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Mitigating the Fuel Consumption of Passenger Cars in Malaysia: A Mini-Review

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ABSTRACT The upsurge in energy consumption by the transportation sector have prompted numerous efforts from the global community to combat its adverse effects on the environment. Vehicular fuel consumption studies have been carried out worldwide in an effort to reduce and regulate fuel consumption especially for passenger cars. The mitigation strategies for energy consumption and emissions from the transportation sector in Malaysia have been reviewed in the literature. However, specific reviews related to the methods used to estimate fuel consumption of passenger cars remains unavailable. In this review, the recent activities related to the mitigation of fuel consumption of passenger cars in the country are presented. The approaches for estimating the consumption of fuel are also reviewed. It is found that a more accurate values of fuel consumption are needed in the country and numerical analysis is an effective method for this purpose. This would be key toward the development and establishing fuel economy policy in the country.

KEYWORDS: Laboratory Test; Numerical Modelling; Passenger Cars; Fuel Consumption; Malaysia
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Review Article

INTRODUCTION

Global warming has become the centre of discussion in recent decades due to its known adverse effects on the global community. The phenomenon is mainly caused by trapped green-house gases such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) within the Earth's atmosphere as a result of emissions from the combustion of non-renewable energy resources such as fossil fuels and coal (Lee et al., 2011). According to Tromop (2015), the transportation sector accounts to about 27% of global energy consumption, in which light-duty vehicles that include passenger cars contributes a significant 70% of the fuel consumption in this sector. Great surge in energy consumption in this sector is expected in the coming years particularly with the ever-increasing number of fuel-powered vehicles on the road. This calls for immediate action from relevant authorities to combat this issue.

The United Nations Environment Programme (UNEP) together with other international organisations from the transport and energy sector had established the Global Fuel Economy Initiative (GFEI) in 2009 to reduce global fuel consumption. GFEI has set a target to reduce global fuel consumption of light-duty vehicles by 50% by 2050 relative to a baseline in 2005 (Global Fuel Economy Initiative, 2016). The baseline data collection was conducted by GFEI and several participating countries (The ASEAN Secretariat, 2019). In response to this initiative, countries around the world have developed or in the progress of developing their own fuel economy policies.

Development of fuel economy policy involves data development and fuel economy analysis. The data development requires a standard test cycle, which varies with countries and regions, to test cars for fuel economy. Test cycle is a defined speed-time profile that a vehicle must follow during a test to check for compliance with established fuel economy and emission standard. This implies that all newly registered vehicle must be subjected to fuel consumption and emission testing using test cycles to evaluate standard compliance before being sold to the market. Furthermore, these standard test cycles would certainly encourage improved vehicle design and engine technologies by auto manufacturers so that the goal of GFEI can be achieved.

The European Union (EU), United States of America (USA) and Japan are the pioneers of fuel economy policy establishment, emission standard development and legislative test procedures for light-duty vehicles (Giakoumis, 2017). The New European Driving Cycle (NEDC), the Federal Test Procedure 1975 (FTP-75) and JC08 are standard test cycles developed by the EU, USA and Japan, respectively. Other countries in the world either employ these test cycles or develop their respective test cycle. For example, Australia developed its own Composite Urban Drive Cycle (CUEDC) to reflect the actual driving behaviour in Australia. In Malaysia, vehicle manufacturer relies on NEDC to perform fuel consumption and emission evaluation but it is necessary to establish its own test cycle standard to better represent the driving characteristics in the country.

The mitigation strategies for energy consumption and emissions from the transportation sector in Malaysia have been reviewed in the past. Mahlia et al. (2012) reviewed the fuel economy testing procedures adopted by countries around the world and proposed a process for selecting the most suitable fuel economy testing procedure for automobiles in Malaysia. Ong et al. (2011) estimated the fuel consumption and emissions of road transport in Malaysia and determined the effectiveness of several mitigation strategies. In a subsequent study by Ong et al. (2012), the energy and emissions pattern of the transportation sector in Malaysia were analysed and prospective mitigation strategies were presented. Shahid et al. (2014) reviewed the state of emissions reduction in the transportation sector and the initiatives taken by the Malaysian authorities, together with proposed reduction strategies that could streamline the efforts in this regard. Ghadimzadeh et al. (2015) reviewed the existing approaches for emissions mitigation and proposed possible implementations for reducing emissions in Malaysia's transportation sector. However, specific reviews related to the methods used to estimate fuel consumption of passenger cars remains unavailable. This paper aims to provide a review about some of the recent activities that have been carried out to mitigate the fuel consumption of passenger vehicles in Malaysia. This includes activities to develop fuel economy policy in the country. Additionally, since fuel consumption data is important in the mitigation activity, the methods for vehicular fuel consumption estimation is also covered in this review.

TOWARD ESTABLISHING A FUEL ECONOMY POLICY IN MALAYSIA

Environmental Issues due to Transportation Sector in Malaysia

According to the Energy Commission (2020), the transportation sector in Malaysia accounts to 35-47% of its total energy consumption. Hosseini et al. (2013) had earlier acknowledged that transportation sector is one of the main contributors of carbon emissions in Malaysia. Land transportation accounts up to 90% of the total carbon emission from the transportation sector and up to 70% of the emissions is attributable to light-duty vehicles such as passenger cars (Briggs and Leong, 2016; Ministry of Transport Malaysia, 2019). This scenario will cause a serious problem due to the emissions of high number of gaseous products, such as unburnt hydrocarbons (HC), carbon dioxide (CO2), oxides of nitrogen (NOx) and carbon monoxide (CO). These emissions are the result of combustion process and evaporation of fuel in the internal combustion engine of the vehicles, which are known to have detrimental effects to the environment and human health.

Briggs and Leong (2016) pointed out that the carbon emissions originating from transportation sector is projected to increase by approximately 200% for the next 20 years if no intervention is implemented or "Business As Usual" (BAU), as illustrated in Figure 1. This calls for a strategic plan and action for carbon emissions reduction in this sector, particularly focusing on passenger vehicles. A successful implementation of emission reduction strategies would hypothetically reduce passenger car related emission by 36% annually (Briggs and Leong, 2016).

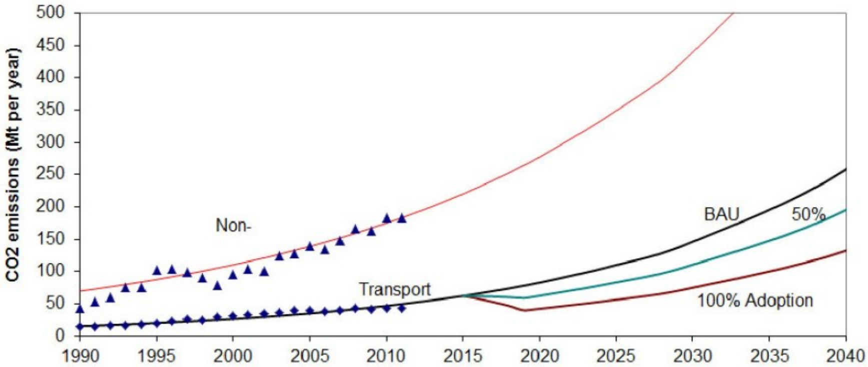

Figure 1. Projected CO_2 emissions at various adoption rates of remediation measures (Briggs and Leong, 2016).

Fuel Economy Initiatives in Malaysia

Malaysia introduced the National Transport Policy 2019-2030 in October 2019 that details various measures to ensure efficient and sustainable utilisation of energy resources in the transportation sector with minimal impact on the environment (Ministry of Transport Malaysia, 2019). The initiative focuses on implementations to improve fuel economy and reduce carbon emissions in private transportations. Among others, the initiative encompasses formulation and implementation of fuel economy policy as well as strategies that promotes the growth of energy efficient vehicles and electric vehicles in Malaysia. The adoption of electric vehicle in the global market has been increasing in the recent years in an effort to reduce vehicular emission and oil reliance (Das et al., 2020). Indeed, the adoption of electric vehicles is essential in reducing Malaysia's carbon footprint and this can be a long-term strategy. This is after considering the problem of electric vehicle adoption in Malaysia, which are related to the high cost involved in the purchasing of such vehicles and deployment of charging facilities (Alghoul et al., 2018). In current situation, implementation of fuel economy policy will give a greater impact in mitigating fuel consumptions and emissions in Malaysia, especially in the short term. This approach would require the establishment and implementation of fuel economy and emission standard in the country.

The Malaysian authority is currently using NEDC to regulate vehicular fuel economy and local vehicle manufacturers rely on NEDC to perform fuel consumption and emissions evaluation (Abas et al., 2018). However, it was found that NEDC is incapable of providing accurate fuel consumption and emission assessments due to inadequate real-world driving representation especially since NEDC was developed using data which is not representative of the driving characteristics in Malaysia (Mahlia et al., 2012; Abas and Martinez-Botas, 2015; Abas et al., 2018). Various studies have shown significant discrepancies between NEDC average fuel consumption and actual fuel consumption subjected to real-world conditions (Ho et al., 2014; Abas et al., 2015; Abas et al, 2018). The findings show that NEDC tests understate the average fuel consumption, hence produce misleading data for fuel economy analysis. Therefore, in order to develop and establish the country's own fuel economy policy a more representative values of fuel consumption are needed.

Fuel Consumption Studies in Malaysia

Abas et al. (2014) developed a representative driving cycle in the area of Kuala Lumpur for fuel consumption and emissions assessments. They collected and analysed actual engine conditions when travelling on routes representing urban driving in an effort to establish the basis of fuel economy analysis in Malaysia. Engine torque and speed derived from actual urban driving and NEDC were compared. The authors observed that the engine torque map derived from NEDC only covers 59% of the actual engine torque map. This leads to a significant deviation in average fuel economy tested over NEDC. Specifically, the average fuel economy tested over NEDC understated the actual fuel economy by 43.1%. In a following study, Abas et al. (2015) had proposed engine conditions to assess fuel consumption and emissions in an urban driving setting like Kuala Lumpur. The proposed engine conditions demonstrated low engine speed and moderate engine torque which are reflective of urban driving condition, where vehicles often traverse in a highly congested traffic.

Subsequently, Abas et al. (2018) developed the Malaysian Urban Driving Cycle (MUDC) using the microtrip method by considering the engine conditions detailed in previous study (Abas et al., 2015) alongside the vehicle parameters. The authors claimed that improved accuracy in fuel economy assessment can be achieved by integrating engine parameters due to the relationship between fuel consumption and engine conditions. The characteristics of MUDC and NEDC were compared against the parameters of actual urban driving data established by Abas et al. (2015). Besides, the comparison was also extended to another widely adopted standardised test cycle, which is known as the Worldwide Harmonised Light-duty Test Cycle (WLTC). Comparing NEDC with the actual urban driving data yielded the largest parameter variation, followed by WLTC and the least variation was observed when compared to MUDC. The MUDC profiles were smoothened to mitigate certain dynamometer limitations and improve repeatability. The average fuel economy measured over the smoothened MUDC is 12.97 L/km. The average fuel economy tested over NEDC and the actual Malaysian urban driving data were 8.06 L/km and 14.17 L/km, respectively (Abas et al., 2015). Fuel economy measurement tested over NEDC was underestimated by 43.1%, whereas the smoothened MUDC reported only 8.5% lower than the actual urban driving.

Anida et al. (2018) developed a driving cycle for Kuala Terengganu in an effort to assess the vehicular fuel consumption and emissions in Kuala Terengganu and reported 7 L/km of fuel consumption. Comparing the fuel consumption figures reported by Anida et al. (2018) and Abas et al. (2018) indicates that significant differences in fuel consumption can be observed at two different geographical locations even within the same country. This suggests that the differences in geographical features and distribution of artificial structures will certainly result in different driving behaviour and thus, producing distinct fuel consumption readings. Furthermore, this highlights the importance of obtaining driving data representative of the driving behaviour of the specific area of study to ensure accurate and representative fuel consumption analysis.

APPROACHES FOR FUEL CONSUMPTION ESTIMATION

Fuel consumption analyses are necessary to provide primary data for policy-makers to develop and implement appropriate fuel economy policies. Estimation of fuel consumption for a vehicle can be performed using different approaches. There are two generalised methods which are through laboratory test and numerical modelling. Abas et al. (2018) and Anida et al. (2018) utilised laboratory test and analytical approach, respectively. Each of these approaches are reviewed in the following sub-sections.

Laboratory Tests

The laboratory tests used in measuring vehicular fuel consumption are categorised into engine and chassis dynamometer tests. In an engine dynamometer test, the engine and after-treatment system are taken out from a vehicle when performing such test and the test adheres to procedures specified by regulatory bodies such as the United States Environmental Protection Agency (USEPA). Engine parameters such as engine power, torque and speed are measured by coupling the engine driveshaft to the dynamometer through load simulation as shown in Figure 2(a). Such method is employed by Ramdan (2017) in a fuel consumption study of a passenger car. Engine dynamometer test could produce high repeatability and accuracy due to the direct connection between the engine driveshaft and the dynamometer which neglects power losses occurring along the powertrain. However, the engine load may not be representative of the actual load due to the omission of the vehicle's weight and additional load subjected to the engine by the weight of driver. This could result in misleading fuel consumption analysis and may not represent real-world consumption when subjected to certain driving conditions and load.

In a chassis dynamometer test, a test vehicle is placed on rollers and the rollers contact directly to the four wheels to simulate resistive forces from aerodynamic drag and road gradient as shown in Figure 2(b). This allows operators to subject the engine to more realistic and representative driving loads. In this test, the operator has to emulate a driving profile to assess the fuel consumption and emissions under certain driving behaviour. Similar to engine dynamometer test, chassis dynamometer test has relatively high repeatability due to fully-controlled testing environment and condition. The results are reliable and accurate due to the fact that the dynamometers are designed to adhere strictly to regulatory standards. Chassis dynamometer test is comparatively more representative of real-world scenario in terms of engine load than engine dynamometer test due to the inclusion of vehicle weight and optionally, human weight, if the test requires an operator driving the vehicle on the dynamometer during a test. Chassis dynamometer test was adopted by several studies regarding vehicular fuel consumption and emissions assessments (Ahn et al., 2002; Rakha and Ding, 2002; Mahlia et al., 2012; Sileghem et al., 2014; Abas et al., 2018; Wen et al., 2021).

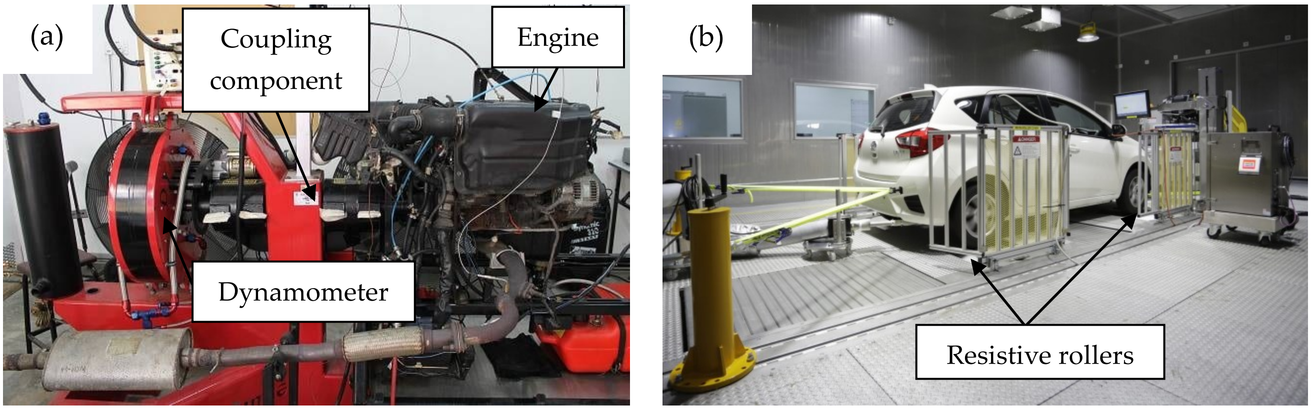

Figure 2. (a) Engine dynamometer (Universiti Teknologi Malaysia, 2019) and **(b)** chassis dynamometer (Malaysia Automotive, Robotic and IoT Institute, 2018).

The use of laboratory tests is particularly beneficial for estimating vehicular fuel consumption due to their ability to fully control the testing environment and parameters intrinsic to such tests (i.e., test cycles and engine load) that will make these tests highly repeatable. Furthermore, if the facilities built to conduct the dynamometer tests adhere strictly to regulatory standards, the results would be reliable and precise. However, the application of laboratory tests for fuel consumption measurement is mainly hindered by the cost incurred from such tests. The equipment and instruments required for these tests are sophisticated and expensive. In addition, the personnel conducting these tests, especially when replicating a test cycle or driving behaviour has to be competent and trained to avoid misleading results.

In laboratory tests, vehicular fuel consumption can be determined via several methods. The fuel consumed after a test can be measured using a fuel meter that measures the flow of fuel from the fuel tank to the engine as employed by Lee et al. (2013). The fuel consumption can also be determined by measuring the mass of fuel before and after a test as demonstrated by Ramdan (2017). The methods employed by Lee et al. (2013) and Ramdan (2017) only report the total fuel consumed by the test. These methods are unable to report the fuel consumption on a second-by-second basis which is essential to comprehensive investigations on the fuel consumed with regards to various vehicle dynamics such as vehicle average speed, acceleration-deceleration frequency, idle time and stop frequency, which offers researchers a finer fuel consumption resolution and allows more in-depth analyses.

Exhaust gas emissions measured from the laboratory tests can also be used to calculate fuel consumption using the carbon balance method as employed by other studies (Song et al., 2009; Zhang et al., 2014). The instantaneous carbon emissions data can be utilised to estimate the instantaneous fuel consumption of a vehicle if a study opts for higher resolution of data analysis. However, in a study by Franco García (2014) showed that there is significant distortion in the instantaneous mass of emissions that could lead to inaccurate second-by-second emissions readings. The distortion is due to the delay between pollutant concentration and exhaust mass flow signals that is caused by mismatch locations where the signals are measured along the gas transportation line. This leads to time discrepancy in the datasheets of the signals (i.e., actual pollutant concentration at an instant of given exhaust gas mass flowrate may only appear few rows down the datasheet). Another cause of distortion is that gas analysers do not respond immediately to inputs, resulting in a smoothened output signal that can lead to overestimation and underestimation of instantaneous emissions. Emission signal distortion can also be attributed to mixing of exhaust gas along gas transportation line which can lead to smoothened emissions signal. Fuel consumption estimation using carbon balance method may yield inaccurate results if no appropriate compensation strategies are implemented.

Numerical Modelling

Numerical models or estimation models are analytical tools developed to predict vehicular fuel consumption and emissions under various driving behaviours and conditions. Estimation models are categorised as macroscopic and microscopic models. Macroscopic simulation model can estimate fleet emission and fuel consumption of a region or on country-wide scale. Examples of commonly used macroscopic models are MOBILE (Vallamsundar and Lin, 2011), EMFAC (United States Environmental Protection Agency, 2019) and COPERT (Smit et al., 2009). The USEPA and California Air Resources Board developed MOBILE and EMFAC, respectively, for regulatory analysis on vehicular emissions. COPERT was developed by the EU as a tool for emission and energy consumption assessment. Microscopic models, on the other hand, are capable of estimating instantaneous fuel consumption and emissions. Examples of microscopic models are the Comprehensive Modal Emissions Model (CMEM) (Barth et al., 2001) and Motor Vehicle Emission Simulator (MOVES) (Vallamsundar and Lin, 2011) developed by the University of California, Riverside and USEPA, respectively.

Macroscopic models are often referred as average-speed models due to the usage of average speed as input in energy consumption and emissions assessment (Smit et al., 2008). The ease of use and simple data requirement contributed to the widespread use of such models (Samaras et al., 2019). These models are suitable to establish energy and emission estimates for large regional areas. However, macroscopic models are limited in some ways. The usage of single traffic-related variable (average speed) may be insufficient for accurate estimation of fuel consumption and emission. This is especially in cases where there is high traffic oscillation, which refers to the high variation in vehicular velocity and acceleration that could influence the fuel consumption (Treiber et al., 2008). Ignoring these important parameters can yield inaccurate estimates of fuel consumption and vehicular emissions. Therefore, these estimation models are unable to reflect the differences between low-speed operations with no stops and high-speed operations with frequent stops if both conditions demonstrate identical average speed. Thus, the omission of velocity and acceleration pattern as explanatory variables renders macroscopic models unsuitable for estimating fuel consumption and emissions caused by traffic oscillation (Smit et al., 2008).

Microscopic models are developed as an alternative to macroscopic ones and to fulfil the need of an ideal approach to fuel consumption estimates on a local scale such as in small road networks or intersections. These models are suitable for estimating vehicular energy consumption and emissions caused by traffic oscillation (Zhang et al., 2011). As mentioned previously, microscopic models are able to estimate instantaneous fuel consumption and emissions on a second-by-second basis. Second-by-second vehicle trajectories are required for such calculations. In addition, these models account engine parameters and other vehicle operating modes such as acceleration, deceleration and idling which may vary significantly across different frequencies of traffic oscillation. Microscopic models are generally more accurate (Kan et al., 2018) and the estimations are more realistic due to the inclusion of the aforementioned vehicle operating modes (Treiber et al., 2008). The strong correlation between modal operations (i.e., instantaneous velocity and acceleration) and fuel consumption and emissions (Mandava et al., 2009) warrants microscopic models as a more accurate approach for numerically estimating fuel consumption when compared to their macroscopic counterpart.

Comparison between Laboratory Tests and Numerical Modelling

As mentioned in previous section, laboratory dynamometer tests measure engine parameters for fuel consumption analysis by subjecting the engine or vehicle to simulated loads. It is noted that these tests are more suitable for estimating the vehicular fuel consumption using a standardised test or driving cycle, such as NEDC and WLTC. However, for studies that require the analysis of fuel consumption with regards to various vehicle operating modes under different traffic flow, it will involve a great deal of velocity profiles to be analysed. In such situation, the laboratory dynamometer test would not be suitable as it would be very time consuming to replicate all of the collected speed-time data on a dynamometer. Besides, it will require other resources such as trained personnel to accurately simulate every velocity profile collected. On the other hand, numerical approach can estimate fuel consumption from huge number of velocity profiles with significantly less time and resources. Furthermore, if there are two or more vehicles to be tested, the parameters can be changed according to the vehicle and engine specifications relatively easily in the analytical tool. For these mentioned reasons, it renders the widespread use of numerical analysis approach for fuel consumption studies especially those that involved a great number of velocity profiles (Song et al., 2009; Ho et al., 2014; Bifulco et al., 2015; Zheng et al., 2017; Coloma et al., 2020).

Several literatures were reviewed to determine the discrepancies in test results between laboratory test and analytical approach. Moskalik et al. (2016) studied the effects of advanced automatic transmissions on vehicular fuel consumption using chassis dynamometer and the Advanced Light-duty Powertrain and Hybrid Analysis (ALPHA) model, an analytical tool developed by the USEPA. The results obtained using the analytical tool closely matched the results obtained using the chassis dynamometer. Samaras et al. (2019) modelled two vehicles in CRUISE, a microscopic emissions model and compared the fuel consumption output with the measured data from a chassis dynamometer. The study reported 97.5% in accuracy in respect of fuel consumption and 90% of correlation between measured and simulated values of other parameters. Moskalik et al. (2020) investigated the CO_2 emissions of a 2018 Toyota Camry with automatic transmission using ALPHA. The results obtained from ALPHA are compared to the test data obtained from a chassis dynamometer and the discrepancy between simulation results and the corresponding test data are observed to be within three percent. Based on these findings, it can be deduced that the results obtained using numerical modelling are reasonably close to the results obtained using laboratory tests. The aforementioned merits of numerical modelling justify the adoption of such approach as the effective method for vehicular fuel consumption studies in the future.

CONCLUSION AND FUTURE OUTLOOK

The strategies and studies involved in mitigating the fuel consumption of passenger cars in Malaysia are presented in this review. The Malaysian government had introduced the National Transport Policy towards improving the fuel economy and reducing the carbon emissions from private transportations in Malaysia. A more representative values of fuel consumption are needed in the country since reliance on NEDC produces inaccurate fuel consumption figures. Several studies carried out at different locations in Malaysia reported distinct fuel consumption figures from one location to another. Laboratory tests and analytical tools are widely adopted by scholars and regulatory bodies to assess vehicular fuel consumption. Laboratory tests are known to be reliable and accurate but the adoption is hindered by the high cost and very time-consuming process especially for studies that require analysis of large amount of velocity profiles. Numerical models are able to analyse huge amount of velocity profiles with significantly less time and resources. The results obtained from analytical approach were found to be comparable with those obtained using laboratory tests. If Malaysia is to establish its own fuel economy policy, a comprehensive study which covers the driving characteristics at different parts of the country is necessary to produce representative fuel consumption results. This will certainly involve a great deal of velocity profiles and thus numerical models is the most suitable approach for an effective fuel consumption analysis.

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