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Data Collection and Data Management Approach for Developing a Driving Cycle: A Review

Nurru Anida Ibrahim[1], Arunkumar Subramaniam[1], Siti Norbakyah Jabar[1,2,3], Salisa Abdul Rahman[1,2,3,*]

[1] Department of Electronics and Instrumentation, Faculty of Ocean Engineering Technology and Informatics, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia
[2] Renewable Energy and Power Research Interest Group (REPRIG), Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia
[3] Energy Storage Research Group (ESRG), Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia

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ABSTRACT

Driving cycles were first proposed and developed for standard emission measurements used by legislative bodies to approve newly developed vehicles. There are many driving cycles that have been developed over the past few years. Most of the research on driving cycles is based on the condition of the vehicle in a specific location, such as the United States FTP75, European ECE 15, Japan 10115, and others. A driving cycle is a representative speed-time profile that reflects the typical driving pattern of a given city or region. A driving cycle consists of a sequence of vehicle operating conditions (idle, acceleration, cruise, and deceleration). The basic methodologies to construct a driving cycle are route selection, data collection, and the development of the driving cycle. However, as far as we know, detailed reviews and in-depth discussions of data collection instruments and data management are rarely present. As a result, this paper reviews and discusses the recent data collection approach, as well as providing a thorough analysis of the mechanisms that they employ. Furthermore, the disadvantages and advantages of the reviewed mechanisms have also been discussed.

1. Introduction

Conceptually, local driving pattern is a term used to define the average driving characteristics of the region. The driving patterns frequently are described by a speed-time series, denominated driving cycle as mentioned by [1]. Driving cycle is a representative speed-time profile that reflects the typical driving pattern of a given city or region [2-5]. A driving cycle consists of a sequence of vehicle operating conditions (idle, acceleration, cruise, and deceleration) [6]. However, operating conditions may vary across cities due to variations in topography, vehicle type under consideration, vehicle composition, and road type [7]. A driving cycle is a common test process used to assess a vehicle's performance and emissions under particular driving circumstances. The cycle includes a set order of

* *Corresponding author.*
E-mail address: salisa@umt.edu.my

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acceleration, deceleration, and steady-state driving that simulates a typical driving style for a specific vehicle category, such as driving on a highway or in an urban area.

A driving cycle is often used by researchers and practicing engineers to understand and model the driving behaviour, emission pattern and energy consumption for different vehicle types [8]. Driving cycles describe the workloads imposed on the vehicles and therefore have been used for assessing the environmental impact of traffic [9], and for optimizing new vehicles' powertrain configurations and engine control strategies to reduce fuel consumption (FC) [10]. Regulatory organisations, including the Environmental Protection Agency (EPA), frequently use the driving cycle to calculate a vehicle's fuel economy and emissions ratings. For customers and governments to make educated judgements about vehicle purchases and environmental legislation, these ratings are crucial.

Driving cycles are mainly used by manufactures and environmental authorities to evaluate the fuel consumption and pollutant emissions from vehicles as part of the regulatory process to introduce new vehicle technologies into the market [11,12]. When the driving cycle is used for regulatory purposes, it is known as a type-approval driving cycle. Currently, the Federal Test Procedure (FTP) 75, Urban Dynamometer Driving Schedule (UDDS), New European Driving Cycle (NEDC), and Worldwide harmonized Light vehicles Test Cycles (WLTC) are some of the most widely type-approval driving cycles used by manufactures to report fuel consumption and emissions from their vehicles [13].

Several driving cycles have been developed in different countries to represent local driving conditions. Driving cycles can be legislative or non-legislative [14,15]. Legislative driving cycles have been established in the US, the European Community, and Japan; FTP75, NEDC, and JC08 respectively. The legislative driving cycles have been used for exhaust emissions specification imposed by governments for car emission certification [16]. Non-legislative driving cycles have been investigated in different countries and cities such as Vadodara [17], Bangalore [18], Kuala Lumpur [19], Hong Kong [20], Pune [21], Edinburgh [22], Athens [23], Singapore [24], and 11 Chinese cities [25]. Non-legislative cycles have broad application in research for energy conservation and pollution evaluation. All have been employed in research ranging from performance estimation to vehicle design [26].

There is no universal or standard approach for creating a driving cycle. Different organizations, governments, and researchers may develop their own driving cycles for various purposes, such as testing vehicle emissions, evaluating fuel economy, or assessing vehicle performance. A driving cycle is often developed by collecting and analysing real-world driving data from a representative sample of vehicles in a certain driving environment, such as speed, acceleration, deceleration, and idling. On-board vehicle sensors, GPS systems, and driver questionnaires can all provide data. Following the collection of data, statistical analysis is carried out to identify common driving patterns and to develop a set of parameters that can be used to define the driving cycle. Briefly, the following steps are usually included in cycle construction methods:

i. real-world driving data collection
ii. segmentation
iii. cycle construction
iv. evaluation and selection of the final cycle [27].

Different methods are used to develop driving cycle from the collected data, such as micro-trip-based cycle construction, segment-based cycle construction, pattern classification method and modal cycle construction [28,29].

The primary goal of this paper is to review and investigate data collection and data management approach used by most of the researchers, as well as to outline the types of significant challenges that may be addressed in every approach. In a nutshell, this paper conducts a systematic review of the relevant papers while also providing in-depth analysis of their applied mechanisms.

2. Related Studies

Before developing a driving cycle, it is a must to collect all the real-world data first. Second-by-second speed data along the predetermined routes have to be collected in order to develop a driving cycle. There are two main elements in the data collection process which are route selection, and data collection technique.

Route selection is an essential process when developing a driving cycle. Traffic congestion in an urban environment is believed to vary depending on the route and time, with heavier traffic congestion expected during normal weekdays and at peak times compared with weekends or public holidays and off-peak times [30]. From the actual road network of the study area, representative routes should be selected, considering traffic flow conditions affected by road type, topography, intersections, population density, gradient, and weather conditions [31]. To select the routes, actual situations that occur along each route must be identified and ascertained [32]. The chosen routes require the following features:

i. a high traffic volume
ii. connecting major centres of population
iii. high emissions on the transit route
iv. various squares and intersections
v. access to public transport systems [33].

After selecting the representative routes, the data collection can be started. Various data collecting methodologies can be used for generating a driving cycle, which is a depiction of typical driving patterns and situations. The approach chosen is determined by criteria such as the desired level of precision, available resources, and the specific objectives of the driving cycle. There are two different techniques to collect the data which is called on-board measurement technique and car chasing technique. Data also can be collected by combining those two methods and it is known as a hybrid method.

2.1 Chase Car Method

The chase car method is a data collecting methodology used in transportation research and vehicle testing that involves following a target vehicle to collect information on its driving behaviour and performance. Cameras, sensors, and data gathering systems are commonly used in chase cars to view and record numerous factors linked to the target vehicle's movement, such as speed, acceleration, deceleration, lane changes, and other driving manoeuvres. Chase car method is an instrumented vehicle which can measure second by second speed data is used to chase a target vehicle in a predetermined route(s) within an area of concern [34].

As in the paper presented by Abas *et al*., [35], the data for Kuala Lumpur driving cycle is collected by using chase car method, where the instrumented test vehicle was driven towards a starting point within the selected urban area, and the data logging was activated there-after. The ‘chase car’ method chooses a vehicle to follow for as long as possible within the area of study, duplicating the chosen vehicle operations at a constant distance [36]. In the case where the chosen vehicle drives off the area of study, the ‘chase car’ immediately chooses a new vehicle to follow. the test was conducted in the weekdays without any public holidays, from Monday to Friday during the peak from 0730 to 1030 h, along the five selected routes. The selected routes and time represent a typical Malaysian urban driving which encompasses a mixture of standstill traffic, slow traffic, smooth traffic and highway driving within the area of study. At the end of each route, the logged data was briefly reviewed to ensure no error before proceeding to the next route. All the collected data are then manually retrieved from the data logger (not specified) to analyse the driving parameters and develop the driving cycle.

Fig. 1. Area of study

The advantages of the chase car method are that it requires lesser sources and much more cost-effective than using other method. However, in this chase car approach, it is drivers’ responsibility to follow the target vehicle in the same way it travels to collect accurate data and this method is very difficult on roads where LOS is low. The chase car method is based on monitoring and recording a single target vehicle's driving behaviour. This small sample size may not adequately represent the driving tendencies of the general population, resulting in data biases. It may not account for the full range of driving scenarios and unpredictability found in real-world conditions. It is also difficult to chase a car when driving behaviours are aggressive, where the chase car might be lost sometimes or chasing will lead to accidents. With these drawbacks in mind, it's critical to consider alternative data collection methods that provide a more representative and cost-effective approach, such as on-road data logging, smartphone apps, or simulation models, depending on the specific objectives and constraints of the driving cycle development project.

2.2 On-Board Measurement Method

In the on-board measurement method, an instrument is installed in selected vehicles and let the vehicles travel along the traffic stream in selected routes. Then second by second speed data is recorded as they travel along the predetermined routes [37]. In this approach, sensors and data collecting devices are directly mounted on a vehicle to gather information about its functioning, behaviour, and other pertinent aspects.

As in the paper discussed by Yang *et al.,* [38], on-board measurement method was used instead of car chasing due to it is difficult and dangerous to follow a target car in heavy traffic flow in Nanjing, China. The SEMTECH-DS (Sensors, Inc.) system is developed as a Portable Emissions Measurement System (PEMS) for on-board measurement to obtain accurate second-by-second vehicle speed and exhaust emissions data in actual road conditions. The system consists of Heated Flame Ionization Detector (FID) for total hydrocarbon (THC) measurement, Non-Dispersive Ultraviolet (NDUV) analyser for nitric oxide (NO) and nitrogen dioxide (NO2) measurement, and Non-Dispersive Infrared (NDIR) analyser for carbon monoxide (CO) and carbon dioxide (CO2) measurement. In addition, some modules such as data logger, digital and analogue I/O, and system control module, vehicle interface (VI) for communication with the vehicle engine control module (ECM), wireless communication module for remote monitoring and control using a personal computer (PC) or a personal digital assistant (PDA), remote weather probe for ambient temperature and humidity measurement are also included. Vehicle location, latitude and speed data are collected by an optional component Global Positioning System (GPS). Then, the data collected by SEMTECH-DS system need to be time synchronized and validated. Some data missing within 5 s, should be calculated by linear interpolation method according to the numerical values before and after the missing data.

Kaymaz *et al.,* [39] in their paper also used the same approach, but with different data collection instrument. In this project, hand held GPS (Garmin GPSmap 60CSx™ with highsensitivity GPS receiver, barometric altimeter, electronic compass) device was used. The data acquisition system used in this test vehicles consists of Modular data logger (M-LOG) and DIAdem software. The M-LOG has real time operating system which is capable to log from CAN, LIN, Ethernet inputs, analogue and digital sensors. Meanwhile, the DIAdem software was used in the analysis of measurements. Signals from CAN infrastructure was logged by the measurement system.

Another research that used the same data collection approach is as presented by Yuhui *et al.,* [40]. In this research, in urban area of Fuzhou city, 211 buses' routes were selected. The data collection device as shown in the Figure 2, was connected with the vehicle's on-board diagnostic system (OBD) and used for data collection. During data collection process, this device was able to collect the speed of the vehicle, engine speed, torque percentage, and the instantaneous fuel consumption at a frequency of 1 HZ. All the data are then retrieved manually from the device, then used MATLAB software to process the data.

Fig. 2. Data collection device (*Source: Yuhui et al.,*) [40]

Meanwhile, in Sangareddy district India, the on-board measurement device (video V-box HD 2) as shown in Figure 3 was used for collecting vehicle trajectory data and speed related parameters (Chandrashekar *et al.*,) [41]. As explained in the research, all the data collected are then retrieved manually form the device. However, the trajectory data from GPS device are often prone to errors mainly due to error in user equivalent range. There were spikes in speed data, irregular data and negative speed data dropouts. All those data are then filtered using Savitzky-Golay filter. Unfortunately, the author did not specify which software they used to analyse and filter all the data.

Fig. 3. Instrumented test vehicle used for the study (Source: Chandrashekar *et al.*,) [41]

In addition, in Guangzhou, China, four handheld Global Positioning System (GPS) devices were used to collect the second-by-second vehicle velocity and location information (longitude and latitude), and Portable Emission Measurement System (PEMS) was used to collect instantaneous exhaust emission, which applied to calibrate emission estimates by local driving cycles [42]. In order to improve the construction of driving cycles, the original driving data were pre-processed. Due to GPS signal problems, velocity and acceleration data collected by on-board measures sometimes were irregular. Thus, events whose velocity exceeded 120 km/h, or the absolute value of acceleration was greater than 4.0 m/s2 was removed according to the road limit in China (up to 120 km/h) and the maximum acceleration of most common light-duty gasoline passenger cars (about 4.0 m/s2) in China.

The on-board measuring approach offers a thorough and accurate depiction of the behaviour and performance of the vehicle in actual driving situations since it collects data directly from the vehicle. Using this technique, researchers, engineers, and analysts may keep an eye on and examine how the vehicle is operating, assess its effectiveness, performance, and compliance with regulatory standards, and then use the information gathered to inform their judgements. As conclusion, on-board measurement method is the preferred one by most researchers since this method is suitable for the countries where the driving behaviour is irregular and aggressive. Also, for the countries which have traffic related databases to accurately select the routes.

However, implementing the on-board measurement method can be costly, especially when specialized sensors, data loggers, and other equipment need to be installed on the vehicle. Additionally, the complexity of the system and the expertise required to set up and maintain it can add to the overall cost. The device also, for example GPS, tend to have errors and irregular data.

Given these drawbacks, it's crucial to properly plan and build the on-board measuring system, choose representative vehicles, and account for potential biases or restrictions when interpreting and analysing the obtained data. A more thorough understanding of the issue under inquiry can be achieved by combining the on-board measurement approach with other data gathering methods, which can assist to offset some of these limitations.

2.3 Hybrid Method

The combination of on-board measurement method and also chase car method is called the hybrid method [43,44]. A hybrid data collecting method is one that combines a number of data collection procedures or techniques to assemble data or insights on a certain topic. To get over the drawbacks of individual procedures and acquire a more complete and accurate data set, it entails combining and maximizing the strengths of various methodologies.

As in the paper written by Bhatti *et al.,* [45], the car chase method and on-board measurement method are used for driving data collection in the Islamabad area. In the car chase method, an instrumented vehicle is equipped with a GPS sensor and data logger. This instrumented vehicle chooses random vehicles from traffic on the test route and follows it to capture the variance of driving behaviour between different drivers. While, in the onboard measurement method, the data is collected using the OBD system which is connected to the engine control unit of the vehicle. This method resolves the GPS signal interference issue effectively. In this project, GPS data logger was build using Arduino nano ATmega328 microcontroller and a global navigation satellite system module based on UBLOX UBX-M8030-KT professional-grade chipset having navigation sensitivity of -167 dBm and a horizontal sensitivity of 2-meter circular error probable. On the other hand, the GPS receiver records parameters such as date, coordinated universal time, latitude, longitude, speed, heading, altitude, number of satellites connected, and horizontal dilution of precision (HDOP). The data are then manually retrieved the data from the GPS receiver. To remove noise and distortion from the data signals, the wavelet denoising method was used as it efficiently improves the signal-to-noise ratio of the signals.

Likewise, in the paper explained by M Farhan *et al.,* [46], the hybrid data collection method was applied in their project. For the chase car method, vehicle that is installed with GPS is used to capture the speed of other vehicles. 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.

By combining these data collection approaches, a hybrid method can offer a more holistic understanding of driving behaviour, encompassing both objective measurements and subjective perspectives. It allows researchers to validate and cross-reference data from different sources, improving the reliability and robustness of the findings. This hybrid method seems to be ideal in term of quality and accuracy compared to other methods.

However, a hybrid data collection method's implementation can be difficult and time-consuming. It might entail combining several data collection methods, handling various data types, organising logistics, and allocating enough funds for data gathering, processing, and analysis. The hybrid approach's complexity may increase the study's overall cost and effort requirements. It can be difficult to analyse and interpret data from numerous sources since it often requires using a variety of statistical methodologies, data fusion techniques, or integration strategies. Large amounts of data obtained through numerous ways can be difficult to organise, analyse, and interpret, necessitating sophisticated data management and analytical abilities. It is critical to properly plan the hybrid data gathering approach, specify objectives and research questions, guarantee suitable data quality control procedures, and use powerful data integration and analysis techniques in order to offset these drawbacks. Researchers can maximise the advantages of a hybrid strategy while minimising any potential drawbacks by addressing these issues.

3. Conclusions

This paper is based on a comparative examination of the leading published works on the development of a driving cycle specifically to collect and manage the data. From the review, it can be concluded that there are several ways to collect the data and also manage all the big data. The first method is the chase car method. However, there are a few drawbacks to applying this method, which makes it difficult to follow the target vehicle and can lead to an accident. The second approach, which is the most popular approach, is the on-board measurement method. As with the chase car, the on-board measurement method also has its own weaknesses. Its main weakness is its high operational cost and high likelihood of having incorrect data. The last approach is the hybrid approach, which is a combination of both methods. It seems like the hybrid method is the most ideal since it can avoid both accidents and data errors, despite its high operational cost.

For data management, it seems like most researchers focus only on data collection. To ensure that the obtained data is well-organized, readily available, and prepared for analysis, effective data management and processing are essential for driving data gathering. From the literature, most of the researchers is manually transferred all the data and analysed using different data storage systems and different software. It is not quite practical and time consuming. In future, it is recommended to incorporate the Internet of Things (IoT) into the data management process to make the data analysis easier and less time-consuming.

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