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Development Of Electric Bus Real-Time Driving Cycle: A Case Study Of Pune, India

Avadhut S. Kulkarni[1], Arun Kumar Dwivedi[2], Tushar R. Bagul[3]
[1]Research Scholar, Department of Civil Engineering, SOET, Sandip University, Nashik, Maharashtra, India, 422213; Assistant Professor, D Y Patil College of Engineering, Akurdi, Pune, Maharashtra, India, 411044, kulkarniavadhut89@gmail.com
[2]Professor, Department of Civil Engineering, SOET, Sandip University, Nashik, Maharashtra, India, 422213, arun.dwivedi@sandipuniversity.edu.in
[3]Senior Technical Consultant, The Energy and Resources Institute, India Habitat Center, New Delhi, India, 110003, trbagul@gmail.com

Abstract: *The development of region-specific driving cycles is critical for accurate energy consumption estimation, battery sizing, and performance evaluation of electric buses. This study focuses on the creation of a real-time driving cycle tailored to urban driving conditions in Pune, India. High-resolution vehicle data, including speed and time, were collected from operational electric buses plying on representative city routes. The collected data was analyzed to determine key driving parameters such as average speed, acceleration, deceleration, idle time, cruise and stop frequency. A representative driving cycle was constructed using micro-trip segmentation and statistical methods to ensure it closely reflects actual traffic and operational conditions in Pune. The developed cycle was validated by comparing its characteristics with standard national and international driving cycles. This study highlights the importance of localized driving cycles for accurate electric vehicle performance assessment and contributes to better planning and deployment of electric buses in Indian urban environments.*
Keywords: *Driving characteristics, Micro-trip, Public transportation, Electric bus, energy estimation*

1 INTRODUCTION

The global shift towards sustainable transportation has led to increased adoption of electric vehicles (EVs), particularly electric buses, in urban public transport systems. These vehicles offer significant environmental benefits, including reduced greenhouse gas emissions and improved air quality, making them a vital component of smart and clean city initiatives. However, accurate assessment of their energy consumption, performance, and operational efficiency requires the use of realistic and region-specific driving cycles that represent actual traffic and road conditions.

Driving cycles are graphical representations of a vehicle's speed over time and serve as essential tools for simulating vehicle behavior under typical operating conditions. Standard driving cycles, such as the Urban Dynamometer Driving Schedule (UDDS) or the European Urban Driving Cycle (EUDC), have been widely used for conventional internal combustion engine vehicles. However, these cycles often fail to reflect the unique and dynamic traffic patterns, road geometries, and driving behaviors observed in specific urban areas, especially in densely populated and diverse cities like Pune, India.

The lack of locally developed driving cycles can lead to inaccurate estimation of energy usage, improper battery sizing, and suboptimal route planning for electric buses. Therefore, there is a pressing need to develop real-time, city-specific driving cycles based on actual vehicle operation data. Such cycles are particularly important for electric buses, where energy consumption is highly sensitive to factors like acceleration, deceleration, idling, and stop-and-go conditions.

This study addresses this gap by developing a real-time driving cycle for electric buses operating in Pune city. It involves the collection of high-resolution speed-time data from electric buses on selected urban routes and the extraction of key driving parameters. The driving cycle is constructed using micro-trip segmentation and validated by comparing it with established national and international cycles. The outcome of this research provides a foundational tool for evaluating electric bus performance in Pune and can serve as a model for other Indian cities aiming to transition towards electric public transportation systems.

2 LITERATURE REVIEW

The worldwide initiative to combat pollution and lower greenhouse gas emissions has accelerated the shift toward alternatives to conventional internal combustion engine vehicles. Among these, battery electric buses are gaining prominence as a sustainable replacement for traditional diesel buses in urban public transport systems. To support this transition, it is vital to assess and quantify energy consumption and emissions accurately, as this information plays a key role in improving air quality and safeguarding public health. (Luque P et al., 2021)

A real-time driving cycle reflects the actual driving behavior of vehicles under real-world traffic conditions. Developing such a cycle is crucial for accurately estimating energy consumption and vehicular emissions, as driving patterns differ based on location and traffic conditions (Kamble Sanghpriya et al., 2009). Real-time driving cycles help evaluate the true fuel efficiency and emission levels of vehicles in everyday scenarios, offering a realistic insight into their performance and energy usage (Zhao Xuan, et al., 2020).

Recent studies have also explored advanced techniques such as micro-trip analysis, cluster-based segmentation, and GPS-enabled data logging for real-time driving cycle development. These approaches provide higher resolution and better represent traffic variability, enabling more accurate modeling for electric vehicle energy consumption, battery degradation, and regenerative braking effectiveness.

Despite these advances, limited work has been done on developing and validating electric bus-specific driving cycles in Indian cities. This study contributes to that gap by creating a real-time, Pune-specific electric bus driving cycle based on high-resolution speed-time data, offering a more precise tool for evaluating electric bus operations in urban India.

3 METHODOLOGY

This methodology is demonstrated through a case study utilizing data collected from Pune, a major urban hub in Maharashtra, India. Pune is one of the fastest-growing metropolitan areas in the country and has one of the highest concentrations of E-bus. The addition of thousands of new vehicles each month has led to a significant rise in traffic congestion. As a result, the average travel speeds on city roads have declined drastically, also traffic conditions can change significantly over short distances so the method has been thoroughly illustrated by analyzing traffic variation and its effects. The following are the steps to develop the driving cycle. i) Selection of road routes ii) Driving data collection (speed-time) iii) Construction of Micro-trips iv) Preliminary assessment of data v) Development of real-time driving cycle.

3.1 Selection of Road routes

Roads have selected such that it covers and represents the Pune city. Roads have considered as arterial and sub arterial roads as per municipal corporation maps and highest traffic mobility on these roads in peak hours. Initially, a total of 16 major roads were selected as per the Road network map of Pune BRT and PCMC BRT.

Figure 1 shows the test road considered for the study. It is as follows-

Under Pune Municipal Corporation (PMC):

- Aundh to Hadapsar Gadital
- Warje to Kharadi
- Kharadi to Hadapsar Gadital
- Hadapsar Gadital to Dhayari
- Dhyari to Wakad
- Aundh to Katraj
- Kothrud depo to Vishrantwadi
- Visharntwadi to Nigdi

Under Pimpri Chinchwad Municipal Corporation (PCMC):

- Kiwale to Hinjewadi
- Kalewadi phata to Aundh
- Nigdi to Shivaji Nagar
- Nigdi to Dange chowk
- Dange chowk to Aundh
- Kalewadi phata to Warje
- Hinjwadi to Bhosari
- Katraj to Dange chowk

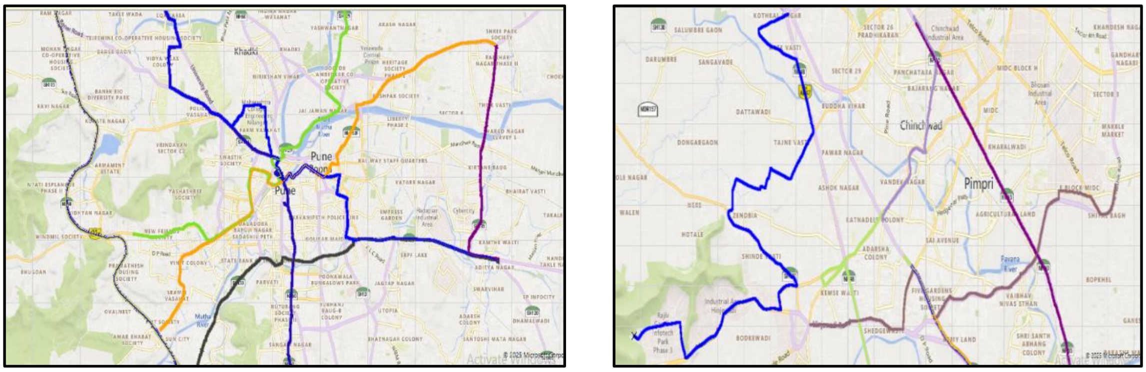

Figure – 1: Test Roads

To establish a representative driving cycle for a city, it is essential to analyze traffic data from the routes commonly used by E-bus. However as the vast number of potential routes, it is not feasible to conduct direct speed measurements on every road. To address this, a practical approach involves selecting a limited number of test routes that effectively reflect the predominant traffic conditions across the city. This study adopts a systematic methodology to identify representative road within the study area. Using the micro-trip approach, a typical driving cycle for E-bus has constructed. This method captures recurring driving patterns that drivers typically experience during their daily operations. The speed patterns used in this analysis are influenced by real-time traffic flow data.

For all above the selected road routes travel speed is measured in MPH for each road section and converted in to KmPH. Average travel speed of entire road is calculated from speed of each road section. Based on the difference between average speed and average speed of each road representative test road has selected. Representative test road has selected based on the minimum difference with average speed of that corridor.

3.2 Test Vehicle

The Electric bus (E-bus) used for the study as test vehicle. The electric bus having age in between 0 to 5 years has considered. On the selected test road route detailed characteristics of electric bus and battery specifications has considered.

Specifications of E-bus:
Manufacturer: Olectra Greentech
Model: K9D
Length: 12 m, Width: 2.6 m, Height: 3.8 m
Seating capacity: 33 plus driver
Peak Load capacity: 60
Type: Air conditioned
Battery: Li-ion (Lithium-ion) battery having Lithium Iron Phosphate (LFP) battery technology.
Range: Around 200 km on a single charge.
Battery capacity: 300 kWh

3.3 Development of Driving cycle

Figure 2 shows the flow chart of development of driving cycle of E-bus. Further a typical driving cycle for Pune city has developed from traffic data of along the travelling roads of E-bus. The E-bus driving cycle for Pune city has developed using micro trip method that represents driving pattern.

Details of selected representative test road like length of road, width of road, type of road, average speed has collected. Detailed driving characteristics like traffic flow, average traffic speed, vehicle density has measured on selected route. All round trips originating from the starting point were included in the analysis. The chosen test route, covering more traffic intersections. The route features relatively flat terrain, with no steep gradients. As a result, this selected road network effectively captures the full range of driving speed patterns typically observed in the city. It was therefore utilized for real-time driving tests to gather comprehensive driving behavior data, specifically speed versus time measurements.

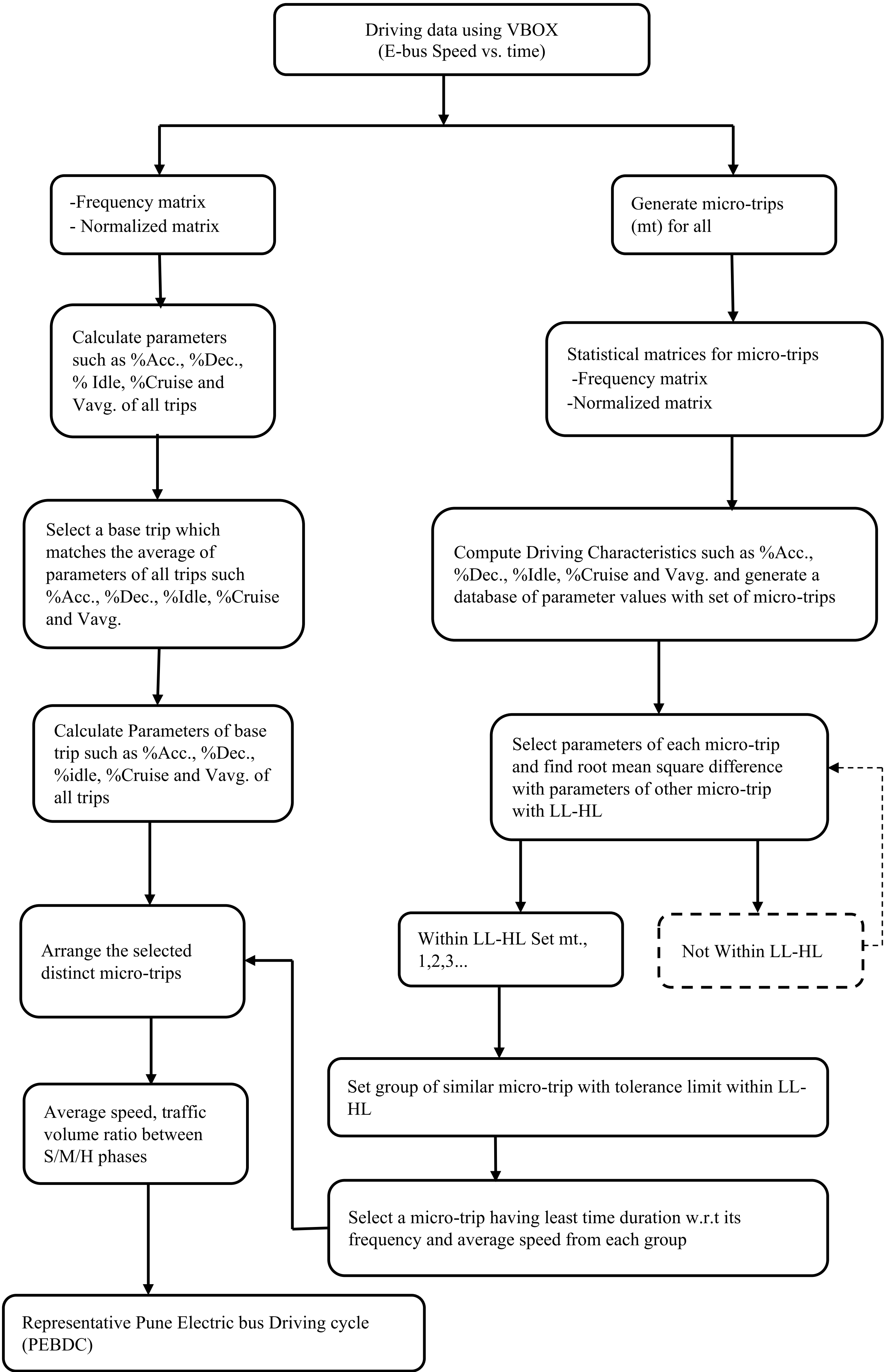
Driving data using VBOX
(E-bus Speed vs. time)
-Frequency matrix
- Normalized matrix
Generate micro-trips
(mt) for all
Calculate parameters such as %Acc., %Dec., % Idle, %Cruise and Vavg. of all trips
Statistical matrices for micro-trips
-Frequency matrix
-Normalized matrix
Select a base trip which matches the average of parameters of all trips such %Acc., %Dec., %Idle, %Cruise and Vavg.
Compute Driving Characteristics such as %Acc., %Dec., %Idle, %Cruise and Vavg. and generate a database of parameter values with set of micro-trips
Calculate Parameters of base trip such as %Acc., %Dec., %idle, %Cruise and Vavg. of all trips
Select parameters of each micro-trip and find root mean square difference with parameters of other micro-trip with LL-HL
Arrange the selected distinct micro-trips
Within LL-HL Set mt., 1,2,3...
Not Within LL-HL
Set group of similar micro-trip with tolerance limit within LL-HL
Average speed, traffic volume ratio between S/M/H phases
Select a micro-trip having least time duration w.r.t its frequency and average speed from each group
Representative Pune Electric bus Driving cycle (PEBDC)

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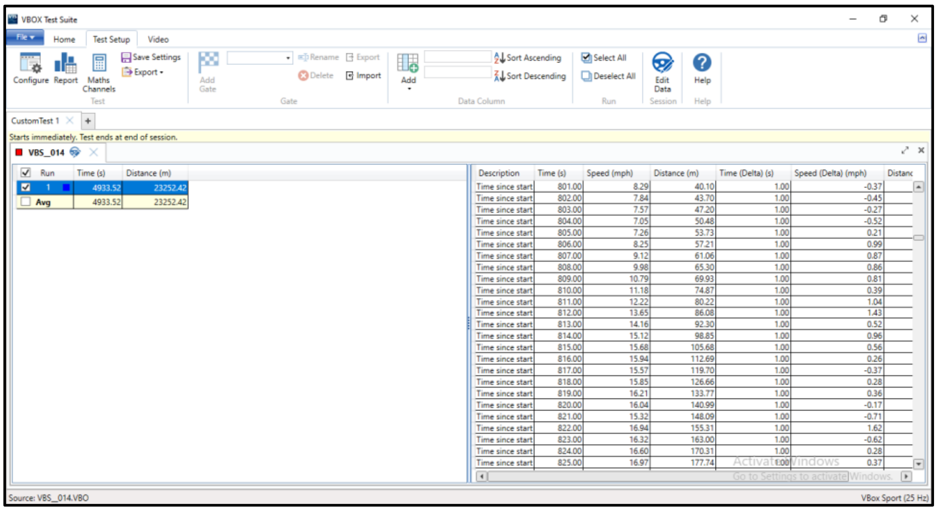
Figure – 2: Flow chart of development of driving cycle

4 Speed time data collection

Speed time data has collected by on-board measurement technique on all selected road routes. To collect this data, VBOX Sport (figure 3) with GPS used to record the speed-time sequence along selected test roads. The data logger recorded the information on an 8 GB Secure Digital (SD) card, a type of flash memory. This data then transferred to a laptop. Driving cycle parameters, such as trip distance, acceleration, and speed-time data, were extracted at 1 second intervals. To ensure natural driving behavior, the driver was not informed about the purpose of the instrumentation.

Figure – 3: VBOX Sport

Figure 4 shows the Speed time data table for Road route Hadapsar to Nigdi.



Run	Time (s)	Distance (m)
1	4933.52	23252.42
Avg	4933.52	23252.42

Description	Time (s)	Speed (mph)	Distance (m)	Time (Delta) (s)	Speed (Delta) (mph)
Time since start	801.00	8.29	40.10	1.00	-0.37
Time since start	802.00	7.84	43.70	1.00	-0.45
Time since start	803.00	7.57	47.20	1.00	-0.27
Time since start	804.00	7.05	50.48	1.00	-0.52
Time since start	805.00	7.26	53.73	1.00	0.21
Time since start	806.00	8.25	57.21	1.00	0.99
Time since start	807.00	9.12	61.06	1.00	0.87
Time since start	808.00	9.98	65.30	1.00	0.86
Time since start	809.00	10.79	69.93	1.00	0.81
Time since start	810.00	11.18	74.87	1.00	0.39
Time since start	811.00	12.22	80.22	1.00	1.04
Time since start	812.00	13.65	86.08	1.00	1.43
Time since start	813.00	14.16	92.30	1.00	0.52
Time since start	814.00	15.12	98.85	1.00	0.96
Time since start	815.00	15.68	105.68	1.00	0.56
Time since start	816.00	15.94	112.69	1.00	0.26
Time since start	817.00	15.57	119.70	1.00	-0.37
Time since start	818.00	15.85	126.66	1.00	0.28
Time since start	819.00	16.21	133.77	1.00	0.36
Time since start	820.00	16.04	140.99	1.00	-0.17
Time since start	821.00	15.32	148.09	1.00	-0.71
Time since start	822.00	16.94	155.31	1.00	1.62
Time since start	823.00	16.32	163.00	1.00	-0.62
Time since start	824.00	16.60	170.31	1.00	0.28
Time since start	825.00	16.97	177.74	1.00	0.37

Figure – 4: Speed Time data

Further data has collected for selected representative test road route Hadapsar to Nigdi. The traffic flow characteristics for road Hadapsar to Nigdi via Bopodi are same with road Bopodi to Nigdi and vice versa along with average speed of 16.48 kmph. Also to consider more number of round trips in a day representative short route has to consider. Hence further data collection and analysis has done on road Bopodi to Nigdi and Nigdi to Bopodi. Four round trips were conducted each day along the test route during the months of January - February, covering both peak and off-peak traffic periods. Data collection took place between 08:00 AM to12:00 PM and 04:00 PM to 8:00 PM. Electric bus operation modes like acceleration, deceleration, cruise and idling has observed. The peak traffic hours were identified as 08:00 AM to 09:00 AM and 06:00 PM to 07:00 PM.

5 Speed time data analysis and Results

After collecting data, analysis done by using VBOX Test Suite software. Speed time data and driving characteristics analyzed during the entire trip from start to end for all the selected road routes. Figure 5 shows the driving characteristics at start of trip for road route Hadapsar to Nigdi and figure 6 shows the driving characteristics at end of trip for road route Hadapsar to Nigdi.

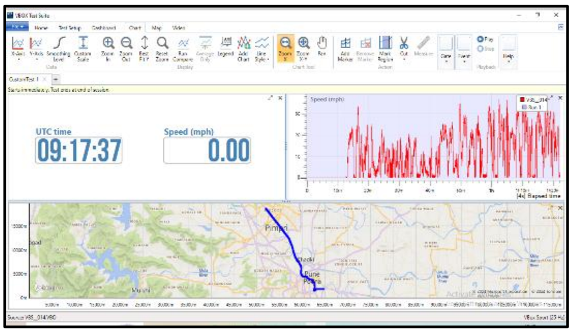


Figure – 5: Driving characteristics at start of trip

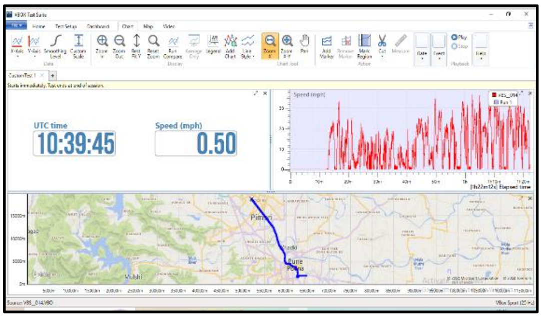


Figure –6: Driving characteristics at end of trip

Speed-time data analysis has done and representative test road has selected and shown in Table 1.

Table – 1: Selection of representative test road

Sr. No.	Road Route	Actual Distance Travelled (km)	Actual time required (sec)	Actual time required (mins)	Average Travel speed (mph)	Average Travel speed (kmph)	Difference between avg speed and avg travel speed of each road	Selection of Representative test road (Min difference with avg speed of each road)
1	Kiwale to Hinjewadi	19.72	3479	58	12.97	20.87	4.19	----
2	Kalewadi Phata to Hadapsar	24.63	5406	90	10.8	17.38	0.70	----
3	Hadapsar to Nigdi	23.25	4933	82	10.52	16.93	0.25	Yes
4	Kalewadi Phata to Warje	18.89	3798	63	11.36	18.28	1.60	----
5	Warje to Kharadi	19.42	3863	64	10.86	17.48	0.80	----
6	Kharadi to Hadapsar	7.67	2319	39	7.41	11.93	4.75	----
7	Hadapsar to Dhayari	17.12	4363	73	8.5	13.68	3.00	----
8	Dhayari to Wakad	20.28	5856	98	7.49	12.05	4.63	----
9	Kalewadi Phata to Pune Corporation	13.74	2333	39	13.02	20.95	4.27	----
10	Pune Corporation to Katraj	7.38	2993	50	6.17	9.92	6.76	----
11	Katraj to Dange Chowk	28.98	4634	77	14.09	22.67	5.99	----
12	Wakad to Kothrud	6.13	1495	25	9.56	15.38	1.30	----
13	Kothrud to Vishrantwadi	14.78	3766	63	9.19	14.79	1.89	----

14	Vishrantwadi to Nigdi	16.15	3204	53	11.46	18.44	1.76	----
15	Nigdi to Dange Chowk	6.18	1140	19	11.85	19.07	2.39	----
16	Hinjewadi to Bhosari	15.28	3202	53	10.64	17.12	0.44	----
				Average Speed		16.68		

In this study, for selected road routes actual distance travelled, actual time required to reach at destination, average travel speed in mph determined from the collected data. Average travel speed from mph to kmph is calculated by multiplying 1.609 to mph value. From average travel speed of selected each road routes average speed of the Pune city is determined which is 16.68 kmph.
Average Speed (kmph) =
(20.87+17.38+16.93+18.28+17.48+11.93+13.68+12.05+20.95+9.92+22.67+15.38+ 14.79+18.44+19.07+17.12)/16 = 16.68
Then Difference between average speed and average travel speed of each road calculated. For Kiwale to Hinjewadi route, Difference between average speed and average travel speed is considered in absolute value |16.68-20.87| = 4.19 kmph. Similarly for all road routes difference is calculated.
Representative test road has selected based on the minimum difference with average speed of that road route. The road route Hadapsar to Nigdi is having minimum difference with average speed which is 0.25 kmph, so it is considered as representative test road. Further study has done on this route only to represent the Pune city and to determine real time driving cycle of electric bus.
Further data has collected for selected representative test road route Hadapsar to Nigdi. The traffic flow characteristics for road Hadapsar to Nigdi via Bopodi are same with road Bopodi to Nigdi and vice versa along with average speed of 16.48 kmph. Also to consider more number of round trips in a day representative short route has to consider. Hence further analysis has done on road Bopodi to Nigdi and Nigdi to Bopodi.
Further analysis has done by Advance excel and Python software. From analysis, real time driving cycle of electric bus has developed and actual behavior of electric bus studied to know the actual travel time in between two stations and energy requirement.
Figure 7 shows the Representative test road Nigdi to Bopodi.

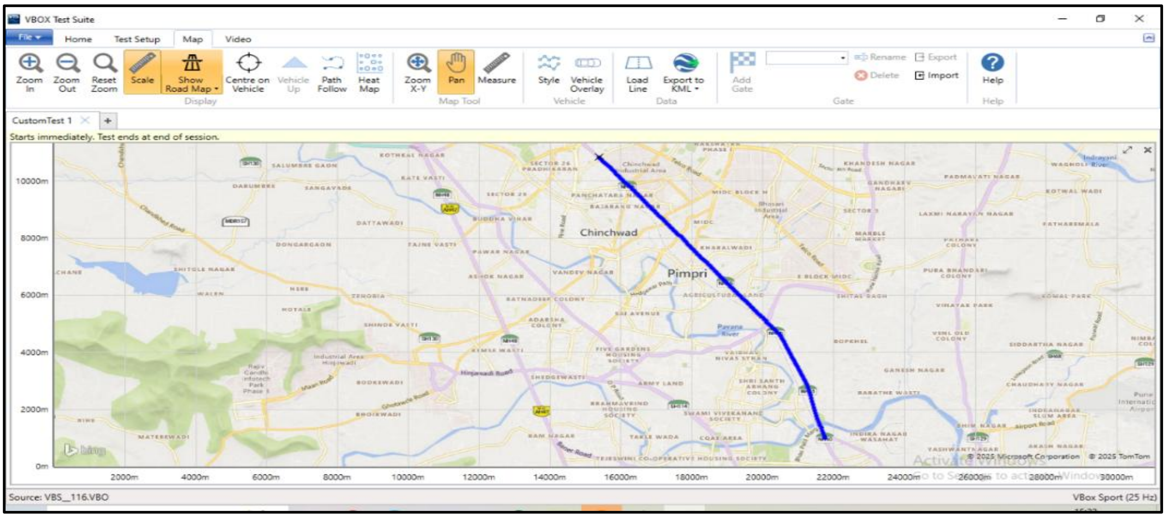


Figure – 7: Representative test road Nigdi to Bopodi
From the data analysis details of selected representative test road has determined and tabulated in Table 2.

Table – 2: Details of selected representative test road

Route	Length (km)	Total Width of road (m)	Carriageway type	Average speed (km/h)	No. of Intersections	No. of Bus stops
Nigdi to Bopodi	12	45	5 lane divided	16.48	11	18

Construction of micro-trips

Micro-trips are defined as segments of a time-speed profile that begin and end at zero speed, capturing the complete cycle of acceleration, cruising, and deceleration phases (Kamble et al., 2009). Each micro-trip represents a discrete unit of vehicle motion, typically bookended by idle periods at the start and end. To enable detailed analysis, the continuous time-series data is segmented into several such micro-trips.

Speed-time data from representative road segments are further divided into n subgroups, each corresponding to different driving modes of the E-bus. The segmentation is typically triggered at the onset of each idle phase. The micro-trip approach has proven to be an effective method for constructing realistic driving cycles for Indian conditions (Kamble et al., 2009; Bagul et al., 2021).

For efficient processing of the large dataset, a custom computer program was developed using Python. This tool employs a deviation-based algorithm to synthesize representative driving cycles.

Table 3 shows the details of distance covered and test repetition.

Table – 3: Details of distance covered and test repetition

Route	Length (km)	Timing (peak hours)		Number of test repetition	Month and Year
		Morning Session	Evening Session		
Nigdi to Bopodi	12	08:00 am to 12:00 noon	04:00 pm to 8:00 pm	1week (two round trips in each session)	January-February 2025

Total distance covered with number of repetition is 768 km.

Composition of traffic

The traffic analysis has done on selected road route. The average daily traffic data reveals the composition of vehicles using the roadway. This composition includes categories such as cars, trucks, buses, motorcycles, and other types of vehicles. The distribution provides insights into traffic patterns, helping to understand the predominance of two-wheeler over other types and their contribution to the overall traffic flow. This understanding is crucial for designing effective traffic management strategies tailored to the dominant vehicle types. The percentage of two-wheeler is the highest (77%), which was expected too, four-wheeler holds (15%) of the total count and other vehicles such as three wheelers (4%) and buses (2%), composition of traffic shows quite less percentage of public transport, directing the excessive use of private vehicle. The percentage of buses also includes the count of private buses as well. The observed PMPML buses were full passengers, so if the number of city buses is increased can result in less use of private vehicles making the traffic system much more efficient and eco-friendlier. The percentage of LCV is (1%) which includes the vehicles such as small tempo, pick-ups, mini trucks, etc. And HCV is also (1%) which includes trolly, trucks, dumpers, they are mostly restricted to travel in day time as they turn out the reason for the traffic congestion. Hence, they are permitted to travel in night time in empty road and less traffic conditions.

Development of Driving cycle

Preliminary assessment of data

The base driving data was analyzed in two stages:

(i) Preliminary-level assessment
(ii) (ii) Micro-trip level assessment

The preliminary analysis involved the construction of two key matrices:

Speed-Acceleration Frequency Matrix (SAFM) and Speed-Acceleration Probability Matrix. (SAPM).

The SAFM (table 4) represents the distribution of frequency for various speed-acceleration and speed-deceleration combinations, corresponding to different driving modes such as idling, acceleration, cruising, and deceleration. The SAPM (table 5) is derived from the SAFM by normalizing each cell – dividing by the sum of all frequencies and then multiplying by 100 to express values as percentages.

Table – 4: Speed-Acceleration Frequency Matrix (SAFM)

Speed (kmph)	Acceleration (kmph/s)																					
	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	Total
0-5	2	1		2	4	5	10	12	26	106	872	99	21	11	2	1	0	0	0	0	0	1174
5-10	0	0	2	3	4	6	1	6	9	26	26	25	10	8	8	4	0	2	0	0	1	141
10-15	0	0	1	2	3	5	5	8	17	24	19	15	13	8	8	4	4	0	0	0	0	136
15-20	0	1	0	0	8	8	6	9	16	18	18	12	13	11	14	5	1	0	1	0	0	141
20-25	0	2	1	0	4	5	6	12	17	29	24	19	16	15	11	4	1	2	1	1	0	170
25-30	0	0	0	1	2	5	11	13	22	40	46	24	28	13	7	3	3	2	1	0	0	221
30-35	0	0	1	0	2	4	5	5	12	28	19	32	21	11	6	5	1	1	2	1	1	157
35-40	0	0	0	0	2	3	3	4	7	17	22	26	19	14	1	1	0	0	0	0	0	119
40-45	0	0	0	0	0	1	2	7	3	10	15	16	15	3	0	0	0	0	0	0	0	72
45-50	0	0	0	0	0	0	3	1	6	15	16	24	8	6	2	0	0	0	0	0	0	81
50-55	0	0	0	0	0	0	0	0	6	9	17	14	6	1	0	1	0	0	0	0	0	54
55-60	0	0	0	0	0	0	0	0	0	1	6	1	1	0	0	0	0	0	0	0	0	9
Total	2	4	5	8	29	42	52	77	141	323	1100	307	171	101	59	28	10	7	5	2	2	2475

Table – 5: Speed-Acceleration Probability Matrix (SAPM)

Speed (kmph)	Acceleration (kmph/s)																				
	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	Total
0-5	0.9	0.4	0	0.9	0.2	0.2	0.4	0.5	1.6	4.3	35.2	4	0.8	0.4	0.9	0.4	0	0	0	0	0	47
5-10	0	0	0.9	0.1	0.2	0.2	0.4	0.2	0.4	1.6	1.56	1.1	0.4	0.3	0.3	0.2	0	0.9	0	0	0.4	6
10-15	0	0	0.4	0.9	0.1	0.2	0.2	0.3	0.7	1	0.77	0.7	0.5	0.3	0.3	0.2	0.2	0	0	0	0	5
15-20	0	0.4	0	0	0.3	0.3	0.2	0.4	0.6	0.7	0.73	0.5	0.5	0.4	0.6	0.2	0.4	0	0.4	0	0	6
20-25	0	0.9	0.4	0	0.2	0.2	0.2	0.5	0.7	1.2	0.97	0.8	0.6	0.7	0.4	0.2	0.4	0.9	0.4	0.4	0	7
25-30	0	0	0	0.4	0.9	0.2	0.4	0.5	0.9	1.6	1.86	1	1.1	0.5	0.3	0.1	0.1	0.9	0.4	0	0	9
30-35	0	0	0.4	0	0.9	0.2	0.2	0.2	0.5	1.1	0.77	1.3	0.8	0.4	0.2	0.2	0.4	0.4	0.9	0.4	0.4	6
35-40	0	0	0	0	0.9	0.1	0.1	0.2	0.3	0.7	0.89	1.6	0.8	0.6	0.4	0.4	0	0	0	0	0	5
40-45	0	0	0	0	0	0.4	0.9	0.3	0.1	0.4	0.67	0.6	0.7	0.1	0	0	0	0	0	0	0	3
45-50	0	0	0	0	0	0	0.1	0.4	0.2	0.7	0.65	1	0.3	0.2	0.9	0	0	0	0	0	0	3
50-55	0	0	0	0	0	0	0	0	0.2	0.4	0.69	0.6	0.2	0.4	0	0.4	0	0	0	0	0	2
55-60	0	0	0	0	0	0	0	0	0	0.4	0.24	0.4	0.4	0	0	0	0	0	0	0	0	0
Total	0.1	0.2	0.2	0.3	1.2	1.7	2.1	3.1	5.7	13	44.4	12	6.9	4.1	2.4	1.1	0.4	0.3	0.2	0.1	0.1	100

From this analysis, five key parameters were derived to characterize the driving behavior, referred to as target parameters such as-

Percentage of Acceleration (% Acceleration), Percentage of Deceleration (% Deceleration), Percentage of Cruising (% Cruise), Percentage of Idle (% Idle), Average Speed.

This target parameters defined as follows (Nesamani and Subramanian 2011; De Haan and Keller 2004).

- Acceleration: Speed greater than 5 km/h and acceleration greater than 0.1 m/s^2.
- Deceleration: Same as acceleration except that acceleration should be negative.
- Cruising: Velocity is constant and acceleration is zero.
- Idle: Speed is zero.

For practical purposes we have considered a tolerance of ± 0.1 m/s^2 for acceleration and deceleration. These parameters ensure the accurate and realistic representation of a driving cycle. The core of driving cycle development lies in capturing the speed and acceleration patterns. Among these, acceleration plays a vital role in determining the certainty (or likelihood) of a particular event in the speed-time data. This assists in selecting highly repetitive and representative data segments on specific road sections. Using such filtering helps to reduce the length of the cycle by focusing only on significant and recurring micro-trips, thereby streamlining the development process of a representative driving cycle.

The python program (figure 8) chooses micro-trips from distinct categories, ensuring each selected trip has a minimum duration and is representative in nature. From the total K micro-trips, a subset of k micro-trips is selected based on their frequency and average speed. These selected trips are then concatenated to construct a real-time driving cycle that mimics the base trip parameters, including percentage time spent in acceleration, deceleration, cruising, idling and average speed.

During this stage, all identified "k" micro-trips are initially considered and sequenced in a manner that aligns with the base data. If the resulting driving cycle fails to match the base trip's parameters, the selected micro-trips are reordered and realigned according to their respective frequencies to ensure better conformity.

Daily travel characteristics has tabulated in table 6 for round trip from Nigdi to Bopodi and Bopodi to Nigdi. Target parameters calculated for each day. Then average parameters calculated for each route.

Table – 6: Daily travel characteristics
Route: Nigdi to Bopodi

Sr. No.	Date	Trips	Avg. Speed (mph)	Time (S)	% Acceleration	% Deceleration	% Cruise	% Idle	MTF
1	31-01-2025	4	8.91	2552	30.24	24.13	9.24	36.39	84
2	01-02-2025	4	11.9	2051	37.87	29	11.16	21.98	49
3	02-02-2025	4	13.82	1880	39.07	27.06	11.64	22.22	30
4	03-02-2025	4	13.92	1856	38.93	33.93	13.52	13.62	14
5	04-02-2025	4	7.49	3487	31.42	24.83	10.21	33.54	105
6	05-02-2025	4	10.63	2295	32.88	21.86	9.06	36.19	50
7	06-02-2025	4	13.21	1930	39.41	33.56	12.89	14.14	20
8	07-02-2025	4	10.76	2441	34.93	25.06	10.44	29.57	39
		Avg. Value	11.33	2311.5	35.59	27.43	11.02	25.96	49

Average Speed (kmph) = 18.23, Time (S) = 2311.5 = 38.53 min

Route: Bopodi to Nigdi

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Sr. No.	Date	Trips	Avg. Speed (mph)	Time (S)	% Acceleration	% Deceleration	% Cruise	% Idle	MTF
1	31-01-2025	4	15.6	1599	42.88	33.62	11.19	12.31	28
2	01-02-2025	4	11.82	2142	39.01	30.42	11.99	18.57	46
3	02-02-2025	4	8.08	1234	24.13	14.98	4.37	56.52	12
4	03-02-2025	4	12.25	2026	40.21	29.7	11.3	18.8	45
5	04-02-2025	4	8.91	2689	33.61	24.65	10.11	31.64	82
6	05-02-2025	4	10.33	1161	37.78	28.06	5.42	28.74	30
7	06-02-2025	4	8.42	3052	26.26	19.1	5.67	48.58	33
8	07-02-2025	4	9.84	2582	37.82	30.66	9.68	21.84	47
		Avg Value	10.66	2060.63	35.21	26.40	8.72	29.63	40

Average Speed (kmph) = 17.15, Time (S) = 2060.75 = 34.35 min

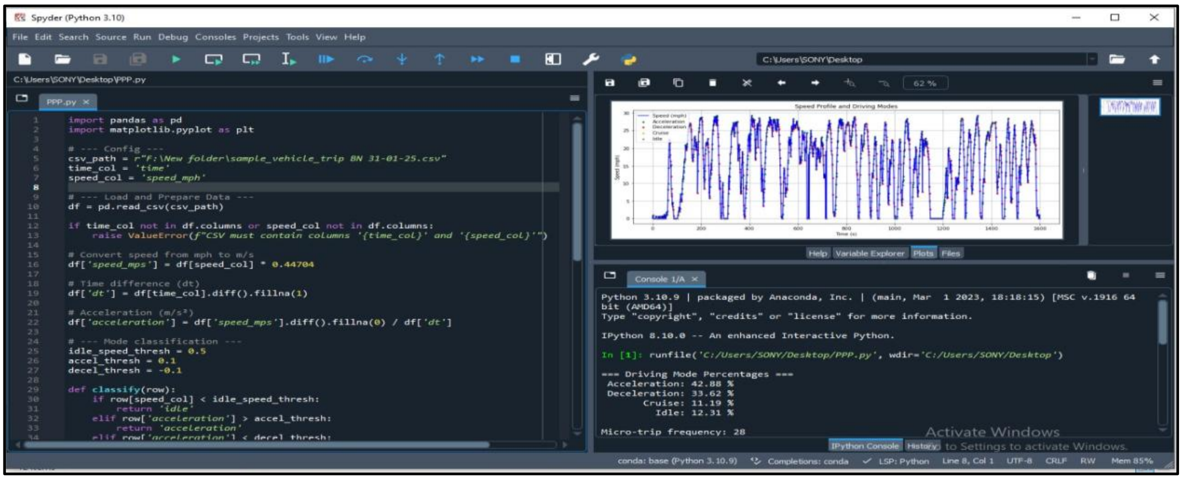

Figure – 8: Sample Python Programming with input and output

Figure 9 shows the Speed Profile and driving modes during the trip. It is a time-series plot that provides a detailed visualization of the speed behavior of an electric bus over time, along with its associated driving modes.

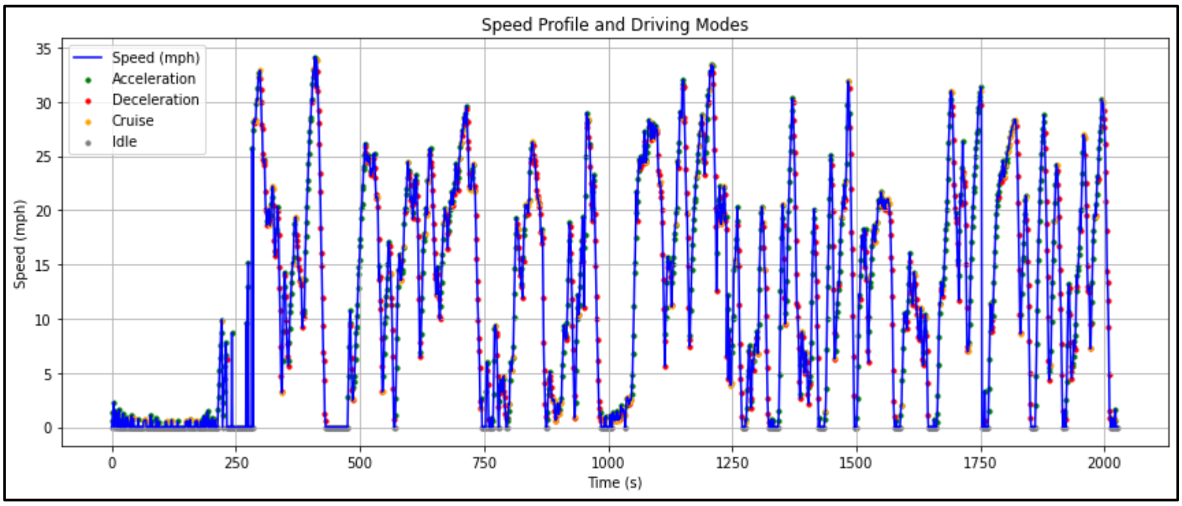

Figure – 9: Speed Profile and driving modes

Driving cycle characteristics

Table – 7: Driving mode Characteristics

Sr. No.	Route	Trips	Avg. Speed (mph)	Time (S)	% Acceleration	% Deceleration	% Cruise	% Idle	MTF
1	Nigdi to Bopodi	32	11.33	2311.5	35.59	27.43	11.02	25.96	48.87
2	Bopodi to Nigdi	32	10.66	2060.63	35.21	26.40	8.72	29.63	40
	Average Value		10.99	2186.06	35.40	26.91	9.87	27.79	44.63

Avg. Speed (kmph)	**Time (min)**	**% Acceleration**	**% Deceleration**	**% Cruise**	**% Idle**	**MTF**
17.68	**36.43**	**35.41**	**26.91**	**9.87**	**27.81**	**45**

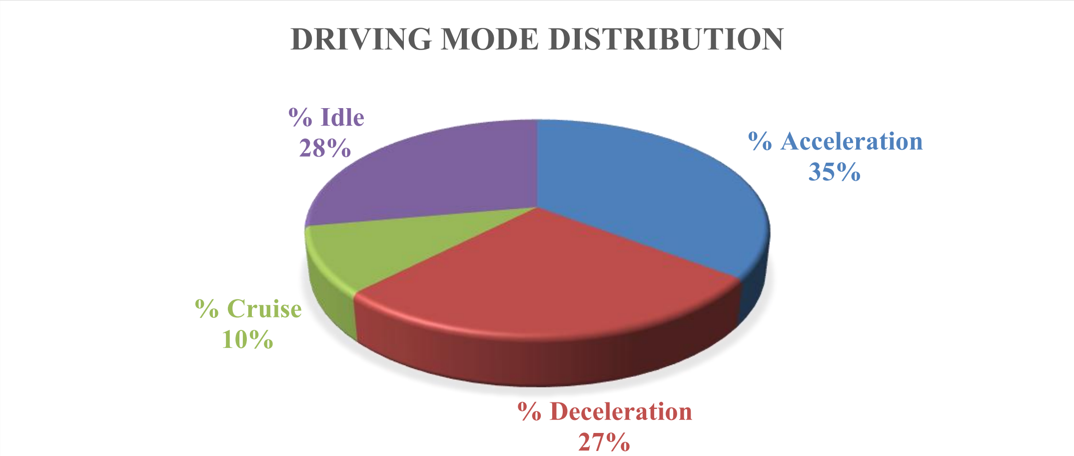

Figure – 10: Driving mode distribution

The driving characteristics and Pune Electric Bus Driving Cycle (PEBDC) were analyzed. These characteristics were then benchmarked against driving cycles from other cities to highlight regional differences. Table 8 presents a comparative analysis of five key parameters: average speed, and the percentage of time spent idling, cruising, accelerating, and decelerating. The developed Pune driving cycle is evaluated alongside several established standard driving cycles, including IDC, Surat, Dhanbad, Vietnam, FTT US, and EUDC (Bagul et al., 2021; Tong et al., 2011; Adak et al., 2016). This comparison helps to assess the suitability of existing cycles for transport planning in the context of electric bus operations in Indian urban environments.

Table – 8: Comparison parameters of all regions with IDC and worldwide driving cycle

	Pune	IDC	Surat	Dhanbad	Vietnam	US	EUDC
Avg. Speed (kmph)	17.68	21.41	17.06	13.41	19.4	11.5	33.4
% Acceleration	35.41	35.15	46.29	40.21	33.03	29.43	18.3
% Deceleration	26.91	33.39	38.28	43.5	36.17	29.26	15.8
% Cruise	9.87	16.65	9.03	7.02	21.18	10.2	42.2
% Idle	27.81	14.8	6.39	9.31	9.62	31.1	23.7

The driving cycle (DC) of electric bus is largely influenced by traffic-related factors such as traffic volume and congestion, as well as driving behavior—particularly the frequent stopping for passenger pick-up and drop-off, whether at intersections or arbitrary points along the route. These elements contribute significantly to fluctuations in vehicle movement and prolonged idling periods.

Results shows that for PEBDC, average speed was 17.68 km/h, % time in cruising was 6.78%, 11.31%, 32.33%, 0.33% lower than IDC, Vietnam, EUDC and US driving cycle and 2.85% higher than Dhanbad and 0.84% higher than Surat driving cycle. Another comparison with the PEBDC to the ECE+EUDC, showed higher % of acceleration and % of deceleration rates in the PEBDC. In the case of PEBDC, %

time in idling is higher than IDC, Vietnam, EUDC, US, Dhanbad and Surat. Due to increased idling, it was attributed to delays caused by intersection stops, passenger boarding times, and traffic congestion. The acceleration–deceleration rate reflects the aggressiveness of driving behaviour and significantly influences the vehicle's energy consumption.

6 CONCLUSIONS

Electric bus plays a significant role as Public Transport mode in India. Their operation is largely influenced by commuter demand, resulting in frequent stop-and-go movement across urban areas. This distinctive driving behavior leads to a unique driving pattern, which differs considerably from that of motorcycles or other vehicles. As a result, conventional driving cycles are not suitable for electric bus.

To address this, a region-specific driving cycle was developed for Pune city based on prevailing speed conditions. Representative test route were identified within city and real-time speed data was collected. The data was then analyzed using the micro-trip method to construct driving cycle that accurately reflect the operational characteristics of electric bus.

For Pune city driving cycle (PEBDC) has developed with a 17.68 km/h average speed.

Results shows that for PEBDC, % time in cruising was 6.78%, 11.31%, 32.33%, 0.33% lower than IDC, Vietnam, EUDC and US driving cycle and 2.85% higher than Dhanbad and 0.84% higher than Surat driving cycle. Another comparison with the PEBDC to the ECE+EUDC, showed higher % of acceleration and % of deceleration rates in the PEBDC. In the case of PEBDC, % time in idling is higher than IDC, Vietnam, EUDC, US, Dhanbad and Surat. Due to increased idling, it was attributed to delays caused by intersection stops, passenger boarding times, and traffic congestion. The acceleration–deceleration rate reflects the aggressiveness of driving behaviour and significantly influences the vehicle's energy consumption.

Abbreviations

BRT, Bus Rapid Transit; E-bus, Electric bus; EUDC, European Urban Driving Cycle; IDC, Indian Driving Cycle; kmph, Kilometers per hour; mph, Miles per hour; MTF, Micro Trip Frequency; PCMC, Pimpri Chinchwad Municipal Corporation; PEBDC, Pune Electric Bus Driving Cycle; PMC, Pune Municipal Corporation; PMPML, Pune Mahanagar Parivahan Mahamandal Limited; US, United States.

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