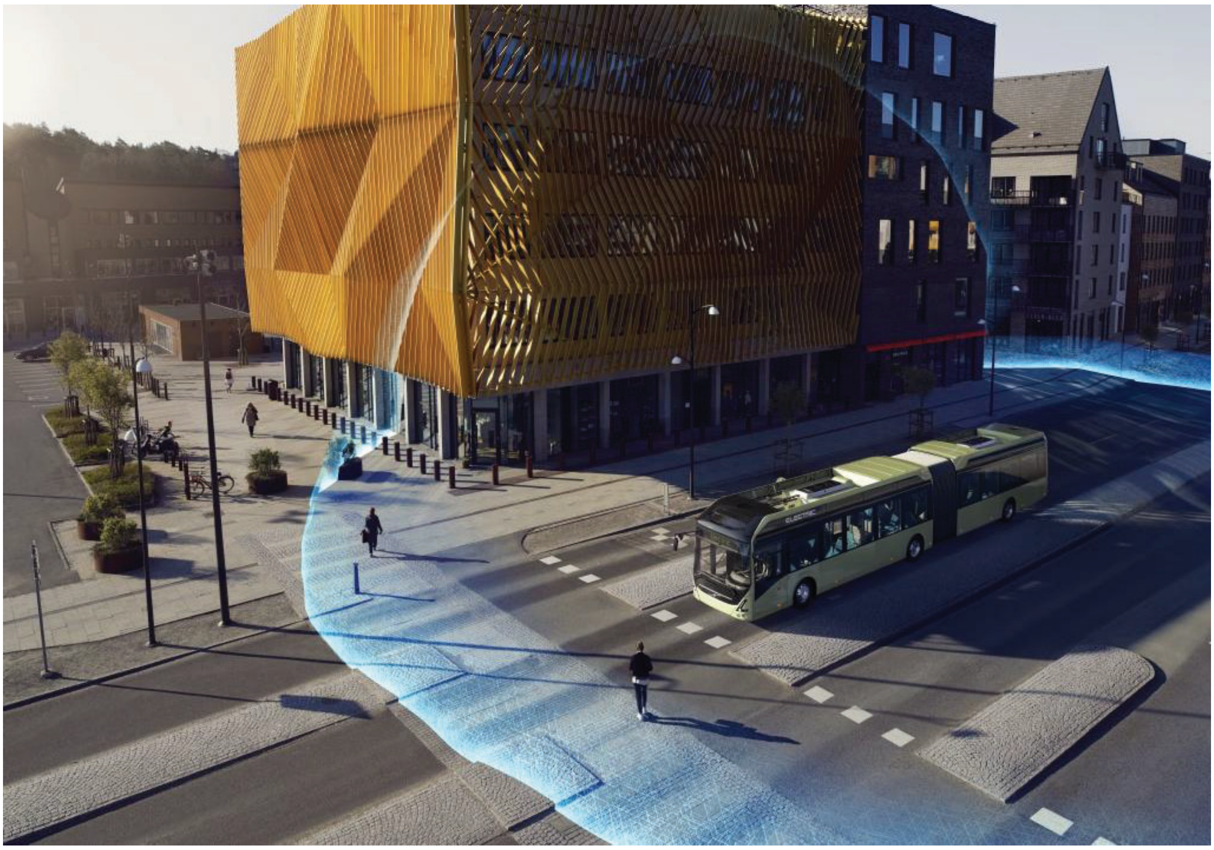
EVE

Extending life of Vehicles within Electromobility era



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Partners: Volvo Buses (VBC), Volvo Group Connected Solution (VGCS), Halmstad University (HH)

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A project within FFI: Effective and connected transport system

FFI Fordonsstrategisk Forskning och Innovation

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1 Sammanfattning

EVE projektet har varit ett forskningsprojekt för att utforska användandet av data, data-analys och maskininlärning för att förlänga livslängden på elektrifierade fordon. Projektet har fokuserat på de mest kritiska komponenterna i den elektriska drivlinan såsom batteri, styrenheter, hårdvara för laddning och laddinfrastruktur. Att förlänga livstiden på dessa kritiska komponenter för tunga fordon ger stor positiv påverkan på fordonets totala kostnad, både i ekonomiska och miljömässiga termer.

Projektet har utforskat olika tekniker och metoder. Transfer Learning metodik har använts för att använda lärdomar från hybrid bussar in i nyare generationer för att signifikant förbättra modeller för beräkning av batterihälsa jämfört med klassiska övervakade regressionsmodeller. Projektet har även använt maskininlärning för att skapa algoritmer för prediktivt underhåll av drivlinan vilket möjliggör snabbare identifiering av fel och skapar möjligheter för förlängd livstid av fordonet. Projektet har även använt FLAML för att träna modeller på högfrekvent positionsdata för att prediktera energiförbrukning hos elektrifierade bussar under olika körscenarion, vilket har gett en ökad kunskap kring kritiska komponenter och deras bidrag till energiförbrukningen

Resultaten har implementerats och delats på olika sätt inom organisationen. En del har presenterats som rapporter till ledning och ingenjörer inom området. Fokus har varit att dela kunskap och insikter för att utveckla produkter och tjänster för utökad fordonslivslängd. Modeller för hälsobedömning av de elektriska komponenterna har implementerats i Volvos monitorerings tjänster, där de idag används för att förutspå fel och möjliggöra prediktivt underhåll vilket skapar bättre fordonstillgänglighet och lägre slitage på viktiga komponenter för Volvos kunder.

I tillägg har projektet resulterat i flertalet publikationer med bidrag till teoretisk forskning på domänanpassning, vidareutveckling av metoder och applicerad forskning inom modellering för hälsobedöming av elektriska komponenter. Genom detta samarbete har två Doktorsdisputationer planerats for kommande år och en licentiats avhandling har framgångsrikt genomförts. Projektresultatet har även presenterats vid flertalet nationella och interna konferenser och även nått ut inom AI Swedens nätverk.

Projektet har pågått under fyra år från 01-05-2019 till 30-04-2023. Projektpartners har varit Volvo Bus Corporation (VBC), Volvo Group Connected Solutions (VGCS), och Halmstad University (HU).

2 Executive summary in English

The EVE project has been a research project to explore the use of data, analytics, and machine learning to prolong the lifetime of electric vehicles. In this endeavor, the project has focused on the most crucial components of an electric drivetrain, such as the battery, ECUs, charging hardware, and charging infrastructure to identify potentials to extend the lifetime of the components. Extending the lifetime of these vital components will in turn have a large impact on the total cost and environmental impact of electric vehicles, as the drivetrain and energy storage systems stand for a significant amount of the cost and environmental footprint of the heavy-duty vehicles.

During the project, we have investigated different techniques and methods. For example, Transfer Learning methods were utilized to transfer insights from the older hybrid buses into newer generations, providing a significant increase in the ability to calculate and model Battery State of Health over classical Supervised Regression Models. The project has also utilized Machine Learning methods to create predictive maintenance algorithms for the drivetrain, enabling faster identification of errors and, therefore, a longer lifetime of the vehicles. The project has also used FLAML to identify and train models on real-world data to predict the energy consumption of full-electric vehicles in different driving scenarios, giving insights into critical components and drivers of consumption in the vehicles.

The results have been implemented and shared in different ways. Some were provided as insight reports to engineering and management, providing experts with new knowledge to develop products and services that can increase the lifespan in future generations of the products. Other models that work on the status of electric components have been implemented in Volvo Monitoring Systems to directly provide customer and societal benefits in terms of earlier identification of potential errors, allowing for less downtime and lower wear on subsequent components.

Additionally, the project has resulted in several high-quality publications with contributions to theoretical research on domain adaptation and evolutionary methods and applied research in modeling the state of health estimation of electric components. Due to this collaboration, two Ph.D. defenses are planned for the coming year, and one licentiate thesis has been successfully disseminated. The project results have been presented at several national and internal conferences and outreached to the AI Sweden community.

The project carried on for four years, from 01-05-2019 until 30-04-2023. Project partners were Volvo Bus Corporation (VBC), Volvo Group Connected Solutions (VGCS), and Halmstad University (HU).

3 Background

The EVE project played a crucial role in promoting the widespread adoption of electric vehicles, contributing to the development of a sustainable and environmentally friendly interconnected transportation network. The transition from fossil fuel to electromobility is well underway and accelerating, all actors, e.g., OEMs, fleet managers, drivers, and workshop technicians, will be affected. The OEMs need to create new services to match end users' expectations, e.g., increasing uptime for electric components, since they are costly equipment. The EVE project focused on monitoring city and intercity buses, where the penalties for not adhering to the schedule are also quite high. Therefore it is important that all actors involved in transportation services prioritize maintaining these vehicles to optimize their performance. In practice, Uptime is becoming a prerequisite in the sales of buses which plays an important role in the competitiveness of Volvo as a Swedish manufacturer in both domestic and international markets.

The introduction of new electrical components means entering new, less well-known territories. For example, operating conditions, e.g., types of operation or temperature, can have a huge impact on accelerated component wear in electric drive-line. A technological shift in this transition poses challenges to most actors since the sector lacks experience with these new technologies. Moreover, those risks are even higher in complex connected systems since new and unexpected interactions between actors can magnify even minor issues. For example, developing a service that works on an electromobility ecosystem needs to incorporate knowledge from charging infrastructure, safety aspects, and vehicle conditions. This even becomes more challenging because not only workshop technicians are not yet familiar with symptoms of various faults, but also the drivers' inexperience with using the electric driveline leads to usage patterns that may accelerate component wear.

Drive batteries of hybrid and fully electric buses are a good example of this challenge. Optimizing these components' deployment, usage, and maintenance requires a better understanding of the component's health under diverse operational settings. Such batteries are expensive, and prolonging their effective life is crucial to achieving a sustainable transportation system, low-cost operation, and market satisfaction. Two critical concerns of this component are reliability and longevity, which must be addressed before electromobility becomes an economically viable alternative for diesel on a large scale. It is important to keep in mind that the solutions should be adaptable to different providers of drive batteries.

That is to say, the reliability and longevity of this expensive component are the two critical concerns that must be addressed before electromobility becomes an economically viable alternative for diesel on a large scale. Continuous changes and improvements of the batteries challenge the experts and statistical models currently in use. Today, lack of experience and historical data means there is large uncertainty related to the total cost of ownership, which is a very serious risk for OEMs. Therefore development and delivery of scalable support in predictive and prescriptive maintenance have become particularly critical in this sector.

Managing the health status of the Energy Storage System (ESS) is crucial to improve the reliability and longevity of electromobility. Predicting the State-of-the-Health of the batteries in ESS and tracking its deterioration process allow fleet operators to manage the maintenance scheduling better. One of the challenges we addressed in the project is dealing with the vehicle population's heterogeneity with domain adaptation since the operating condition, geolocation, and tasks assigned to EVs in different fleet varies. Models trained on a specific EV population might not perform well when forecasting prediction for a significantly different population, i.e., the models do not directly adapt and transfer to a satisfactory state. Therefore, transfer learning techniques like domain adaptation has been employed to mitigate the difference in modeling and forecasting of SOH deterioration. Another good example application is to detect drastic changes in contactor wear since it is a vital component of the energy supply. The efficiency reduces if a worn-out battery contactor is not replaced early enough. Aligned with the focus on ESS, analyzing the energy consumption patterns is of interest to understand the usage of EVs, and the result is useful for planning the charging infrastructure, grid management, optimizing energy consumption, and the cost for EV's operation. To address the challenges mentioned above, domain adaptation, invariant feature selection, evolutionary programming, and fleet-based approaches were employed for the applications mentioned above.

4 Purpose, research questions, and method

The general purpose of the EVE project is to help build and deliver services that will greatly improve support for the electromobility market and lead to a higher acceptance rate of the new technologies, e.g., monitoring the electric driveline, understanding the usage pattern of the vehicles and their impact on the degradation of the components. In the project, we investigated relevant state-of-the-art scientific methods, developed a few new methods, and explored different variations. The main research question that motivates the EVE project is: **how to develop a framework that enables effective monitoring and extending the lifetime of the electric driveline components based on available data?** We have proposed and decomposed into a few sub-research questions:

- Can we produce a robust state-of-health estimator for batteries in electric buses via invariant features selection or domain adaptation methods?
- How can transfer learning (or domain adaptation) be utilized to estimate the health status of the electric driveline component in heterogeneous fleets of vehicles?
- How can evolutionary computing be used to optimize the SOH estimations of the batteries?
- How can vehicle usage patterns be utilized for understanding and forecasting energy consumption efficiency?

The methods we have employed for finding the solution to the research questions are based on inductive reasoning, performing analysis on data acquired from the real-world operation of EVs, and making conclusions based on the analytical results.

We have explored the following:

1) **Survival analysis to learn the distinctive characteristics of the population of the vehicles given battery replacement strategy.** A Random Survival Forests model was used to learn the survival probability of batteries in hybrid buses [14]. Such a model captures the information related to battery replacement strategies. The proposed method utilizes the model to find different survival patterns in its predictions, representing vehicle subpopulations with distinctive survival behaviors. A proxy model and Shapley values were then used to explain the characteristics of such subpopulations. The explanations provided insights into the factors that led to the replacement decisions in different scenarios.

2) **Classification and regression methods such as random forest and neural networks for modeling end of life and remaining useful life of the components.** We have trained classification and regression models (e.g., random forest, extreme gradient boost, ridge regression, nearest neighbor-based methods, and neural networks, etc.) for performing machine prognosis, i.e., predicting failures in a given future time frame and forecasting time to failure (remaining useful life prediction) for equipment. A few studies on training regression models for estimating the state of the health (SOH) of the batteries and the degree of wear of contactors were conducted [1, 5, 8]. Furthermore, studies on using distance to the peers features were conducted and explored for estimating the remaining useful life of equipment under both traditional machine learning and transfer learning settings [2]. Classification models were trained to predict component faults or failures [3, 6, 7, 9, 10].
3) **Evolutionary algorithms and causal inferences for selecting domain invariant features so that the models become robust with configurations and operating conditions changes.** We have explored a few well-known feature selection methods and a state-of-the-art causality-based method in predicting SOH under a few transfer learning settings, e.g., testing models training from single- and double-decker buses on articulated buses. The experiment result shows that although the evolutionary algorithm outperforms well-known and causality-based approaches in selecting sets of features predicting SOH for the batteries when generalizing to an unseen domain from multiple source domains, it shows increased variations in feature selected w.r.t. other methods. We have also explored several settings [4, 11] in applying evolutionary algorithms as a surrogate method searching for suitable loss functions for training regression models for predicting SOH values. The result shows clear improvements when the specialized loss function was adopted in the training process. It is discovered the loss functions that underweighs the outliers in the training process perform the best.
4) **Domain Adversarial Neural Networks for estimating the health status of the batteries in a robust manner, adapting the regression model to multiple different domains.** The proposed method [8, 12, 13] finds a common latent feature space that has predictive power for the regression task, and the health status of the components was estimated. With a loss function based on Pairwise Similarity Preserver, the proposed domain adaptation method for regression under conditional shift (DRAC) outperforms a few popular approaches in predicting SOH for EV in a novel domain that is not included in the training population. Different from the invariant feature selection approaches proposed using a set of robust features for various domains, the DRAC projects features of different domains into a shared latent feature space, minimizing marginal distribution between the domains and preserving the predictive quality for SOH regression. DRAC is considered to be more flexible and adaptable, while the approach utilizes invariant features that are straightforward and easy to implement for real-world deployment. It is discovered that feature extractors that can preserve the geometrical relations between samples for each domain and can reduce the differences of marginal distribution across various domains perform the best.
5) **Clustering-based approaches for finding energy consumption patterns over different populations and employed fleet-based approach for forecasting energy efficiency.** The proposed approach utilizes clustering methods to group vehicles with similar energy consumption patterns. It is observed that, based on fitted parameters using polynomial models for modeling energy consumption of subsystems in the vehicles, the clustering resulted in reduced variations in energy efficiency estimation for each group. The fleet-based approach is essentially based on divide and conquer, i.e., training a few compact and domain-specific models for each sub-fleets of homogenous vehicles, and forecasting the prediction, instead of training a huge model for the entire population of heterogeneous vehicles. The clustering of sub-fleets is performed based on using polynomial models for learning the representation of each vehicle. A few regression models were tested for energy efficiency prediction. With experiments on analyzing the energy consumption of full-electric buses, we have concluded that using a fleet-based approach based on clustering similar vehicles into a grouping for

modeling outperforms traditional approaches. It is discovered that using representations comprising each sub-system's usage pattern performs best.

5 Goal

Following the list of objectives stated in the application and the objectives achieved in the project:

Goals stated	Detailed goals achieved
Methods & services for battery monitoring and extending its lifetime	☑ Identified relevant parameters for monitoring batteries ☑ Created pre-processing pipelines ☑ Developed models for predicting the lifetime of each individual battery ☑ Developed models for predicting the replacement strategy for battery ☑ Familiarized with usage patterns of drive batteries ☑ Proposed a solution for extending the lifetime of one of the generations of batteries installed in hybrid buses
Monitoring of other critical components of electric driveline	☑ Modeled wear of battery contactor ☑ Investigated failure detection for bus doors
Fully automatic monitoring of new components based on transfer learning	☑ Domain adaptation (DA) between different vehicle types ☑ DA between different battery generation ☑ DA between different countries ☑ DA between different age groups ☑ DA between data-driven grouping
Support for drivers and operators in their daily routines to take full advantage of electromobility	☑ Created a service for enhancing the estimation of end of life of batteries ☑ Created charging insight reports for drivers and operators ☑ Communicated the methods and results with Volvo Monitoring Center

As shown in the table above, we have successfully carried out several research directions which matched the project's goals. Below is a list of a few items which deviated from this project connected to the stated goals. Some of these items can develop into future collaborations:

- **Proposed a method for extending the lifetime of batteries for full-electric buses.** We haven’t proceeded with this research question since there are no good health indicators when it comes to full-electric vehicles. Most of the state of health parameters of batteries offered by battery manufacturers don’t capture different usage patterns.
- **Monitoring other critical components in electromobility, such as an electric motor.** We have created a prioritized list of critical components, and during the project, we covered two of these components. This research can be potentially extended to other critical components, especially since aging of these components provides more examples of failures.

- **Developing transfer learning services.** We have shown that domain adaptation can improve the state of health and end-of-life modeling since there is a large variation in the usage of Volvo buses. The next step is to develop a service based on these results, which remains as future work.
- **Investigating energy consumption and charging patterns.** Analyzing the energy consumption and charging pattern were not part of the original proposal, but we decided to work on it because of its connection to end-of-life modeling.
- **Domain adaptation between electric buses and electric trucks.** This is out of the scope of this project. However, since electric buses have been operating a lot longer than electric trucks, this seems like a natural extension that we should try in the future to better estimate the state of the health of batteries in younger vehicles.
- **Connecting electromobility actors in Sweden.** This is again out of the scope of this project. However, we have reached several conclusions about best practices connected to charging of buses which could be shared with other actors such as electric grid providers and legislation parties. This can be potentially developed into a future research project.

6 Results and goal achievement

We have contributed to the FFI goals as follows:

- The project was one of the pioneers in adapting to electromobility in society. The knowledge gained positioned Swedish industry and research as leaders in data-driven electromobility research and created opportunities for competitive research and innovation environments. The technological advancements of ML and AI in this project make it a good example of how advanced technology can be applied in real-world applications.
- The proposal aimed to achieve a greener and more sustainable future for the Swedish automotive industry by combining state-of-the-art ML research with predictive maintenance and electric driveline modeling. This has been achieved by mapping the normal operations of vehicles with the degradation patterns of components.
- Predictive maintenance can help create a more sustainable society by prolonging the life of vehicles. Additionally, this positively affects society since it leads to fewer traffic disruptions and increased safety. Accurate monitoring of component health is especially crucial for highly toxic components such as batteries.
- Better digital infrastructure, which has been developed during the project, allows for the collection of more relevant data from connected vehicles and helps service and planning operations, leading to higher efficiency. New solutions based on analyzing data and artificial intelligence allow for close monitoring of assets and fast reaction times, and so are critical for the wide acceptance of electromobility.
- Electromobility leads to a change in how we see and use vehicles. It has greatly sped up the shift from the current hardware model employed by most OEMs towards a more service-oriented model.

In the rest of this section, we will align the results of the project with work packages:

WP0: Knowledge dissemination and project management
The scientific results of the project have been disseminated through 14 articles published and presented in various journals and conferences. Although the number of articles matches the initial promise made in the proposal, the portion between the number of journal and conference papers differs. There are two journal publications and 12 conference papers. Two Ph.D. defenses are planned for the upcoming year, and one licentiate thesis has already been successfully disseminated. Practical results have been presented both internally and externally to interested audiences. We have organized several events to reach a broader audience, as listed in Section 7.1.

WP1: Extending battery lifetime

In WP1, the focus was on battery parameters and medium frequency data from hybrid buses. The project investigated State of Health parameters together with utilization figures from the buses to investigate the validity of the State of Health (SoH) parameters presented by the manufacturers. The approach of combining the different data-sources was novel and Machine Learning methods were used to estimate the degradation patterns and identify correlations in the data between the different data-points. The results were shared with engineering and initiated separate investigations and discussions with manufacturers to create SoH variables with higher quality and dependency for future applications, effectively increasing the battery lifetime.
The project also investigated events in the battery and driveline as the battery approached the calculated End of Life (EOL). The project investigated the effect on the vehicles as the battery health degraded, and was able to identify some software implemented limitations that could be adjusted to extend the vehicle lifetime. Utilizing the Machine Learning models and learnings from the State of Health analysis the project was able to better predict when EOL would occur, increasing accuracy in purchasing predictions and lessening the demand on the supply chain.

WP2: Prescriptive maintenance for complete electric driveline
This WP is responsible for predicting the wear of the components in electric vehicles when they are operating in a different situation or when they have different configurations. We have used Domain Adaptation (DA) to reduce the differences in the distribution of data between different domains. In particular, we have created models for predicting “the state of health (SOH) of a vehicle's battery” and “wear of contactor” based on sensor readings from multiple heavy-duty buses operating in different domains. In this analysis, we have considered six domains: Vehicle type (single-decker, double-decker, articulated), Battery generation, Countries, Placement of equipment, Age Group (Yearly), and data-driven grouping.
The results show that the model trained on several domains using DA can achieve better results than the model only trained on the target environment. This is mainly because of capturing the data diversity using DA and creating a more robust model with regard to distribution shift. Of course, this is only useful when we have a distribution shift between domains. For example, we have learned that there is no need for domain adaptation with regard to the placement of the equipment in a single vehicle. Another important assumption for the usefulness of DA is that there is not enough data in the target domain in a way that we can train a good enough model from scratch. For example, you might have an order of magnitude less data for vehicles that are older than a certain threshold.

WP3: Connecting actors through interactive service
We have presented the knowledge to engineers from Volvo Group, particularly the electromobility group in group truck technology and bus monitoring center. Additionally, we had a discussion with battery suppliers to understand the parameters for monitoring batteries. We have been in contact with public transportation planning providers to connect multiple actors throughout the industry.

WP4: Understanding patterns of vehicle usage
In WP4, vehicle groups were clustered based on the degradation of battery state of health (SOH). Random Forest Regression was utilized to model SOH, and features from the proximity matrix were used to compare the behavior of two buses throughout their lifetime. This approach enabled comparisons of similar buses in different countries, similar buses with different battery generations, and buses within the same fleet but with different operations. Additionally, Random Survival Forest was applied to identify the distinctive characteristics of the hybrid bus population in relation to battery replacement strategies. The proposed method revealed different survival patterns, representing vehicle subpopulations with unique survival behaviors. To explain the factors influencing replacement decisions in various scenarios, a proxy model and Shapley values were utilized. Furthermore, a data-driven grouping of vehicles was achieved by creating a representation of SOH per bus from sensor data and clustering similar vehicles in the representation space. Subsequently, the health indicator for each cluster was modeled, enabling the comparison of testing units to these cluster centers and making predictions on the health indicator.
As part of Work Package 4, the team has investigated the utilization patterns of full-electric buses to gain insights into energy consumption and factors driving energy consumption. This analysis was enabled by the migration of the Fleet Management System into Volvo Connect and the release of new

parameters for full electric vehicles done in project P5942, so that the team had access to high frequency positioning and telematics data from the buses. This data was utilized to train machine learning models in predicting energy consumption for all identified scenarios. The method of utilizing telematics and positioning data from real world cases to predict Energy Consumption is novel and different from the current test-bed methods and provides insights into how the buses operate in real-world scenarios. The project utilized Multi-Task Neural Networks and FLAML to identify and create machine learning models for predicting the energy consumption, and SHAP analysis to investigate feature importance and generate insights into the underlying drivers. The results were two-fold; a well functioning energy prediction model that was on par or better with previous academic attempts in the area, as well as multiple reports describing factors driving the energy consumption that was shared with product engineering and product development to enhance the performance of full electric buses. As a side-investigation the project also deep-dived into the effects of cold weather on the operations and vehicle usage.

WP5: Personalized electromobility services
In WP5, the project has worked with high-frequency positioning data coupled with charging and consumption data to investigate the potential of developing smart and personalized charging services. The aim is to optimize the individual vehicle to maximize utilization of battery-friendly low-power charging and maximize operation time in an optimal SoC window which will both provide both economical benefits to the customer and battery longevity. The project developed multiple methods to create dynamic charging services, and follow-up projects are initiated to productionalize the services.

7 Dissemination and publication

7.1 Dissemination of knowledge and results

Hur har/planeras projektresultatet att användas och spridas?	Marker a med X	Kommentar
Increase knowledge in the area	X	Increased knowledged in electromobility including operation of electric vehicles, data availability and analytics
Carried forward to other advanced technology development projects	X	CAISR+ (KKs)
Forwarded to product development projects	X	DREEMER (Vinnova), development of realtime monitoring services
Introduced to the market	X	Internal monitoring services and reporting for fully electric and hybrid buses
Used in investigations/regulations/permit matters/political decisions		No.

Events

- Organised a tutorial and workshop at ECML/PKDD 2020 conference on IoT Stream for Data-Driven Predictive Maintenance.
- Organised the “Summer School on Data-Driven Predictive Maintenance for Industry 4.0” collocated with IEEE DSAA conference.
- Organised the workshop and tutorial “IoT Streams for Predictive Maintenance Third Edition”, ECML/PKDD 2022.
- Presentation on “Transfer Learning for predictive maintenance in electromobility”, AI innovation of Sweden, October 2021.
- PhD project presentation, by Ghaith Altarabichi, Swedish AI Society Workshop, SAIS 2022.

Award

- Achieved 2nd place (13 international teams in total) in The Aramis Challenge on Prognostic and Health Management in Evolving Environments, organized by the 30th European Safety and Reliability Conference and the 15th Probabilistic Safety Assessment and Management.

7.2 Publications

The contributions resulted in a number of publications summarizing the newly developed algorithms and reporting performed experiments.

1. M. Gh. Altarabichi, et al."Predicting State of Health and End of Life for Batteries in Hybrid Energy Buses." Proceedings of the 30th European Safety and Reliability Conference and the 15th Probabilistic Safety Assessment and Management Conference Venice, Italy, 1 - 6 November 2020
2. Y. Fan, et al. "Transfer learning for remaining useful life prediction based on consensus self-organizing models." Reliability Engineering & System Safety 203 (2020): 107098.
3. M. Gh. Altarabichi et al. "Stacking Ensembles of Heterogeneous Classifiers for Fault Detection in Evolving Environments." Proceedings of the 30th European Safety and Reliability Conference and the 15th Probabilistic Safety Assessment and Management Conference Venice, Italy, 1 - 6 November 2020.
4. M. Gh. Altarabichi et al. “Surrogate-Assisted Genetic Algorithm for Wrapper Feature Selection”, IEEE CEC 2021.
5. M. Gh. Altarabichi, et al. “Extracting Invariant Features for Predicting State of Health of Batteries in Hybrid Energy Buses”, 2021 IEEE 8th International Conference on Data Science and Advanced Analytics (DSAA)
6. Z. Taghiyarrenani, et al. “Noise-robust representation for fault identification with limited data via data augmentation” 7th European Conference of the Prognostics and Health Management society 2022.
7. Z. Taghiyarrenani, et al. “An Analysis of Vibrations and Currents for Broken Rotor Bar Detection in Three-phase Induction Motors”, 7th European Conference of the Prognostics and Health Management society 2022.
8. Z. Taghiyarrenani, et al. “Towards Geometry-Preserving Domain Adaptation for Fault Identification”, ECML/PKDD 2022, IoT Streams for Predictive Maintenance workshop.
9. A. Berenji et.al. “curr2vib: Modality Embedding Translation for Broken-Rotor Bar Detection”, ECML/PKDD 2022, IoT Streams for Predictive Maintenance workshop.
10. Y. Fan, et. al. Incorporating physics-based models into data-driven approaches for air leak detection in city buses. In 2022 European Conference on Machine Learning and Principles and Practice of Knowledge Discovery in Databases. Springer, 2022
11. M. Gh. Altarabichi et al. “Fast Genetic Algorithm for feature selection — A qualitative approximation approach”, Expert Systems With Applications, 2022.
12. Z. Taghiyarrenani et al. Multi-domain adaptation for regression under conditional distribution shift. Expert Systems with Applications 224.
13. Z. Taghiyarrenani Licentiate thesis, ‘Learning from multiple domains’, Halmstad University Dissertations no. 92. 2022.
14. A. Alabdallah, et al. "SurvSHAP: A Proxy-Based Algorithm for Explaining Survival Models with SHAP," 2022 IEEE 9th International Conference on Data Science and Advanced Analytics (DSAA)

8 Conclusions and continued research

The EVE project had a primary focus on leveraging machine learning techniques and analytics to provide services related to electromobility. This project exemplifies the utilization of advanced ML techniques, such as transfer learning, to overcome data diversity challenges and enhance prediction accuracy.

EVE monitored the behavior of the vehicle using on-board signals, which provided an understanding of the patterns associated with quality degradation. Early symptoms identified through this monitoring were used to create a predictive maintenance service. This involved aggregating available information from both hybrid and fully electric buses, combining data from multiple sources, and constructing an appropriate feature space for transfer learning. The successful results of transfer learning for buses inspired a new project to adapt degradation battery models for medium duty trucks. Currently, we are in discussions with Volvo Monitoring Center to pursue this direction.

Additionally, EVE investigated energy consumption and charging patterns to identify possibilities for optimizing internal auxiliary consumption in different applications. This led to several ideas for continuation projects aimed at controlling energy consumption in emergency scenarios. Volvo initiated a new project called DREEMER (Vinnova) to collect the necessary data for this task, and we also granted the FREEPORT project (Vinnova) to explore monitoring energy consumption for safety critical systems. Another potential research direction for the future could be the placement of charging depots based on the charging needs of scheduled buses.

9 Participating parties and contact persons

Volvo Buses, as the problem owner, recognizes that uptime and quality are core values for their customers. Through close collaboration and interaction with customers worldwide, they communicated valuable insight into their customer's needs. Furthermore, they have investigated the possibility of developing new business models and services based on the results of the EVE project.
Contact person: Markus Sirnemark, Service Area Manager Lifecycle Services,
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Volvo Group Connected Solutions is Volvo's business unit delivering digital services and connectivity to the vehicles. VGCS has a Center of Excellence for Advanced Analytics and AI that has supported the project with data science capabilities and analysis of high frequency telematics data.
Contact person: Niklas Tedenbrant, Senior Data Scientist, niklas.tedenbrant@volvo.com

Halmstad University's Centre for Applied Intelligent Systems Research (CAISR) provided the research environment for the project. Halmstad University contributed to developing and testing advanced machine learning solutions for tasks and data proposed by Volvo.
Contact person: Sepideh Pashami, Senior Lecturer (sepideh.pashami@hh.se)

VOLVO

Volvo Group Connected Solutions

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Halmstad University

VOLVO

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