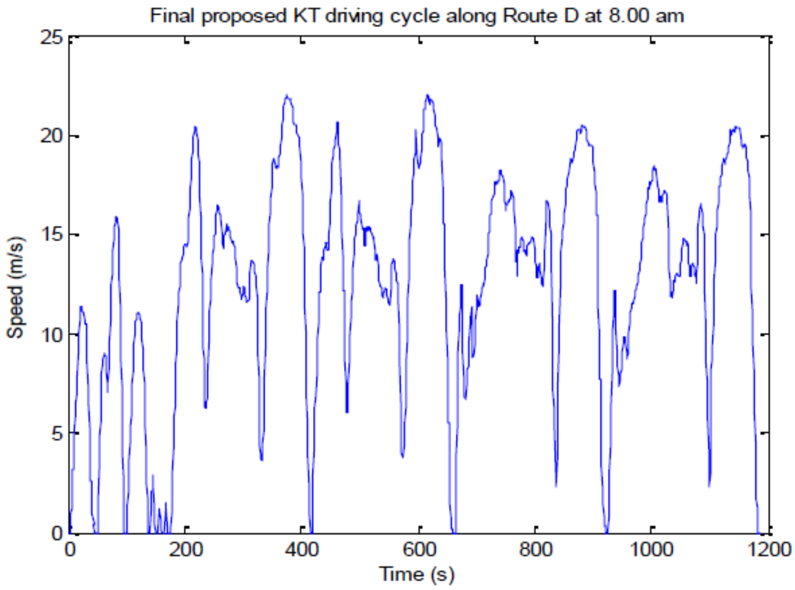

Figure 4. Proposed KT driving cycle.

4. CONCLUSION

There are lots of methods that have been applied in order to develop a driving cycle. Each represents both advantages and disadvantages. However, most of the past researchers focus on different area or states in Malaysia for example Kuala Lumpur and Terengganu. Thus, it will not represent a real Malaysian driving cycle. For the future work, in order to develop an accurate Malaysian driving cycle, all states and cities in Malaysia should be considered. With statewide access to driving data, it is envisaged that the results would be more precise, and the assessment of emissions and fuel consumption will be more rigorous. As a result, it can be inferred that using driving behaviour data collected from various places around Malaysia, a better estimate of vehicular exhaust emissions may be made.

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