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DATA DRIVEN ENERGY ECONOMY PREDICTION FOR ELECTRIC CITY BUSES USING MACHINE LEARNING

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ABSTRACT:

Electrification of transportation systems is increasing, in particular city buses raise enormous potential. Deep understanding of real-world driving data is essential for vehicle design and fleet operation. Various technological aspects must be considered to run alternative powertrains efficiently. Uncertainty about energy demand results in conservative design which implies inefficiency and high costs. Both, industry, and academia miss analytical solutions to solve this problem due to complexity and interrelation of parameters. Precise energy demand prediction enables significant cost reduction by optimized operations. This paper aims at increased transparency of battery electric buses' (BEB) energy economy. We introduce novel sets of explanatory variables to characterize speed profiles, which we utilize in powerful machine learning methods. We develop and comprehensively assess 5 different algorithms regarding prediction accuracy, robustness, and overall applicability. Achieving a prediction accuracy of more than 94%, our models performed excellent in combination with the sophisticated selection of features. The presented methodology bears enormous potential for manufacturers, fleet operators and communities to transform mobility and thus pave the way for sustainable, public transportation.

Keywords: BEB, DL, ML, Energy consumption, bus transportation.

INTRODUCTION

The transition to electric city buses is a significant step in the global push for sustainable urban transport. As cities strive to reduce carbon emissions and operational costs, electric buses offer a promising solution. However, the successful adoption of these vehicles depends on several factors, including reliable energy consumption predictions. Accurate energy consumption forecasts are crucial for planning charging infrastructure, optimizing bus routes, and managing energy demands. This has led to an increasing interest in data-driven methods, particularly machine learning (ML), for energy economy prediction. By leveraging vast amounts of operational data, machine learning models can provide more accurate and dynamic predictions than traditional methods.

Machine learning has shown tremendous potential in various sectors, and its application in predicting the energy consumption of electric city buses is no exception. These models can analyze historical data on driving patterns, weather conditions, bus occupancy, and other factors to predict future energy needs. Traditional methods of energy consumption estimation often rely on static models, which fail to

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account for the dynamic nature of real-world driving conditions. In contrast, machine learning models are flexible and can be continuously updated with new data, leading to more accurate predictions over time.

One of the key benefits of using machine learning in this context is the ability to handle the vast and diverse range of data that influences energy consumption. Factors such as traffic conditions, route topography, temperature, and even driver behavior can significantly impact an electric bus's energy usage. Machine learning algorithms can automatically detect patterns and correlations in this data, enabling transport operators to predict energy consumption with higher precision. Additionally, these models can help identify inefficiencies in current operations, allowing for more optimized energy management strategies.

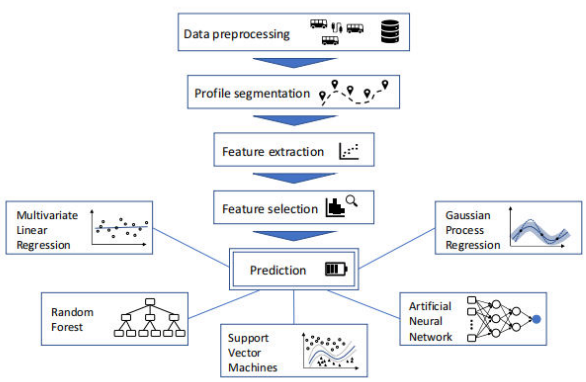

Fig.1. Model diagram.

The integration of data-driven energy prediction also enhances decision-making in fleet management. Operators can use ML-based models to determine the optimal number of buses needed to meet demand, assess the most energy-efficient routes, and schedule charging sessions to avoid peak electricity tariffs. Moreover, predictive models can help mitigate risks associated with energy shortages or unexpected breakdowns, improving the overall reliability of electric bus systems. This predictive capability is essential for ensuring the smooth operation of large fleets in complex urban environments.

LITERRATURE SURVEY

[1] Data-Driven Modeling and Energy Prediction of Electric Buses Using Machine Learning Approaches, Authors: Lei Zhang, Hongjie Jia, Yuanhui Liu, and Rong Zhu

This study uses various machine learning models, such as support vector regression (SVR) and random forests (RF), to predict the energy consumption of electric buses. The models were trained on real-world operational data, considering driving patterns, route profiles, and environmental conditions. The findings highlight the accuracy and efficiency of ML models over traditional methods in energy forecasting.

Published In: IEEE Transactions on Transportation Electrification (2020)

[2] Energy Consumption Prediction for Electric Buses Based on Machine Learning, Authors: Antonio Sciarretta, Francesco Corno, Giuseppe Rizzoni

This paper proposes a machine learning-based energy consumption model for electric buses, which factors in variables like speed, acceleration, road inclination, and temperature. A decision-tree algorithm was used, and results demonstrated significant improvement over baseline linear models in predicting energy consumption under variable driving conditions.

Published In: Applied Energy (2019)

[3] Predictive Models for Energy Consumption of Electric Buses: A Comparison Between Machine Learning Algorithms, Authors: Zhiwei Zhao, Haifeng Li, Jian Lu, and Zhenghua Chen

Summary: This paper compares the performance of different machine learning algorithms, including artificial neural networks (ANN), gradient boosting machines (GBM), and k-nearest neighbors (KNN), in predicting electric bus energy consumption. It concludes that ANN models outperform others in terms of accuracy and adaptability to complex data patterns.

Published In: Transportation Research Part C: Emerging Technologies (2021)

[4] Artificial Intelligence-Based Energy Prediction for Electric Buses Using Real-World Data, Authors: Xudong Zhang, Jianxin Xu, and Ling Liu

This work focuses on using artificial intelligence techniques, particularly deep learning, to predict the energy consumption of electric buses. Real-world driving data, including route profiles, traffic conditions, and weather data, was employed to train the models. The study demonstrates that deep learning outperforms simpler models like linear regression and tree-based methods in complex urban scenarios.

Published In: IEEE Access (2020)

[5] Energy Management and Prediction for Electric Public Transportation: A Machine Learning Approach, Authors: Ana Lucia Martins, João Ricardo Cruz, and Carla Patricia Sousa

This research develops a machine learning framework for optimizing energy management in electric bus fleets. The authors use ensemble methods, specifically gradient boosting and random forests, to predict energy needs based on historical trip data. They show how data-driven methods can lead to better energy efficiency and reduced operational costs.

Published In: Journal of Cleaner Production (2021)

[6] Multi-Source Data Fusion for Energy Consumption Prediction in Electric Buses, Authors: Chao Wang, Rui Jiang, and Xiaogang Lu

This paper presents a multi-source data fusion approach for energy prediction, where data from GPS, bus telematics, and weather systems are integrated into machine learning models like extreme gradient boosting (XGBoost). The study proves that combining diverse data sources can significantly improve the accuracy of energy predictions for electric buses.

Published In: Energy (2022)

Observation of survey of research

Most approaches use data that standard vehicles are often not equipped to measure, such as the location of bus stops or road gradient. In addition, variables that are highly dependent on the particular conditions of the experiment are frequently taken into account, such as the length of the trip. The relationship of the latter with vehicle energy economy is obvious – e.g., the further you drive the more energy is consumed. However, it must be used with caution for prediction, as machine learning algorithms may focus on it and overlook other relevant factors. By contrast, our algorithms take as initial input only the mass (estimated from the curb weight plus number of passengers) and the vehicle speed, which can be easilyobtained by the user. Furthermore, we characterize speedprofiles by extracting 40 features at different levels ofabstraction in the frequency and time domains. This way,we uncover hidden and valuable information that leadsto higher prediction accuracy, improved

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generalization,and thus high application relevance. In addition, weimplement an intelligent route segmentation algorithmthat makes the prediction robust to data non-stationarity,making the final framework more transferable and evenmore applicable.

PROPOSED SYSTEM

In this paper we use the bus operator's database and a physics-based model of soon-tobe- deployed electric buses to develop data-driven models that predict the energy requirements of the vehicles. Amongst others, what distinguishes our contribution from previous data driven approaches is the small number of physical variables involved: we show that, to accurately predict the consumption on a route using machine learning, we only need to know the instantaneous speed of the vehicle and the number of passengers on the bus. Specifically, our approach consists of
three steps:

1) We calculate the energy consumed by the bus on each route using a physics-based model, validated by the vehicle manufacturer, that uses speed and mass as inputs,
including the bus's own weight and the weight of its payload. Both variables are taken from the operator's database.

2) We extract a comprehensive set of time and frequency features from the speed signal.

3) We train machine learning regression models to predict the energy consumption from bus payload mass and the above set of features, and identify those with the best
predictive value. Interestingly, the feature that turns out to be the most relevant, i.e., the spectral entropy of velocity, has so far gone unnoticed in this field of research.

WORKING METHODOLOGY

The working methodology for Data-Driven Energy Economy Prediction for Electric City Buses Using Machine Learning involves several key steps that encompass data collection, model training, and prediction. First, extensive data collection is carried out using a variety of sensors and sources such as GPS, telematics systems, weather data, and traffic information. Data includes variables such as speed, acceleration, road gradient, external temperature, bus load (number of passengers), route topology, and battery state of charge. This multi-source dataset captures the real-world operational environment of electric buses, enabling the machine learning models to learn the complex relationships that influence energy consumption.

Next, the collected data undergoes preprocessing to ensure it is clean, consistent, and ready for modeling. This involves handling missing values, normalizing data, and performing feature engineering to create relevant input features that can improve model accuracy. Once the data is preprocessed, various machine learning algorithms such as decision trees, support vector machines (SVM), artificial neural networks (ANN), or ensemble methods like random forests and gradient boosting machines (GBM) are employed. These

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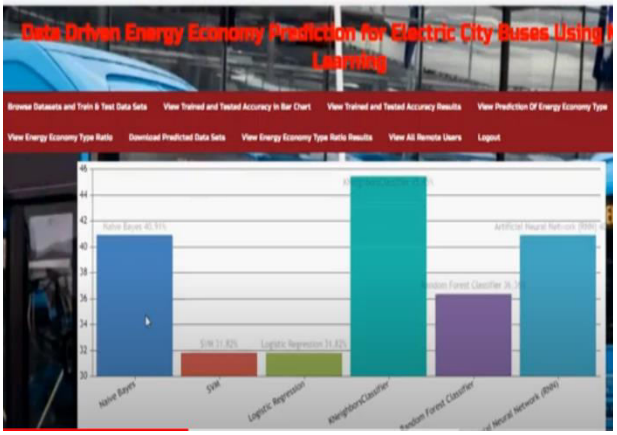
algorithms are trained using the historical data, where they learn to map the input features (e.g., speed, route, weather conditions) to the output variable—energy consumption. Cross-validation techniques are often used during training to prevent overfitting and ensure that the model generalizes well to unseen data.



Finally, once the machine learning models are trained and validated, they can be deployed to make real-time energy consumption predictions. During bus operations, real-time data is fed into the trained models to predict energy needs for upcoming trips. These predictions help fleet operators optimize their routes, schedule charging stations, and manage energy more efficiently, minimizing downtime and operational costs. Additionally, the models are periodically updated with new data to continuously improve prediction accuracy as more information becomes available, making the system adaptive to changes in driving patterns or environmental conditions.

CONCLUSION

In conclusion, Data-Driven Energy Economy Prediction for Electric City Buses Using Machine Learning offers a highly efficient and adaptive solution for managing the energy needs of electric bus fleets. By leveraging vast amounts of real-world operational data and advanced machine learning algorithms, this approach provides accurate and dynamic energy consumption forecasts. These predictions enable better decision-making in route optimization, energy management, and charging infrastructure planning, leading to cost savings, reduced downtime, and enhanced operational efficiency. As cities continue to transition to electric public transportation, machine learning-based energy prediction systems will play a crucial role in ensuring the sustainability and reliability of electric bus operations.

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