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Development of Muar Driving Cycle Based on Real-World Driving Conditions

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Abstract: A driving cycle is a graph that represents vehicle speed over time of a specific area and characterizes a typical driving pattern for a city's population at different driving conditions such as peak and off-peak. This research aims to design and develop Muar Driving Cycle (MDC) based on the actual driving condition. Selection of routes made via Google Traffic based on the congestion level and driving conditions for urban, semi-urban and rural areas in the Muar district. The data was collected using the test vehicle Proton Saga 1.3 L CVT, equipped with the data logger system. Recording data has been segregated according to the maximum vehicle speed for each micro-trip. Micro-trips were combined to construct the Muar Driving Cycle based on target speed and acceleration. The initial driving pattern of MDC has been developed and the cycle characteristic are presented. The results obtained are compared with the current driving cycle including NEDC, WLTC and the MUDC. MDC has the high velocity with an average of 40.66 km/h with a maximum speed of 112.06 km/h and average acceleration of 0.263 m/s^2. The drive cycle should be validated through vehicle simulation and the chassis emission cycle test in the future. The findings from the study would benefit in identifying the optimum solution for powertrain and vehicle technologies for Malaysian driving conditions.

Keywords: Muar Driving Cycle, Micro-Trip, Driving Condition

1. Introduction

Fuel economy is a metric that expresses how far a vehicle can go on a single liter of petrol. It is expressed in kilometer per liter[1]. The inverse of fuel economy is fuel consumption. Fuel economy is measured in kilometers per liter, while fuel consumption is measured in liters per 100 kilometers [1]. The amount of fuel consumed is determined by the engine, the fuel type, and the efficiency with which the engine's output is conveyed to the wheels. This fuel energy is needed to overcome rolling resistance

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caused by tires flexing, aerodynamic drag (which is caused by air resisting vehicle motion), inertia and hill-climbing forces, and engine and driveline losses [1].

Nowadays, many research and innovation that have been made to improve fuel consumption. Development of driving cycles in Malaysia is widely made to understand the driving characteristic as an alternative to improve fuel consumption. A driving cycle is a driving pattern that represents vehicle speed over time of a specific area or a city based on the actual driving behavior condition. Driving cycles are also defined by operating conditions such as idle, acceleration, deceleration, and cruising [2]. The driving cycle also represents a typical driving pattern for a city's population at different driving conditions such as peak, off-peak, and weekend [2]. This research presents the development of Muar driving cycle as a reference to the vehicle manufacturing sector to study vehicle fuel efficiency based on Malaysia's actual traffic conditions and driving behavior. The research's main objective is to analyze the actual on road data collection to construct and develop the Muar Driving Cycle.

1.1 Literature review

From the literature review, there are stages in driving cycles development: route selection, data collection, data analysis, and cycle construction. In constructing the 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 [2]. Route selection is usually made before data collection to ensure the targeted route are suitable to collect data according to the traffic conditions during peak hours [2]. For the route selection method in Malaysia, the route selected for data collection is based on data from Road Traffic Volume Malaysia (RTVM) [3] and Google Traffic [2]. The Level of Service (LOS) of a traffic facility is an approach introduced to describe the quality of traffic service to a given flow rate [4]. The traffic flow and quality of traffic service for each route is categorized based on level of service (LOS). Raw traffic volume data is extracted first from RTVM 2015 then ranked up based on the LOS and peak hour traffic flow [3].The route was selected to simulate actual driving conditions in the city [5]. Before route data collection begins, self-assessment and route validation are required to guarantee that the selected routes are free of major road construction and any road diversion.

In developing the driving cycle, the data collection for on-road data is performed using the chase car method for driving technique with on-board measurement as proposed by previous researchers [1, 5]. The chase-car method is where the drivers will randomly select a car and chase it along their route to collect the data [2]. The 'chase car' method selects a vehicle to follow for as long as possible within the research area, mimicking the selected vehicle's activities at a constant distance. If the chosen vehicle departs from the study area, the 'chase car' selects a new vehicle to follow instantly [7]. The tests were conducted by a similar driver and a co-driver on-board to continuously observe the instantaneous data.[5]. Besides using on-board measurement, the study was done for Batu Pahat and Basrah driving cycle using Global Positioning System (GPS) [8]. This method is done by installing control devices distance between vehicles and choose targets at random by the laser beam [6].

The cycle can be built by extracting the acquired speed data and dividing it into micro-trips, then building a driving cycle by generating a speed graph against time using the combined micro-trips and idle period based on the assessment criteria. The goal of this research is to create a more sensible driving cycle for estimating fuel consumption and exhaust emissions [2]. The vehicle and engine parameters were then simplified through principal component analysis and followed by clustering the data using TwoStep technique. The means for the combination of micro-trip used as the target criterion in selecting eligible micro-trips as the sub-cycles [7]. The cycle selected with the lowest error represents the driving cycle for the city. Besides the TwoStep technique, K-means clustering method also has been used for cycle construction. K-means is one of the simplest unsupervised learning algorithms that solve the clustering problem [9]. The procedure follows a simple and easy way to classify a given data set through a certain number of clusters (assume k clusters) fixed a priori [9].

1.2 Research background

The driving cycle is representing the driving behaviour and pattern based on the city's topography and road system. Many driving cycles have been developed, such as New European Driving Cycle (NEDC), Federal Test Procedure (FTP75), and Worldwide harmonized Light-duty vehicles Test Procedure (WLTP) [5]. Malaysia still used the NEDC data even though the NEDC is outdated (1997). The WLTC[10] was developed to replace the NEDC, but the development of this cycle does not consist of the driving condition in ASEAN regions. As a result, the fuel consumption estimated from a lab test using these cycles differs significantly from the actual measurement. Some of the main reasons for these discrepancies are the generalization of drive-cycles to cover a wide range of driving conditions and the evolution of other factors such as technologies and infrastructures [11]. Due to this issue, Malaysia has started to develop a driving cycle that could represent Malaysia, such as Malaysia Urban Driving Cycle (MUDC) in 2018. However, the developed cycle is not officialized yet today. Therefore, the need to develop a Muar driving cycle to help the researcher study engine operating conditions based on Muar driving behaviour and be an alternative to understand the driving characteristic focusing on the Muar district region.

This research aims to construct a Muar Driving Cycle and study the vehicle driving characteristics from the actual on-road in the Muar district. The scope of the research is only used one type of vehicle that is 2018 Proton Saga 1.3L Standard CVT DOHC, to collect accurate data and avoid data discrepancies. The car is attached with onboard diagnostic to collect data for speed, acceleration, deceleration, distance and duration for each trip. Routes are selected based on a driving condition: urban, semi-urban, and rural at Muar district. The study only focuses on a light-duty passenger vehicle. This study uses route selection by Google Traffic and self-assessment to ensure the selected route are free from construction and road diversion. Data was collected using onboard diagnostic attached to the test vehicle and the chase-car method for driving technique. The data extracted are divided into micro-trip based on the selected criterion. The cycle construction based on the combination of micro-trip consisting of low difference will be chosen as Muar driving cycle.

2. Methodology

The Muar driving cycle was created starting from traffic observations within the Muar district to select the test routes for the data collection. Google Traffic was used in this study to monitor live traffic congestion in the research area regularly. To illustrate the normal driving condition in Muar, ten routes with various traffic conditions were chosen. The actual driving data was collected using an instrumented passenger vehicle to collect the data during peak hours on the selected routes. The collected data was then analysed by dividing the recorded travels into micro-trips. The data were subsequently clustered using the micro-trip combination technique. The target criterion for selecting suitable micro-trips as sub-cycles was the means of the created clusters. The sub-cycles were then assembled and built as the initial Muar driving cycle. Finally, the initial drive cycle was compared to NEDC, WLTC, and MUDC.

2.1 Route selection and driving technique

This study was conducted in the district of Muar, which has three types of Levels of Service (LOS) based on data released by RVTM. The route selection to collect data is guided by this LOS in Muar. Muar district has LOS A, which will represent rural, LOS C, semi-urban, and LOS D, representing urban. Based on the observation, traffic congestion in Muar district is the same either during weekends and public holidays or weekdays and peak hours. The test was conducted on Friday and Saturday from 8 am to 5 pm. The study area includes a combination of intermittent traffic, slow traffic, smooth traffic, and highway driving. There is data collection with different directions for the selected route.

2.2 Data collection

The driving technique used for this study is the chase-car method where this technique is mainly used to develop the driving cycle. This chase-car method selects one car as the target car or reference car to mimic the driver's driving style. The technique will follow a target car with the constant distance in a predetermined route. If the target car goes out of the designated road, the driver will continue to follow the other vehicle and be made the new target car until the endpoint. The selection of the target vehicle also considers the way the driver drives. If the driving style is dangerous, the vehicle is not selected as the target vehicle to avoid accidents.

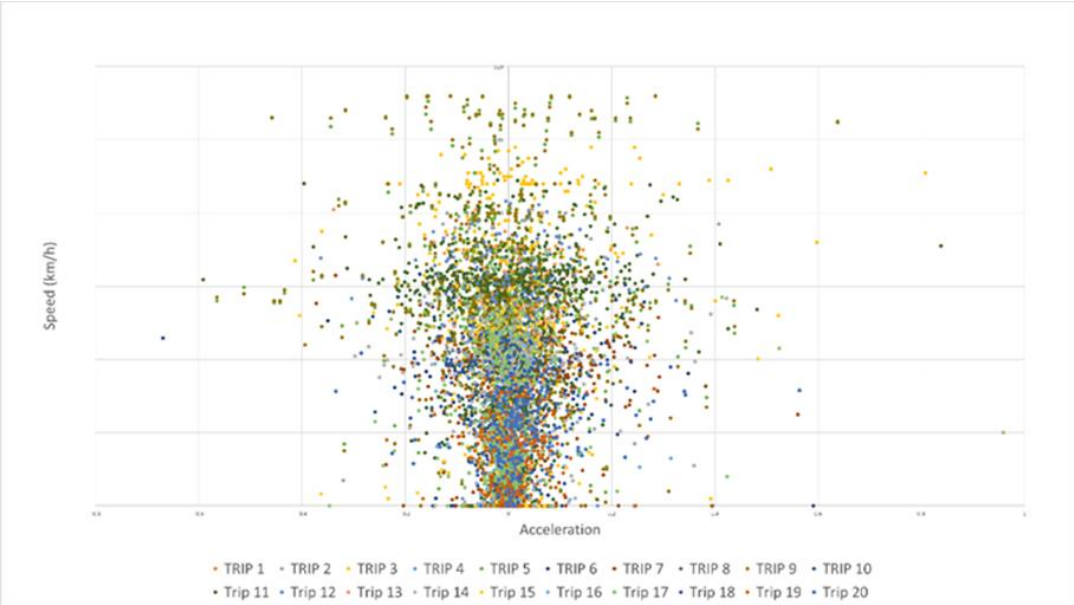

Figure 1: The Speed Acceleration Frequency Distribution (SAFD) graph for combination of all trip

Table 2: The statistical value for overall trip

Parameter	Overall Trips
V_{avg} (km/h)	35.58
V_{max} (km/h)	112.07
A_{avg} (m/s^2)	0.58
A_{max} (m/s^2)	1.51
D_{max} (m/s^2)	-0.67

2.3 Micro-trip elimination and data segregation

A micro-trip can be a single trip or a subset of the filtered dataset. The micro-trip concept allows extensive trips to be split into a series while maintaining the activity characteristics. All micro-trip will be combined and analyzed based on criteria that have been stated in the development of WLTC Micro-trip that do not fulfil the designated criteria and will be eliminated. The criteria are;

- An idle duration of more than 10 meters.
- A short journey of fewer than 10 seconds.
- A short journey with a maximum speed of less than 3.6 km/h.
- A short journey with an acceleration of more than 4m/s^2 and less than -4.5 m/s^2.

All micro trips will be separated based on the specified speed category low, medium and high speed. Micro trip classification refers to the speed category as stated in Table 1. The maximum speed of each trip will determine the category for the trip.

Table 1: Speed category for micro-trip

Types of speed	Maximum speed
Low speed	< 40 km/h
Medium speed	40 km/h < Medium speed < 80 km/h
High speed	≥ 80 km/h

2.4 Data analysis

From the obtained data collection, the target parameters were defined. The velocity, acceleration (or deceleration), distance and trip duration are calculated for each recorded trip. The means for each trip are calculated. Each of the micro-trips groups for each speed category will have a target value for defined parameters. Then, the micro-trips were arranged according to the specific speed range and compared with the candidate cycles.

Table 3: The statistical value for micro-trip group

Parameter	Low-speed	Medium-speed	High-speed
V_{avg} (km/h)	19.12	38.23	58.19
V_{max} (km/h)	39.53	79.00	112.07
A_{avg} (m/s^2)	0.13	0.37	0.42
A_{max} (m/s^2)	0.28	0.60	0.64
D_{max} (m/s^2)	-0.24	-0.10	-0.35

2.5 Construction of driving cycle

The combination of micro-trip is created based on the target parameter and cycle duration that has been determined. Several sample for each grouping is made that will be probably represent the low, medium and high-speed cycle. From the sample variation that have been made, the sample that has the closest mean value with the mean value for each group were selected The WLTC cycle duration was employed to determine the test cycle duration. The test cycle is scheduled to run for 1800 seconds for this study. Cycle durations have been employed for WLTC and have become a worldwide reference, rather than the length of this cycle being sufficient for statistical analysis representation and experimental working gas sampling in the chassis dynamometer laboratory tests [12].

By combining all of these trips into one driving cycle, a driving cycle representing statistics for the overall traffic conditions in the research area can be created. However, it is possible that it cannot explain the distribution of the various driving patterns, and the trajectory will be too long for modelling purposes. As a result, the driving cycle in this study was developed using a micro-trip-based selection strategy. In addition, the driving cycle validation used average speed, average maximum acceleration, maximum speed, maximum acceleration, and maximum deceleration as control groups. Data for low, medium and high micro travel speeds were identified. Based on cycle times and percentages referring to WLTC development, a combination of micro trips for each speed is close to the average data created for each speed type.

3. Results and Discussion

The selected routes data were analyzed from the above driving cycle construction method. Each speed category contains the micro-trip combinations that are the most similar to the overall statistic data for each speed category. The proposed Muar Driving Cycle in Figure 1 shows that 15 combinations of the micro trips represent the three-speed category. Since the sample selection for each speed follows the cycle duration and percentage for each speed category determined, the total time for the proposed Muar Driving Cycle is 1800 seconds with a distance of 16.5 kilometers.

3.1 Results

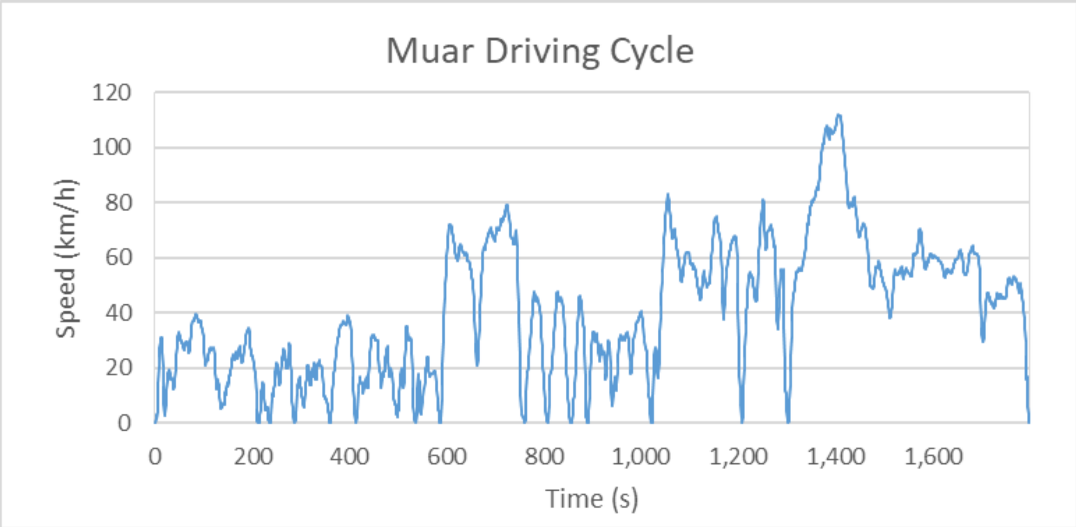

Figure 2: Developed driving cycle for Muar district

3.2 Discussions

The developed Muar driving cycle (MDC) consists of 15 combinations of micro-trip due to the vehicle experiencing frequent "stop and go" conditions. Therefore, the average speed is 40.65 km/h. The vehicles are moving slower, and more micro-trips are found below the average speed. Therefore, more fuel consumption and emission take place during that period due to frequent stops along the road [2]. Compared to the actual recording data, the average speed for MDC is slightly higher with a different percentage of 23.00 %. The maximum speed for both cycles is the same because of the free flow traffic condition in which the vehicle did not face frequent stops. Comparison between the actual recorded data and proposed Muar driving cycle for average speed has the most significant value in percentage difference since the selected micro-trip are short trips which is the duration in between 10 to 20 seconds. Thus, the vehicle has lower acceleration.

Comparison between the current cycles was made with NEDC, WLTC and MUDC. The distance for a complete cycle of MDC is the highest compared to another cycle. The cycle duration for MDC and WLTC are the same because the cycle duration of MDC is taken from WLTC since the WLTC have become a worldwide reference. The maximum speed for MDC is nearly correlated to NEDC, but the WLTC has the highest maximum speed. For the average speed, MDC has the highest speed among the existing cycles but for the average maximum acceleration, MDC has the lowest value compared to others.

Table 4: Comparison between MDC and actual data

Variable	Actual	Vs (%)	MDC
Vmax (km/h)	112.07	0	112.07

Vavg (km/h)	33.01	23	40.66
Amax (m/s²)	0.58	11	0.64
Aavg (m/s²)	0.576	54	0.26

Table 5: Comparison of MDC with NEDC, WLTC and MUDC

Parameter	NEDC	WLTC	MUDC	MDC
Cycle duration (s)	1184	1800	1500	1800
Distance (km)	10.93	3.09	5.68	16.50
Maximum velocity (km/h)	120.00	131.30	91.00	112.07
Average velocity (km/h)	32.21	33.7	31.89	40.66
Average maximum acceleration (m/s^2)	0.53	0.49	0.75	0.26

4. Conclusion

This study aims to develop the Muar driving cycle based on real-world conditions. Route selection, vehicle, and engine condition were crucial to construct a new driving cycle for Muar. The method used to create the Muar driving cycle is taken from previous research especially on route selection and driving techniques.

The Muar driving cycle uses the micro trip method for analysis, which follows the most known approaches to designing drive cycles. The primary component analysis was used to break down data into components during the creation of the Muar drive cycle. The driving characteristics are then classified by clustering the parameters within each component. When picking representative micro trips, the mean of the clusters is employed as the target criterion. The micro trip is divided into three-speed categories: low, medium, and high. The target parameter for this study is maximum speed, average speed, maximum acceleration, average maximum acceleration and maximum deceleration. Each speed category target parameter will be identified and compared with the combination of the micro trip. The final combination of cycles will be presented as proposed Muar driving. The proposed driving cycle will be compared against actual recording, NEDC, WLTC and Malaysian urban driving cycle. Muar driving cycle speed and duration are higher than NEDC, WLTC and MUDC but lower maximum acceleration.

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