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Development of a Driving Cycle to Characterize the Driving Behaviour of Two-wheelers and Three-wheelers in Colombo Metropolitan Area

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Abstract: As a result of the rapid motorization, fuel consumption and greenhouse gas emissions have become two of the major concerns in the context of contemporary vehicular industry. In order to achieve the targets set by the sustainable development goals, most of the local authorities have imposed stringent limitations on both energy consumption and emissions of vehicles, which need to be adhered to by the respective manufacturers. When defining the limitations, having a proper benchmarking tool is of paramount importance. In this context, one such significant and reflective tool is the driving cycle, which can be defined as the representative time speed profile of selected vehicle categories within a defined geographical scope. Besides few attempts of developing a local driving cycle for Sri Lanka, there is a clear gap to be addressed in terms of developing a more reflective local driving cycle. This paper converges its focus into the route selection, data collection, driving cycle construction and the validation of the representative driving cycle. The geographical scope is selected as the Colombo Metropolitan area. A representative driving cycle is developed having a time length of 1215 seconds, an average speed of 3.87 m/s and an idle time percentage of 12.75%.

Keywords: Driving cycle, Three-wheeler, Two-wheeler, Fuel consumption, Emissions

1. Introduction

Driving patterns have been extensively studied since 1970s due to their significant influence on fuel consumption and emissions [1]. Driving Cycles (DCs), the time speed profiles of a certain vehicle type for a given road segment, can be considered as one of the main tools to quantify and to assess the performance of a given vehicle category. Moreover, it can be defined as gear-selection as a function of time [2], speed versus distance [3] and time versus gradient [4]. DCs are used for three main purposes, viz., to quantify fuel consumption, to quantify emission inventories, and for traffic engineering purposes [5]. When focusing on the emission and fuel consumption, there are two main methods of estimations, viz., travel-based methodology and fuel-based methodology [6]. DCs fall under the category of travel-based method. Based on the representation of the kinematics, DCs can be segregated into two main categories, viz., transient DCs and modal DCs [7]. The modal cycles are composed of constant speed sections, acceleration and deceleration phases, whereas transient cycles comprise of wider range and variation of speeds and accelerations [8].

Development of driving cycles has become one of the major research areas pertaining to the sustainable mobility. Driving cycles have been developed for both regulatory purposes and to evaluate the driving behaviour of a respective geographic region. During the study, the focus converges towards motorcycles which fall under light duty vehicles having a gross vehicle weight rating less than 3.5 tons. Colloquially, the motorcycles are referred to as two-wheeled motor vehicles. Yet, in the scientific context, motorcycle is defined with a larger spectrum of vehicle classes, viz. mopeds, motor bicycles, motor tricycles, quadricycles, etc. Different classification norms have been adopted throughout the world for motorcycles. When considering general categorization of all types of road vehicles with respect to European Union (EU) standards, the following types stated in Table 1 can be shown [9].

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Table 1 – General Vehicle Categorization in the European Union

Vehicle Category	Characteristics
Category L	Mopeds, Motorcycles, Motor Tricycles and Quadricycles
Category M	Motor vehicles having at least four wheels and for the carriage of passengers
Category N	Power-driven vehicles having at least four wheels and for the carriage of goods
Category O	Trailers (including semitrailers)

As stated in Table 1, during the study, an emphasis was placed on Category L type vehicles. When focusing on the categorization stated in Table 1 it is clear that all types of 2W and 3W are included within 'Category L'. In addition to 2W and 3W, quadricycles too have been included into Category L. When considering Light Duty Vehicles (LDVs), all the vehicles falling under Category L and a subset of Category M and Category N are included. When considering the portions which get included within LDVs from Category M and Category N are the sub-classes of motor vehicles having at least four wheels and the Gross Vehicle Weight Rating (GVWR) not exceeding 3.5 tons. Despite the development of the latest versions of Worldwide Harmonized Light Vehicle Test Procedure (WLTP), which is the benchmark driving cycle across the globe for all types of LDVs, yet a separate driving cycle has been developed for the Category L vehicles, i.e., Worldwide Harmonized Motorcycle Test Cycle (WMTC) [10]. Due to its inherent limitations with respect to power output (engine/motor) and the weight ratings (being significantly lighter than Category M and Category N vehicles), the speed responses (quantified as top speed) have major discrepancies comparatively to that of other categories of LDVs. Therefore, when analysing the driving patterns w.r.t shortlisted Characteristic Parameters (CPs), viz., average speed, average acceleration, average deceleration, etc., significant mismatches can be anticipated between Category L and other types of LDVs.

Table 2 – General Vehicle Categorization in the European Union

Vehicle Class	Vehicle Class Name
L1e	Moped
L2e	Three-wheel Moped
L3e	Motorcycle
L4e	Motorcycle and sidecar
L5e	Tricycle
L6e	Light Quadricycle
L7e	Heavy Quadricycle

As stated in Table 2, a much broader classification is performed pertaining to the WMTC vehicle classification [10]. When referring to the classification stated in Table 2, the following key characteristics can be highlighted as portrayed in Table 3 [11].

Table 3 – Key Characteristics of Motorcycle Classes

Vehicle Class	Top Speed (km/h)	Engine Capacity (CC)
L1e	<45	<50
L2e	<45	<50
L3e	>45	>50
L4e	>45	>50
L5e	>45	>50
L6e	<45	<50
L7e	>45	>50

The same categorization criteria are referred to by the International Motorcycle Manufacturers' Association (IMMA) as well [12]. Since the objective of the study is to develop driving cycles to suit the local conditions, it is important to investigate Sri Lankan regulatory landscape w.r.t vehicle classifications. The regulatory landscape is explained as mentioned below. The classification of active LDV fleet in Sri Lanka as per Section 122 of Motor Traffic Act amended by Act no.08 of 2009 is depicted in Table 4 [13].

Table 4 – Classification of Light Duty Vehicles in Sri Lanka

Class	Description
A1	Light motorcycles of which Engine Capacity does not exceed 100CC.
A	Motorcycles of which Engine Capacity exceeds 100CC.
B1	Motor Tricycles or vans of which tare

	does not exceed 500kg and Gross vehicle weight does not exceed 1000 kg; Motor vehicles in this class include an invalid carriage.
B	Dual purpose Motor vehicles of which Gross Vehicle Weight does not exceed 3500kg and the seating capacity does not exceed 9 seats inclusive of the driver's seat.

As per the classification stated in Table 4, there are two motorcycle classes (A1 and A), one tricycle class (B1) and another class for dual purpose motor vehicles (B). Although there are various different sub classes for motorcycles, yet the motorcycles (L3e) and motor tricycles (L5e) are two of the major fleet categories in Sri Lankan context. By 2020, there were over 1.1 million registered three-wheelers claiming a portion of over 14% of the total registered vehicle fleet in Sri Lanka, whereas the two-wheeled motorcycles claim for a staggering portion of over 58%, comprising a fleet of over 4.8 million [14]. Though the quadricycles are a new introduction to the active fleet in Sri Lanka, they can be considered as negligible since the number of quadricycles that is just over two thousand and around 0.03% of the entire road vehicle population. Thus, the study can be narrowed down to two types of vehicle categories, i.e., two-wheeled motorcycles and motor tricycles.

2. Literature Review

When considering the DCs developed with the focus on motorcycles, USA Federal Test Procedure (FTP) is the test cycle that has been used for the emission measurements and type approval procedures of motorcycles in USA since mid-1960's, representing home-to-work commuting in Los Angeles, California. The FTP includes a series of accelerations, decelerations, and idling (such as at stop lights). It also includes starting the vehicle after it has been parked for an extended period of time (called a "cold start"), as well as a start on a warmed-up engine (called a "hot start"). The total distance covered by the FTP is about 11 miles and the average speed is about 21 mph, with a maximum speed of about 56 mph. The maximum acceleration rate is a relatively mild 3.3 mph/sec, which is due to the limitations of the dynamometer technology at the time the test was developed. As per FTP, a motorcycle is defined as "any motor vehicle with a headlight, taillight, and stoplight and having two wheels, or three wheels and a curb mass less than or equal to 793 kilograms (1749 pounds)". Thus, referring to the said definition for a motorcycle under FTP, it also includes both two-wheelers and three-wheelers under the same class.

In most of the regions, the revised-WMTC has been adopted as their emission regulatory driving cycle, especially in EU, Japan, South Korea and in USA which are among the leading vehicle manufacturers. When considering the utility of motorcycles (two-wheelers and three-wheelers in general), South and South-East Asian regions claim for a major portion and Indonesia, Thailand and Vietnam are among them. In these three countries, Euro 3 standard is adopted for motorcycles, which is equivalent to ECE-R40 and ECE-R47 DCs [15], [16], [17], [18], [19]. When analysing the regional utilization of driving cycles to measure emissions of motorcycles, it is clear that a common driving cycle for a particular region/country of interest has been used to benchmark the emission performance of 2W, 3W and 4W quadricycles. Since Sri Lankan driving context can closely be related to South and South-East Asian driving conditions (Indian/Indonesian/Vietnamese etc.), it is advisable and recommended to adhere to a similar procedure in developing driving cycles, especially for motorcycles; that means developing driving cycles for two-wheelers, three-wheelers and four-wheeled quadricycles in general, rather than developing specific driving cycles for each category.

When analyzing the characteristic parameters of the regionally developed DCs, the necessity for the development of a specific driving cycle for Colombo Metropolitan area could be emphasised. When comparing the top speeds of the developed Colombo Metropolitan DC (CMDC) versus Indian Motorcycle Driving Cycle (IMDC), there is a lucid discrepancy between the values since CMDC claims for a top speed of around 36 km/h whereas IMDC claims for a top speed of around 55 km/h [20]. Moreover, the discrepancy between the acceleration values could be highlighted. The average acceleration and deceleration values of IMDC could be cited as 1.26 m/s^2 and -1.33 m/s^2 whereas those of CMDC could be cited as 0.33 m/s^2 and -0.36 m/s^2[20]. This depicts that the average acceleration and deceleration values portray major discrepancies between the proposed CMDC and the compared IMDC. This further highlights the necessity of the development of a dedicated DC to suit Colombo Metropolitan traffic conditions.

3. Methodology for Route Selection

When it comes to the development of driving cycles, there exists a common procedure comprising four steps, viz., route selection, data collection, cycle construction and cycle validation. The first step of DC development is the route selection. When selecting routes, the actual situations that happen along each route should be identified and ascertained. Since DCs represent the behaviour of traffic in a particular route network, the selection of proper route(s) is of greater importance. Several methodologies have been followed to select the best representative route network for DC development. There are several factors that should be looked upon when opting a route network and they can be listed, viz., land-use, road-type, topography, availability of signalized intersections, population density, vertical alignment of the road. When referring to the literature, two main methods can be identified for route selection which have been in practice for DC development throughout the world. They can be listed, viz., based on traffic-related parameters and based on knowledge and experience. Various traffic-related parameters have been utilized as selection criteria for routes. Few such parameters can be listed, viz., Average Annual Daily Traffic (AADT), Level of Service (LoS), kinematics related parameters such as average speed, acceleration, utility of intercity and intracity traffic flow data and a holistic approach with the consideration of land-use, road-type, topography and population density [17]. It is always better to use traffic-related parameters as reference when opting routes. This approach can commonly be seen in countries in European, American, Australian and Japanese regions, where there exists a proper traffic database to track the said parameters. Unlike in these countries, most of the third world developing countries lack the documented traffic data. Thus, knowledge or experience-based methods are commonly used as route selection criteria in these parts of the world. Here the experience or knowledge is referred to that of the researchers or the domain experts. This method is highly dependent over the knowhow capacity of the particular researcher; but since this does not incorporate formal database with data acquisition techniques, this method can be cost-effective and hence is viable for the developing countries.

During the study, a dedicated application called 'MTrada' has been utilized. When opting the routes through the said application, the distance matrix application programming interface (API) powered by Google™ has been used. Since there is a lack of information on average daily traffic (ADT), the aforesaid method is used to determine the routes for driving cycle development. The geographical scope of the study is selected as Colombo Metropolitan Area (CMA) encompassing 20 divisional secretariat divisions (DSDs) of Western Province of Sri Lanka. It also comprises the following 3 districts: Colombo, Gampaha and Kalutara. Furthermore, the CMA comprises 995 km^2 and consists of a population of over 3.6 million. The boundary of the CMA is defined as the area demarcating both night-time and day-time population densities having more than 20 people/hectare. Out of the 20 DSDs, 11 DSDs are located within the Colombo district. Therefore, priority is given to Colombo district when opting routes for data collection. When selecting the routes, attention is given to both intracity and intercity traffic. Intracity routes are selected within the DSDs whereas intercity routes are opted between two respective DSDs.

Data is collected from 19 major routes comprising 72 route links as depicted in Table 5.

Table 5 – Opted Routes for Data Collection in Colombo Metropolitan Area

Route Index	Route
1	Gamsabha Junction – Galle Face
2	Grandpass – Galle Face
3	Mattakkuliya – Galle Face (via Canal Road)
4	Rajagiriya – Galle Face (via Sri Jayawardenepura Road)
5	Gampaha – Kandy Road
6	Gampaha – Yakkala
7	Gampaha - Kadawatha
8	Kaduwela - Ambathale
9	Ambathale - Modara
10	Modara – Galle Face
11	Homagama - Maharagama
12	Maharagama - Nugegoda
13	Piliyandala - Boralesgamuwa
14	Kalutara - Panadura
15	Panadura - Moratuwa
16	Moratuwa - Dehiwala
17	Kesbewa – Piliyandala
18	Bandaragama - Horana
19	Kelaniya - Kiribathgoda

The number of samples to be collected from each route link is determined using the average speed of the vehicles traversing through each route link and the number of lanes of each route link.

$$N = \left(\frac{v_i^{-1}}{v_{max}^{-1}}\right)n \qquad \dots (1)$$

Equation (1) is used to determine the number of samples to be acquired from each route link. In Equation (1), N denotes the number of samples, v_i^{-1} denotes the inverse of the speed of the i^{th} route link segment, v_{max}^{-1} denotes the inverse of the speed of the route link having the maximum speed and n denotes the number of lanes. The formula in Equation (1) has been developed in order to determine the exact sizes of samples that need to be collected from each identified route link segments. Therefore, the number of samples has been determined as 185 from 72 route links.

4. Methodology for Data Collection

Once the number of samples to be collected has been determined, then the sample collection times should be determined. Since the study contains 35 two-laned route link segments, two-laned roads are selected for sample collection period determination. Two route links are chosen randomly from the two-laned route link population set and the recorded average speed per each opted route link segment per 10-minute time interval on a random weekday has been plotted in the same graph as portrayed in Figure 1.

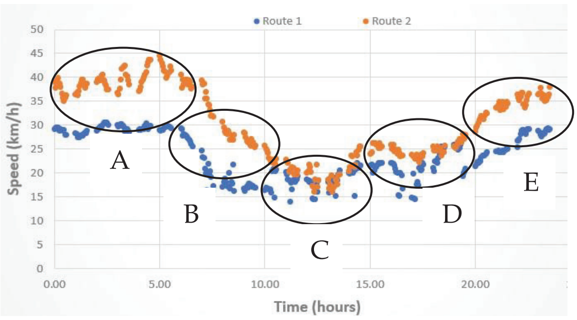

Figure 1 - Annotated Speed Comparison Graph of Two-laned Route Link Segments

The annotated graphs depict five-time segments for data collection from the selected route links. The regions of A, B, C, D and E denote the morning off-peak (MOP), morning peak (MP), afternoon peak (AP), evening peak (EP) and evening off-peak (EOP) time segments. The orange and blue data streams depict the speed data recorded in five minute time intervals in two routes during a weekday. When analysing the two plots shown in Figure 1, it can be stated that both the plots show a similar kind of a trend with an approximate symmetry at mid-day around 12 noon where the highest level of congestion can be seen. Therefore, the data collection is performed under these five-time segments. It is recommended to collect a greater number of samples during peak time segments in order to reflect the level of congestion in the representative driving cycle.

As the secondary step of DC construction, the data collection should be performed. Regardless of the approach adopted, the acquired data should be reliable, representative, consistent and homogeneous. The three main approaches that are in practice throughout the world can be listed, viz., chase-car method, instrumented-car method and hybrid method. Since local driving behaviour incorporates irregular kinematic patterns integrated with aggressive driving behaviour, the instrumented-car method is opted over the chase-car method. Moreover, the operational complexity and the cost associated with the latter approach is higher than that of the opted method.

Even though on-board diagnostics protocol (OBD– II) is available on almost all the four-wheelers after 1996, yet the said methodology is not feasible to acquire data from motorcycles since majority of them do not accommodate an OBD port. Therefore, a mobile application-based method is suggested and recommended for the data collection from motorcycles. The application is named as 'Geo-Updater' and is custom developed for the said research purpose. The said methodology transfers and stores the real-time data to a database. The proposed application is developed ergonomically in a way such that a driver can use it with less education on the functionality of the application. Visual aids have been added to the application in order to make it more user friendly.

Figure 2 - User Interface of the Geo-updater Application (when data collection is on freeze and is active)

Figure 2 portrays the user interfaces of Geo-updater application when the data collection is on halt and when data collection is active. As shown in Figure 2, visual aids have been incorporated using colors and symbols for the functional buttons. The user interface is designed in a way such that it can easily be understood by a driver since there will be drivers of various educational background involved in the data collection phase in order to mitigate the sample bias. When developing the application, one of the most significant aspects to be decided is the average sampling interval of the application. It has been experimentally decided during the study. As per the Nyquist Sampling Criterion, the sampling frequency should be greater than or equal to two times that of the maximum spectral component of a given data set. Nyquist Criterion is shown in Equation (2).

$$f_s > 2f_i \qquad \ldots(2)$$

In Equation (2), f_s denotes sampling frequency and f_i denotes the frequency of the spectral component with the highest frequency. It is important to adhere to Nyquist Criterion in order to mitigate aliasing and loss of data due to under sampling.

During the study, it was observed that the maximum spectral component of the acquired data lies around 0.490 Hz. Therefore, pertaining to Nyquist criterion, the sampling frequency should be 0.980 Hz or greater. Thus, the sampling frequency for the application was opted as 1 Hz.

When collecting data, another critical aspect is the selection of the fleet sample. Ten vehicles comprising five motor tricycles and five motor two-wheelers have been chosen for the study. When selecting the number of vehicles, the number has been decided by Motor Vehicle Emission Simulator's standard which states that five vehicles from each vehicle category should be selected for data collection. Selection of drivers is another aspect which should be paid attention to. When deciding on a driver pool, it should be variable in terms of the age. Therefore, ten drivers have been opted with a mean age of 37.4 years. Data is collected for a period of two weeks covering both weekdays and weekend-days. Per each data point, different data fields have been collected such as, latitude, longitude, instantaneous speed, time stamp and the device identification. The collected data points have been filtered per each user by using the device identification which is a unique number given to each user.

The acquired data is then uploaded onto ArcGIS™ software in order to map the collected locations. The coordinates of the locations of the collected data points are mapped on the shape file containing the map of Sri Lanka. The corresponding map segment is portrayed in Figure 3.

Figure 3 – Collected Data Visualized via ArcGIS Map

5. Methodology for Cycle Construction

As per the four-stepped method in driving cycle construction, the third and the most critical step can be identified as cycle construction step. Various approaches have been adopted by the researchers throughout the world in the development of driving cycles, viz., micro trip-based method, segment-based method, pattern classification method and modal cycle construction method. During the study, driving data is collected from arterial route links omitting the expressways. Therefore, the most prevalent traffic condition is the stop and go driving behaviour. The best method to model the stop and go traffic pattern is micro trip-based method. In this method, the total collected data is segregated into multiple micro trips. A micro trip is defined as a trip having a leading idle period and a stop condition at the end which is depicted in Figure 4.

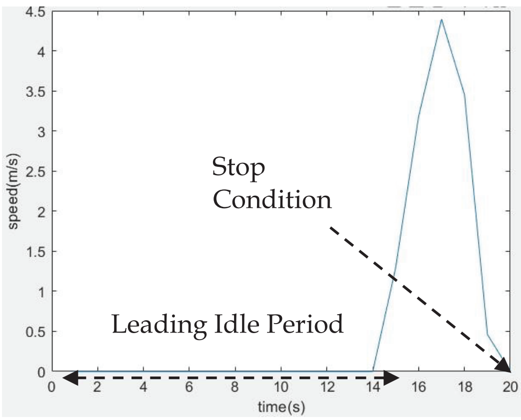

Figure 4 – Portrayal of a Micro Trip

Then the segregated micro trips should be clustered into classes depending on the average speed of each micro trip. There have been 2,556 micro trips in total and a MATLAB program is scripted to determine the average speed of each trip segment. There exist several methods in clustering micro trips. When referring to the literature, k-means clustering method can be found in most of the related research. Fotouhi and Montazeri-Gh (2013) has used k-means clustering method in developing Tehran driving cycle [21]. When developing Fuzhou driving cycle developed by Peng et al. (2020), again the k-means clustering method is utilized for the classification of micro trips [22]. Even though the said studies have used k-means clustering method, yet there is an inconsistency pertaining to the spatial environment, i.e., two adjacent micro trips can be fallen into two different classes. For example, suppose the first micro trip is spanning for five seconds and the adjacent micro trip is spanning another five seconds. But, if the k-means clustering algorithm has 'k' number of clusters, these two adjacent trips can fall into two different classes, let's say urban traffic class and extra-urban traffic class. This kind of a classification is inconsistent in terms of traffic behaviour. Therefore, a spatial mapping is required to better reflect the spatial relationship of the classes and to mitigate the inconsistencies pertaining to classification.

During the study, a novel approach is adopted in clustering the micro trips. Krigging spatial analysis is used to interpolate the speed data and to visualize it in the spatial domain. Using ArcGIS software, the ordinary Krigging interpolation is performed on the collated data set and the respective data is mapped on Sri Lankan map as portrayed in Figure 5.

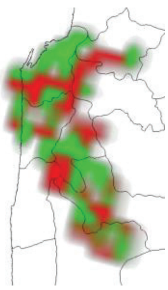

Figure 5 – Spatial Data Mapping for the Collected Data

As depicted in Figure 5, the speed data is classified into two classes which is spatially denoted using green and red. When classifying speed data of the micro trips into two classes, the Jenks Natural Breaks method has been utilized. Here, the two classes can be identified as shown in Table 6.

Table 6 – Classification of Speed Classes

Classification	Average Speed (v) Range
Class 1 (Urban)	0 < v < 3.62 m/s
Class 2 (Extra – Urban)	3.62 m/s<= v < 8.16 m/s

As expected, the consistency of the classified data within their respective classes can be lucidly seen using the spatially interpolated speed data in Figure 6. The two classes have been named as Urban class and Extra-Urban class, respectively. Once classified into two classes, the next step is to determine the length of the representative driving cycle. When it comes to the length of driving cycles, most of the driving cycles which have been used for regulatory purposes span between 900 – 1800 seconds. Therefore, the proposed driving cycle is also planned to have a duration of around 1200 seconds and comprising two phases, i.e., urban phase and extra urban phase. The time proportions of both the phases are determined using the aggregated time duration of micro trips of each class. The urban class claims for a time proportion of 52.75% whereas the extra-urban class claims for a time proportion of 47.25%. When developing the candidate cycles from the pool of micro trips, the said time length is paid attention. The micro trips have been chosen randomly and connected to each other to generate a lengthier micro trip to meet the said criteria of cycle length. Once such candidate cycles have been developed, the next step is to determine the characteristic parameters of the cycles. In the procedure, thirty candidate cycles have been developed. The number, thirty has been opted since it adheres to the central limit theorem and the sample means of the characteristic parameters (CPs) would be converging towards the population means of the said CPs.

6. Methodology for Cycle Validation

Five CPs have been chosen for the selection of the representative cycle from the pool of candidate cycles. This procedure is being performed iteratively for both urban phase and extra-urban phase separately, but in a similar manner. The selected set of CPs can be elaborated, viz., average speed, average running speed, average acceleration, average deceleration and the percentage of idle time. The similarity of each CP of the candidate cycle to that of the population is analysed and quantified using the formula stated in Equation (3).

$$CP_{SI} = (1 - \left|\frac{CP_{Population} - CP_{Candidate}}{CP_{Population}}\right|) \qquad \ldots(3)$$

In Equation (3), CP_{SI} denotes the Similarity Index (SI) of the CPs, $CP_{Population}$ denotes the respective CP of the population data set whereas $CP_{Candidate}$ denotes the respective CP of the candidate cycle. For example, let's take the respective CP as average acceleration. Then, let's assume that the $CP_{Population}$ value is at 1.3587 m/s^2 and $CP_{Candidate}$ value is at 1.3713 m/s^2. Then, once the said values are substituted in Equation (3), an SI of 0.9908 has been obtained. Likewise, the same methodology is performed for other CPs as well.

$$CP_{CSI} = \sum_i^5 (1 - \left|\frac{CP_{i_{Population}} - CP_{i_{Candidate}}}{CP_{i_{Population}}}\right|) \qquad \ldots(4)$$

As depicted in Equation (4), CP_{CSI} denotes the cumulative similarity index (CSI) which is the summation of each similarity index. During the study, five CPs have been opted and five SIs have been aggregated and a CSI has been determined. The candidate cycle with the highest CSI score has been opted as the representative driving cycle. The scores of the highest two candidate driving cycles for both urban and extra-urban phases have been portrayed in Table 7. The opted candidate cycle for the urban phase has a CSI score of 4.5489 whereas that of the extra-urban phase lies at 4.8087. The representative driving cycles for urban and extra-urban phases spanning for 641 s and 574 s, respectively, are shown graphically in Figure 6 and Figure 7.

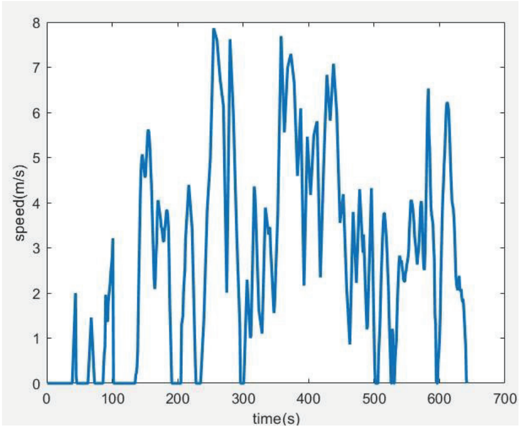

Figure 6 – Representative Urban Driving Cycle

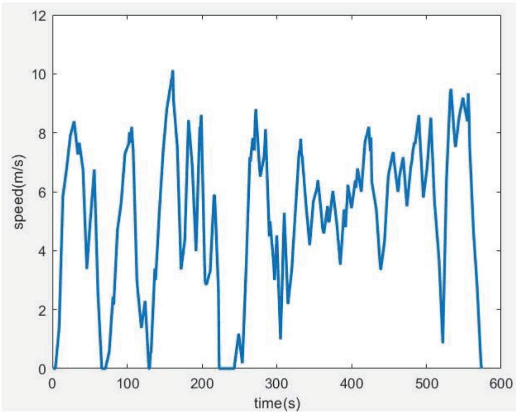

Figure 7 – Representative Extra-Urban Driving Cycle

Figure 8 portrays the combined driving cycle which combines both the urban and extra-urban phases of the driving cycle. The total driving cycle spans for a period of 1215 s. The properties of the representative driving cycle in terms of five selected CPs are depicted in Table 8. Finally, to evaluate the quality of fit of the representative driving cycle to the population data set, Speed Acceleration Frequency Distribution (SAFD) is determined for the representative driving cycle as well as for the population data set.

Table 7 – Selection of Urban and Extra-Urban Representative Cycles using CSI scores of CPs

	Average Speed (CP_1)	Average Running Speed (CP_2)	Average Acceleration (CP_3)	Average Deceleration (CP_4)	Percentage Idle Time (CP_5)	CSI Score (out of 5)
SI of the Representative Urban Cycle	0.8953	0.9379	0.8657	0.8766	0.9732	4.5489
SI of the Representative Extra-Urban Cycle	0.9864	0.9875	0.9296	0.9964	0.9086	4.8087

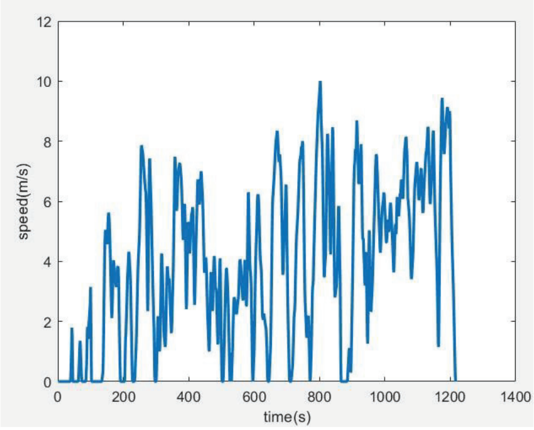

Figure 8 – Representative Driving Cycle

Table 8 – CP values of the Representative Driving Cycle

Characteristic Parameter	Value
Average Speed	3.87 m/s
Maximum Speed	10.01 m/s
Average Running Speed	4.44 m/s
Average Acceleration	0.33 m/s^2
Average Deceleration	-0.36 m/s^2
Idle Time Percentage	12.75%

Then a comparison between the SAFDs of the representative driving cycle and the population data set is performed. Three plots have been developed: one for the speed-frequency distribution of the population data set which is depicted by Figure 9, then the speed-frequency distribution of the representative driving cycle which is depicted by Figure 10 and the other to portray the acceleration-frequency distributions of both population data set and the representative driving cycle graphed together which is portrayed by Figure 11. As shown in Figure 9 and Figure 10, the trends of the representative driving cycle and the population data set for both speed-frequency distributions look similar. Moreover, the trends of the acceleration-frequency distribution of the population data set and the representative driving cycle too remain quite similar. When analyzing the speed-frequency distributions, it can be noted that the highest number of speed-frequency is noted at zero speed, i.e., the idle speed. Similarly, when evaluating the acceleration-frequency distributions, the highest acceleration-frequency is recorded at the origin, denoting the idle and cruising phases. Due to the similarities in SAFD trends, the developed representative driving cycle can be validated against the population data set. Therefore, the quality of fit of the representative driving cycle remains higher.

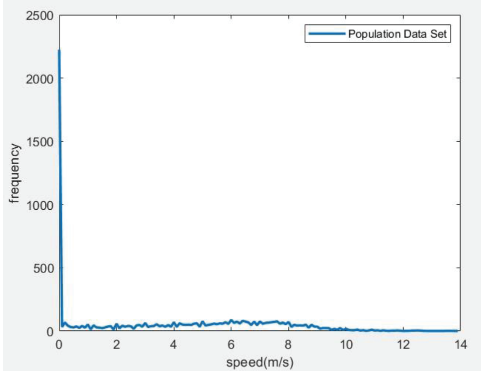

Figure 9 – Speed-Frequency Distribution of the Population data set

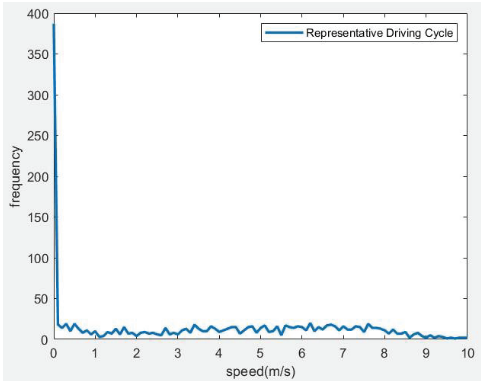

Figure 10 – Speed-Frequency Distribution of the Representative Driving Cycle

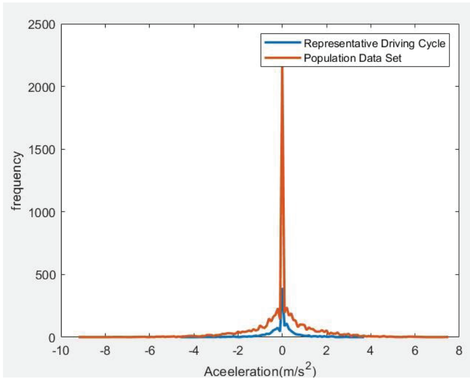

Figure 11 – Comparison of the Graphs for Acceleration-Frequency Distributions

7. Conclusion

During the initial phase of the study, the necessity of a driving cycle construction, specifically for the motorcycles, has been emphasized citing the literature. As a main deliverable of the study, a driving cycle is being developed for motorcycles comprising two-wheeled motorcycles and three-wheeled motor tricycles, in the geographic scope of Colombo Metropolitan Area. The developed driving cycle comprises two phases, i.e., urban-phase and the extra-urban phase. Using five CPs, a representative driving cycle has been opted from a pool of candidate driving cycles. The opted representative driving cycle portrays the characteristics, viz., an average speed of 3.87 m/s, an average running speed of 4.44 m/s, an average acceleration of 0.33 m/s^2, an average deceleration of -0.36 m/s^2, an idle time percentage of 12.75% and a time length of 1215 s. Having an average speed of 3.87 m/s depicts the fact that the level of congestion within Colombo Metropolitan Area remains quite high. The developed representative driving cycle can be utilized for research purposes pertaining to fuel consumption quantification as well as emission characterization.

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