Development of an Optimized Drive Cycle and Power Specifications for Electric Cycle Usage

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Abstract. This research is an investigation into the development of an ideal drive cycle and power requirements for electric cycles on the Thapar Institute of Engineering and Technology Campus in Patiala, Punjab, India. The study explains the fundamental need for cost-effective, environmentally accountable transportation modes in educational campuses. The research introduces a representative drive cycle that is modified to reflect campus conditions developed based on three months of data collection, to simulate and describe energy use and efficiency of electric cycles. This study adds to the state-of-the-art for the implementation of electric vehicles specifically in educational campuses by defining the ideal power train and battery capacity necessary to operate an electric cycle effectively.

1 Introduction

India is taking a historic leading role in the international electric vehicle (EV) market. The imperative endeavor to minimize carbon emissions and reduce reliance on fossil fuels is striving for 30% of total vehicle sales to be electric by 2030 [1]. Currently being driven positively by affordable two-wheeler and three-wheeler EVs, the overall EV proposition still has work to do in terms of improving efficiencies related to costs and energy consumption [2]. Thapar Institute of Engineering and Technology (TIET) in Patiala, Punjab would be an apt case of an educational atmosphere that is leveraging its size - so as to provide opportunities to improve efficiency Table 1. Setting Word's margins.

The TIET campus is 250 acres and houses approximately 15,000 people; with 10,000 undergraduate students, the campus is a logical place to evaluate an EV solution that would operate in an educational context. As shown in Fig.1, the campus is predominantly flat with an average temperature that ranges from 5°C during the winter months to 48°C during the summer months, evoking unique challenges and opportunities for the use of an electric cycle on campus. At present, the TIET campus is governed on approximately 1500 manual bicycles, while TIET has five electric bicycles, this project will facilitate a connection, by

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providing an optimized driving schedule and determining required power and battery specifications for electric cycles, improving the timely experience of commuting.

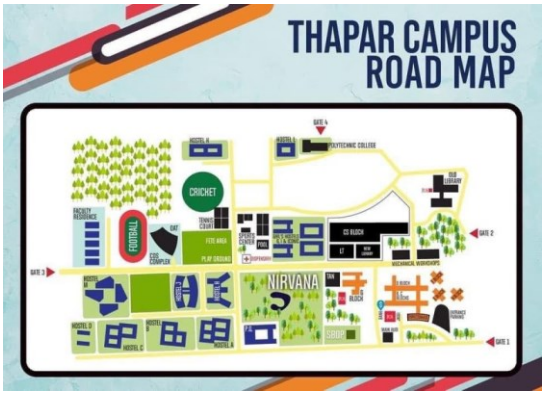

Fig. 1. Road map of Thapar Institute of Engineering & Technology.

Cycle usage data was recorded through a mobile app for a period of three months, resulting in a rich dataset by which to model energy consumption and efficiency overall. This real-world data is paramount for developing a powertrain that works with the specific needs of the campus environment, energy efficiency as well as cost-effectiveness.

2 Methodology

To understand how electric cycles perform in real-world conditions, our research team conducted extensive field testing. For this research, representative drive cycles were derived by performing actual rides both inside and outside the Thapar Institute campus using a standard electric cycle Hero Lectro C6e, shown in Fig. 2. Every day, a unique route was assigned to a different rider from the team to ensure diverse data collection. We called each individual journey a "micro trip," following established research practices [3].

- Battery - 5.8Ah 36V Li-Ion IP67 Rated
- Motor - BLDC 26V 250W Rear Hub Motor
- Mileage - 25 kms(Throttle) and 30 kms(Pedal Assist)
- Charge Time - 4 hours

Fig.2. Specifications and look of the *Hero Lectro C6e* cycle used in the study

The drive cycle was integral to accurately predicting energy consumption, optimizing the powertrain design, and estimating battery capacity. As a result of modeling real-world use patterns within the drive cycle, the motor, controller, and battery could be correctly sized as the electric cycle would operate in campus conditions where greater energy efficiency and sustainability impressions are possible, while minimizing costs. It is unlikely that the performance, range, and power demands would be accurately predicted without the drive cycle [4].

Table 1. Data parameters and their measuring units

Parameter	Unit
Rider's weight	Kg
Time	s
Altitude	m
Acceleration	m/s2
Vertical velocity	m/s
Slope	° (degree)

During these micro trips, several parameters were logged in real-time, enabling full data collection from the electric cycle's performance. The parameters that were included are listed in **Table 1**.

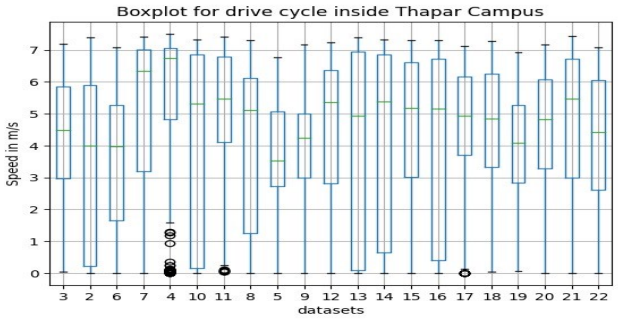

Fig. 3. Boxplot for micro trips inside campus

Data was harvested from the app, *Gauges*, for three months, with varied conditions and terrains that encompass the campus. Once data was harvested, Boxplot analysis provided a way to analyses variances from recorded parameters, and to describe how a Boxplot will help to describe variations in micro trips as well as, identify outliers and trends from the data. Boxplots can show the distribution of parameters, and assist in better descriptions of the data sets [5].

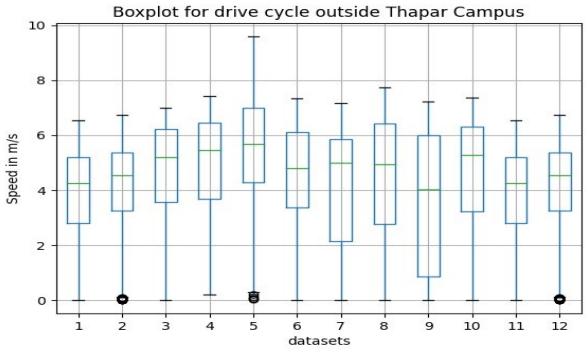

Fig. 4. Boxplot for micro trips outside campus

Fig. 3 and **Fig. 4** are Boxplots for each of the micro trips taken inside and outside campus, respectively, showing differences in speed during each of 22 different trips that involved different routes. The middle line in box plot shows 50th percentile that is middle value i.e. median and top is 75th percentile.

2.1 Derivation of drive cycle

Upon conducting analysis of the micro trips, drive cycles were created from the result of clustering similar data points into centroids with product derived clustering algorithms such as K-Means and Hierarchal Clustering. The best results came from an averaging method. The mean speeds were calculated for each time instance across all the micro trips so that average speeds could be observed during the trips [6].

2.2 Averaging algorithm

Using Python, speed and time data was extracted from each micro trip and compiled into a single Excel file, refer to Table I (Appendix). This file included a common time frame for all trips and corresponding speed values for each micro trip captured for each time instant [7]. The average speed was determined for each time instant across all micro trips to create an average drive cycle. In this way, it was already possible to observe the average speed of the electric cycle at any moment during the trips.

2.3 Calculation of average speed

Each micro trip's speed data was processed using Python and the mean speed at each time instant was calculated. The instantaneous speed was averaged across all micro trips for each time point capturing the average speed profile over time. The average viewing speed of the electric cycle was observed at that specific instant in time, while the electric cycle was on its way.

2.4 Designing the drive cycle

A systematic and complete analysis of the collected driving data was done during this analysis to develop a representative drive cycle for the local conditions at Thapar Institute. This section presents the drive cycle developed by averaging the average velocities and acceleration profiles of the observed data. Average speed and acceleration profiles produce

a representative and greatly simplified baseline cycle that can represent typical driving behaviours, thus forming a basis of comparison for the localized, optimized drive cycle. To visualize the drive cycle, a graph is plotted in Fig. 5, with speed (m/s) on the y-axis and time (s) on the x-axis. This graph represents the electric cycle's performance during typical usage across campus.

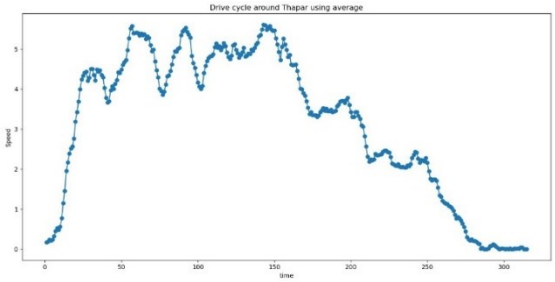

Fig. 5. Optimal Drive cycle around the Thapar Institute campus

2.5 Energy calculations

Using the concept of electric vehicle modeling, the force experienced by the cycle was calculated. The total force acting on the cycle, F_{total}, is expressed as the sum of various forces, including aerodynamic drag, inertial force, tractive force, and rolling frictional force:

$$F_{total} = F_{ad} + F_g + F_{rr} + F_{la} \quad (1)$$

where:

- F_{ad} represents the aerodynamic drag,
- F_g represents the inertial force (gravitational),
- F_{rr} represents the rolling resistance,
- F_{la} represents the tractive force (lateral acceleration).

At each time of a micro trip, the force is computed according to equation (1). Next, the power at each instance is computed using Python, as shown in Fig. 6.

The power values were extracted from each micro trip, and a new Excel file was created see Table II (Appendix), containing the power readings of each micro trip versus time. The average power for each row was then determined along each column. After the average power at each second was obtained, an average power versus time graph was plotted, shown in **Fig. 6**, using the matplotlib library in Python. **Fig. 8** summarizes the complete cycle battery and motor optimization process through a flowchart representation.

Speed	Attitute (m)	Speed (m/s)	Acceleration	Vertical velocity	Slope (degree)	Slope (rad)	Force	Power
0.12414	258.1163	.0.34483	-0.03448	0.275378	-7.54053	-0.013154	-31.7678	-1.09546
0	258.3917	0	0.017355	-0.3159	0	0	92.83469	0
0.062477	258.0758	0.017355	0.075482	-0.19	-21.09335	-0.36796	-229.335	-3.98004
0.334216	257.8878	0.092837	-0.05734	-0.018332	2.339794	0.04816	122.7305	11.39393
0.127788	257.7024	0.035497	0.058319	-0.1855	1.773358	0.030935	125.0247	4.437961
0.337736	257.5169	0.093816	-0.01801	-0.11251	-2.56643	-0.04477	48.59183	4.558669
0.272902	257.4044	0.075806	-0.07581	0.030676	0.428302	0.007471	90.54704	6.864019
0	257.4351	0	0	0	0	0	91.14	0
0	257.4351	0	0.04815	-0.59811	0	0	95.8677	0
0.174293	256.837	0.04815	-0.00137	0.063742	3.848599	0.067137	152.1488	7.366241
0.169366	256.9007	0.047046	0	0.094301	-2.15966	-0.03767	56.80412	2.672413

Fig. 6. shows the Force and power calculation.

The energy required to complete the cycle was calculated by integrating the average power versus time graph using the trapezoidal rule, equation (2).The area under the curve, or energy required, was calculated to be 46,617.65534 Joules. With a 10% error considered, the energy required would be approximately 50,000 Watt-seconds (Joules).

$$E=\int_{t2}^{t1} P(t)dt \tag{2}$$

The distance traveled in equation (3) was obtained by integrating the speed versus time graph.

$$E=\int_{t2}^{t1} P(t)dt \tag{3}$$

If a 10% error is allowed, the approximate distance traveled would be ~ 2 kilometers [9].

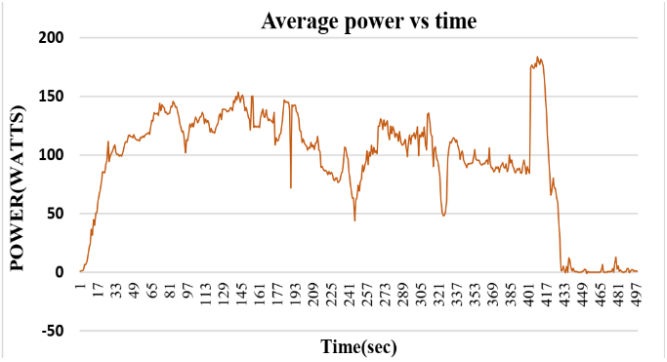

Fig. 7. Average power vs time graph plot

3 Results

This section discusses the powertrain design of the electric cycle, then battery rating and power ratings for different ranges is calculated. Lastly, the most optimum battery and motor rating values for the electric cycles in the Thapar campus are found.

3.1 Designing powertrain

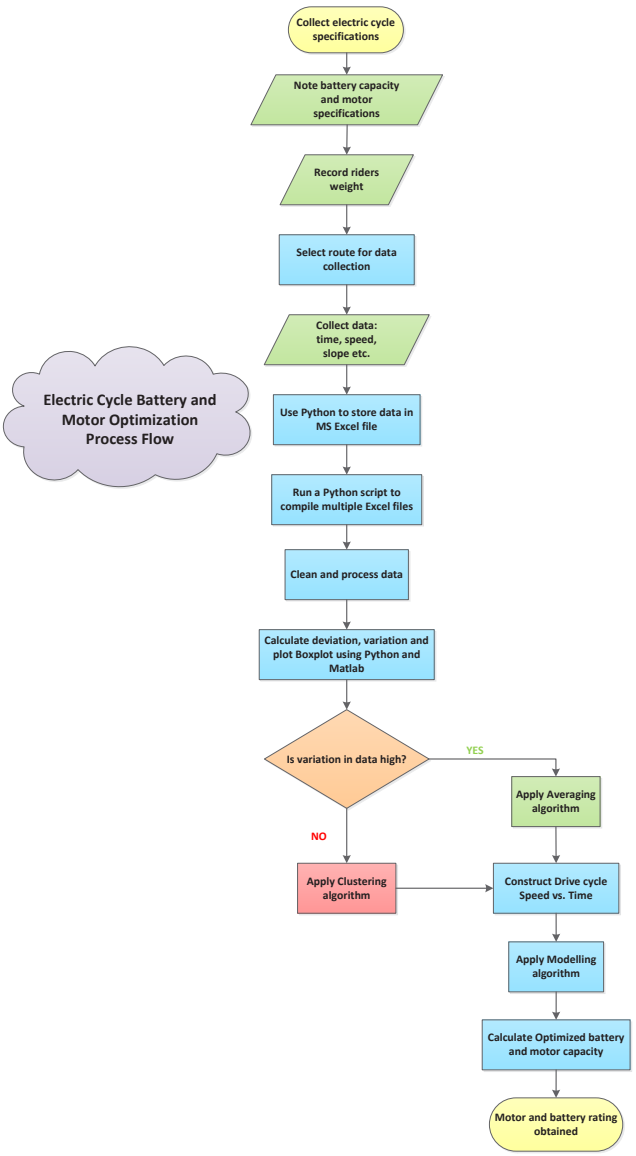

Fig. 8. Flowchart for optimizing the battery and motor of the electric cycle

3.1.1 Convert Joules to Watt-hours (Wh): Since 1 Joule (J) is considered equal to 1 Watt-second (Ws), and 1 Watt-hour (Wh) is considered equal to 3600 Watt-seconds, the energy consumption can be converted as follows:

$$Wh = 50{,}000J/3600W.s = \sim 14\ Wh \quad (4)$$

3.1.2 Convert Watt-hours to Ampere-hours (Ah): To find the battery capacity required, the formula used is:

$$Ah = Wh / Voltage\ (V) \quad (5)$$

For a battery with a voltage of 36V, the calculation is:

$$Ah = 14Wh / 36V = 0.38\ Ah \quad (6)$$

Thus, to travel 2 km within the campus, a battery with a rating of 36V and 0.38Ah is sufficient.

3.2 Battery rating for various ranges

The battery requirements for different travel distances were further extrapolated based on the energy consumed per 2 km. Battery ratings for various distances traveled are provided in **Table 2** [9].

Table 2. Battery rating with power consumption

S.no	Distance to cover (km)	Energy Joules(J)	Power (Wh)	Battery (Ah)
1.	2	50,000	14	0.38
2.	3	75,000	20.8	0.57
3.	4	100,000	27.7	0.77
4.	5	125,000	34.7	1
5.	6	150,000	41.6	1.1
6.	7	175,000	48.6	1.35
7.	8	200,000	55.5	1.54
8.	9	225,000	62.5	1.73
9.	10	250,000	70	2

3.3 Motor specifications

The highest value of average power delivered during travel was extracted using Python on the Excel sheet for the Power vs Time dataset. As shown in Fig. 9, the peak average power was calculated to be 183.8W.

```
Peak value of average power: 183.8553488 W
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Fig. 9. Calculated Average Power Requirement.

By allowing a *10%* margin for error, it can be concluded that a motor of approximately **200W** power would be required for efficient travel inside the campus [10].

4 Discussion

The analysis reiterated that developing a sophisticated drive cycle is a feasible mechanism for significantly improving the energy efficiency of electric cycles, particularly in an academic environment such as a university campus. Developing the powertrain specifications around the unique conditions and usage contexts of the campus ensures that the electric cycles are not only efficient, but practical for daily commuting. The sophisticated drive cycle accommodates the context-specific conditions of elements such as terrain, user disposition and behaviours, and other environmental conditions, which all work together for a more efficient and dependable transportation option.

This study represents an appropriate model for educational institutions, or other like environments, to plan for sustainable transportation. The research shows how a tailored approach to electric cycle usage can successfully demonstrate the potential for enhanced energy efficiency and sustainability in specific contexts.

In addition, the study focused on the important role of gathering and analyzing real-world empirical data. Real-world data pertaining to speed, acceleration, and terrain variations lead to a better and more accurate drive cycle and powertrain configuration which enhances performance and ultimately customer satisfaction levels. The study is an example of how to base transportation solutions on empirical data to better outcomes, rather than basing EV solutions on generalizations. By identifying and understanding the conditions and needs of the campus, the study provides a more accurate and useful solution, rather than a model EV solution.

5 Conclusion

This study was able to successfully develop an optimized drive cycle and appropriate power ratings for electric cycles operating at Thapar Institute. Based on the analysis and observations, a motor with a 200W BLDC (Brushless DC) rating and a battery rated at 36V, 1Ah provides an adequate range for students and faculties to travel in an efficient manner across campus. These positive specifications indicate that electric cycles can satisfy students and faculties' daily commute demands reliably while providing access to an environmentally friendly mode of transportation.

- Motor Rating: 200W BLDC
- Battery Rating: 36V, 1Ah.

The results of this research show the considerable potential of electric cycles to be sustainable transport options in academic settings. Electric cycles will reduce the reliance on fuels from conventional fuel-powered transport and reduce carbon emission while being greener for the campus. This work has addressed the need for Thapar Institute and a greater demonstration of how it can be rolled out in other educational institutions.

Future research might want to focus on scaling this model to larger campuses and urban areas, while looking at how variations in terrains and climates affect some aspects of the efficiency and operational suitability of electric cycles. Furthermore, battery charging through renewable energy and advancements in battery-size technology will also provide even greater sustainability and transportation practicality options.

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Table I and II (Appendix)

Time	Speed	Speed.1	Speed.2	Speed.3	Speed.4	Speed.5	Speed.6	Speed.7	Speed.8	Speed.9	Speed.10	Speed.11	Speed.12	Speed.13	Speed.14	Speed.15	Speed.16	Speed.17	Speed.18	Speed.19	Speed.20	Speed.21
1	0	0	0.231481	0.061394	0.105442	0.18	0	0	0	0.063442	0	0.064068	0.028876	0	0.052217	0.112972	0	0.12414	0	0.037792	0.065295	0.192331
2	0	0.109132	0.135778	0.113501	0.348091	0	0.048671	0	0	0.087028	0	0	0	0	0	0	0	0	0	0.147566	0.090184	0.234666
3	0	0.015903	0.039555	0.086196	0.086575	0	0.026914	0.004277	0.010505	0.06358	0.033522	0	0.371044	0	0.072378	0.031462	0.028452	0.062477	0	0.032639	0.151823	0
4	0	0.039801	0.032393	0.040765	0.062966	0	0.010281	0.064866	0.074761	0.186234	0.029737	0.083943	0.065539	0.040167	0	0	0.055308	0.334213	0	0.087476	0.16184	0
5	0	0.847806	0.337863	0.038643	0.313892	0	0	0.143116	0.141583	0.022778	0.077907	0	0.046681	0.092912	0.260056	0	0.120718	0.127788	0	0.87476	0.246555	0.049746
6	0	0.646895	0.84725	0.388578	0.125261	0	0.037017	0.170749	0.110022	0.233693	0.571375	0.368734	0.014303	0.070455	0.021107	0.215968	0.088885	0.337736	0	0.502845	0.388868	0.074847
7	0	1.604529	1.389038	0.707863	0.181523	0	0.119245	0.103987	0.022512	0.045716	1.719189	0.468866	0.022506	0.069036	0.081637	0.033153	0.98054	0.272902	0	0.517193	1.225489	0.843232
8	0	2.366381	1.505843	1.41757	0.242581	0	0.029122	0.010098	0	0.138863	0.15911	0.735064	0.108137	0.03582	0.16979	0.192726	0.032845	0	0	0.473709	1.582369	1.257552
9	0.2	2.914253	2.727303	1.683368	0.106314	0	0.046295	0.205459	0.025184	0.131407	0.06517	0.272189	0.223656	0.131155	0.209116	0.177918	0.020498	0	0.87	0.032111	1.992349	1.892083
10	0.35	3.00447	3.777734	2.718216	0.156064	0	0.070981	0.055011	0.023345	0.391773	0.081121	0.267396	0.193488	0.215074	0	0.230857	0	0.174293	1.88	0.073681	2.846942	2.730141

Time(sec)	Power	Power	Power	Power	Power	Power	Power	Power	Power	Power	Power	Power	Power	Power	Power	Power	Power	Power	Power	Power	Power	Power	Average power
1	-1.09546	0	1.431733	2.12581	1.094484	0	0	0	0	0.220664	1.611881	2.791128	4.134079	0	0	0	1.534221	0.652743	0	1.235381	1.726353	0	0.793774
2	0	0	5.25647	2.088137	7.226419	1.270926	0	0	3.135646	2.948483	2.850079	-3.77203	0	1.124776	0	0	2.382487	0	0	0	0	0	1.114154
3	-3.98004	0	0.755152	4.225482	0	0	0	0	0.249231	-0.25998	1.640364	2.322333	0	0.713246	0.173338	0.33513	1.485959	18.79309	0	1.726098	0.758195	0.986305	1.360177
4	11.39393	0	3.038864	4.355081	0	2.577891	0	0	1.402478	0.127737	1.065741	1.772114	0	0.253434	1.386693	2.227825	8.462795	1.676998	1.178329	0	0	1.110603	1.910478
5	4.437961	0	24.6617	10.77252	1.732072	39.58799	0	0	31.20387	2.548736	1.261257	7.512109	0	0	2.926148	2.131531	0.517731	0.68826	2.404919	4.164348	0	5.027973	6.435415
6	4.558669	0	10.55669	10.74372	2.304825	2.178632	13.09752	0	28.70275	5.15217	33.58389	11.37329	0	1.163078	3.589754	2.027549	5.245504	0.357024	1.831116	0.574321	2.710928	2.885254	6.483486
7	6.864019	0	12.2573	38.81422	21.40091	19.91437	0	0	51.60632	4.755583	15.90641	4.154889	0	2.158069	0.152856	2.478484	1.197388	0.56285	1.160184	1.709021	1.159877	2.743222	8.59068
8	0	0	5.610858	44.5505	38.30382	62.22173	5.858034	0	71.99097	5.430698	45.90699	0.340328	0	7.027476	0.268067	0	3.204926	3.131494	0.956039	3.508626	4.514122	0.828105	13.8024
9	0	24.23388	1.011936	65.12002	63.98825	47.21507	7.149462	5.657706	80.7182	29.61749	60.83628	3.297996	0	1.059844	4.440532	0.720982	3.914516	4.330555	2.84116	5.463166	35.34143	0.468891	20.33761
10	7.366241	56.47567	1.425089	68.23264	79.6647	35.28451	0	8.19648	87.19845	-6.37882	156.7882	4.1458	0	2.953093	1.331514	1.111394	10.0657	3.155206	6.86336	0	3.758803	0	23.98355