SHared automation Operating models for Worldwide adoption

SHOW

Grant Agreement Number: 875530

D6.3: SHOW Marketplace and services – final version

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Legal Disclaimer

Executive Summary

Deliverable ***D6.3 SHOW Marketplace and services – final version*** is the final deliverable of **WP6: Services Marketplace**. Hence, the purpose of this deliverable is to present the work carried out during the final period (M31-M57) within the five activities composing WP6, namely, describes the work activities, ***A6.1: SHOW Marketplace***, ***A6.2: Metadata-based Value Added Services***, ***A6.3: SHOW Operational services***, ***A6.4: Energy Management services*** and ***A6.5 Dynamic Personalized Services***.

The present deliverable, firstly presents the final business plan of the SHOW marketplace, analysing prominent **economic aspects** of it such as the market analysis, the business overview, the marketing and exploitation strategies, and the financial plan. Moreover, a significant part of this deliverable deals with the development of services within WP6 such as: i) ***Centralized Platoon Control System***, ii) ***Low Carbon Mobility Management***, iii) ***Comprehensive Analysis of Electrified Powertrains across Different Driving Scenarios using Real-World Data***, and iv) ***Mitigating range anxiety and enhancing battery efficiency in AVs based on SoC forecasting***.

In D6.3, all new product items that have been integrated into the SHOW marketplace, are presented briefly. In total **15 novel product** items have been integrated the reporting period (M31-M57), leading to a **total** of **28** products. The overview of these 28 products is presented, highlighting the various product items existing in the SHOW marketplace and the different service providers including **universities**, **research organizations** and **SMEs**.

Finally, a crucial point for the SHOW marketplace is the user feedback and the adoption of the suggested platform from the CCAM community. For this reason, i) a ***questionnaire***, was given to various stakeholders to evaluate the SHOW marketplace, ii) several ***promotional campaigns*** were performed, and iii) the ***Google analytics*** are tracked. The results from all the aforementioned activities are encouraging, underlining that the SHOW marketplace achieves its purpose to be the first one stop shop for the overall CCAM community.

Document Control Sheet

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Lead authors:	Georgios Nikoletos (CERTH-ITI), Evangelos Athanasakis (CERTH-ITI), Georgios Spanos (CERTH-ITI), Konstantinos Giapantzis (CERTH-ITI), Avraam Tepelidis (CERTH-ITI), Iordanis Papoutsoglou (CERTH-ITI), Dimitrios Tsiktsiris (CERTH-ITI), Alexandros Papadopoulos (CERTH-ITI), Athanasios Sersemis (CERTH-ITI), Evangelos Antypas (CERTH-ITI), Theoktisti Marinopoulou (CERTH-ITI), Antonios Lalas (CERTH-ITI), Konstantinos Votis (CERTH-ITI)
Other authors involved:	Mattia Venditti (AVL/DE), Romina Quaranta (T-Systems), Olaf Else (FEV), Pavlos Spanidis (CERTH-HIT)
Internal Reviewers:	Maria Gkemou (CERTH)
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2.0	16/10/2024	Final submitted version	CERTH

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Abbreviation List

Abbreviation	Definition
AD	Autonomous driving
ADAS	Advanced driver assistance systems
AV	Autonomous vehicle
B2B	Business to business
BEV	Battery Electric Vehicles
CCAM	Connected, cooperative, and automated mobility
CCAV	Centre for Connected & Autonomous Vehicles
C-ITS	Cooperative Intelligent Transport Systems
CLM	Cooperative Lane Merge
CMP	Cooperative Manoeuvre Protocol
ICEV	Internal Combustion Engine Vehicles
IRS	Internal Revenue Service
KPI	Key Performance Indicator
ML	Machine Learning
MPC	Model Predictive Control
OEM	Original Equipment Manufacturer
PESTLE	Political, Economic, Social, Technological, Environmental and Legal
PHEV	Plug-In Hybrid Electric Vehicle
PTA	Public Transport Authority
PTO	Public Transport Operator
R&D	Research and Development
SaaS	Software as a Service
SAE	Society of Automotive Engineers
SME	Small and medium-sized enterprise
SoC	State of Charge
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-everything
VAT	Value Added Tax

1 Introduction

1.1 Purpose and structure of the document

The purpose of this document is to describe, present, analyse and offer valuable insights related to the work performed the period between M31 and M57 within WP6 Services Marketplaces. The structure of the document is as follows:

- **Section 2** presents the SHOW marketplace business plan, providing details about the market analysis, and the marketing, exploitation and financial plan.
- **Section 3** describes the services that were implemented during the previous period under WP6.
- **Section 4** briefly presents the 15 new product items integrated in the SHOW marketplace from M31 until M57, also depicting the product details as appeared in the marketplace.
- **Section 5** summarizes the 28 product items existing in the SHOW marketplace offering some descriptive statistics.
- **Section 6** analyses the results of the SHOW marketplaces evaluation as reflected by the responses of the stakeholders in the corresponding questionnaire.
- **Section 7** provides details about the SHOW marketplace traffic as presented by the Google analytics.
- **Section 8** present the promotional campaigns through different marketing channels.
- **Section 9** summarizes the main outcomes of this deliverable and provides valuable conclusions.

1.2 Intended Audience

The intended audience of the final deliverable as in the previous two versions (D6.1 & D6.2) includes:

- Technical team of SHOW pilot sites.
- OEMs responsible for the CCAV deployment in pilot sites.
- Service designers.
- Evaluation team of WP9.
- Business stakeholders.

Academic and research community outside SHOW in the domain of CCAV.

1.3 Interrelations

The interrelated activities and WPs are the same with the previous two deliverable (D6.1 & D6.2) and are as follows:

- A1.1 – System needs.
- A1.3 – Use cases.
- WP3 - Ethical and legal issues.
- WP4 – System architecture & tools.
- WP5 – Big Data collection, processing, & analytics.

2 Business Plan

2.1 Introduction

The scope of this document is to provide information concerning the SHOW Marketplace that was developed as part of the SHOW project, and it mainly presents the business logic and a detailed business plan for the Marketplace as a whole. The work that is presented is an evolution of the Business Model that was developed for the SHOW Marketplace in the previous deliverable [2]. The SHOW Marketplace aims (as all existing Marketplaces) to become an online platform which initiates, facilitates, coordinates, and concludes buying and selling of services between service seekers and service providers. The SHOW Marketplace is an innovative business solution based on the observed market and behavioural trends. The increase in popularity of the sharing and gig economy is a clear opportunity and, aligned with the digital growth that is currently taking place, a differentiating offer can be launched onto the market.

The main objective of the Marketplace is to act as a **one-stop place** encouraging participation from the Connected, Cooperative & Automated mobility (**CCAM**) community to accelerate awareness and offering of innovative CCAM technologies and services. The intended users of the Marketplace vary from Public Transportation Operators and Service Providers to Research and Academia Institutions. In addition to that, the Marketplace will be available to public and private operators who will have the liberty to act as service providers through the platform, by uploading their products and services and making them available for purchase. The platform will host products and services developed within the SHOW project but also from other European projects that create CCAM technologies and services.

2.2 Market Analysis

The first step of the analysis involves the external, internal and competitive factors of the current market. Through this screening, it will be possible to identify the attractiveness of the market and the business potential as well as the risks that might emerge. To be able to analyse thoroughly all of the above components, three different dimensions were considered:

- ***External Analysis***:
    - Industry definition and industry data - Current condition of the industry and market size.
    - Ansoff Matrix
    - PESTLE (Political, Economic, Social, Technological, Environmental and Legal) Analysis – Definition of the external environment and context, as well as how it affects the project.
- ***Competitors Analysis***:
    - Porter's 5 Forces model – The weight considered for each of the five forces provides a better evaluation and estimation of the market attractiveness and how companies can improve their competitive position.
- ***SWOT Analysis***:
    - A strategic planning tool that provides a concise overview of an organization's internal Strengths and Weaknesses, as well as external Opportunities and Threats. It helps businesses and individuals assess their current position and

make informed decisions by identifying key factors that can affect their success.

- ***Qualitative and Quantitative Research***:
    - To perform in-depth analysis, the qualitative and quantitative analysis regarding the SHOW Marketplace is performed through a Business and Software Evaluation Questionnaire that targets the partners within the SHOW project. The Questionnaire and its results are presented in Appendix and Evaluation of the SHOW marketplace Section, respectively.

2.2.1 External Analysis

2.2.1.1 Industry definition

The electrification and automation of mobility in urban and suburban areas is one of the most challenging milestones to be achieved during the next decade across European countries. Connected and automated transport will play a key role in European strategies for clean, efficient, and safe ("vision zero") transport. Viable business models, in combination with well-defined AV procurement schemes, will create a favourable ecosystem for mobility services, SMEs, PTOs, PTAs, and other relevant parties. Transport and mobility should fully contribute to achieving the emission reduction target of 55% by 2030 [3].

2.2.1.2 Industry data

The CCAM industry is constantly evolving, by regularly introducing new products, standards, and regulations. Despite this constant innovation, the sector remains on a trajectory of growth and is projected to generate revenues ranging from $300 billion to $400 billion by 2035 [4]. The European economy, responsible for 23% of the world's motor vehicle production and handling almost 72% of inland freight transportation by road, is poised to experience substantial impacts from the full integration of CCAM technologies [5].

Autonomous driving aims at revolutionizing the mobility paradigm. AD systems intend to make the driving experience safer and more convenient, by minimizing the hours spent on the road. Especially for people with long commutes, workers, elderly people, and disabled people, the travelling experience will substantially become better. However, since the SHOW Marketplace specifically targets automated vehicles, the current and future advancements in AD capabilities greatly influence the positioning of the marketplace in the current and future market. Along with these consumer benefits, AD has the potential to create extra value for the automotive industry. Currently, most cars are equipped with basic ADAS features but major advancements in AD capabilities are on the horizon. Vehicles are moving toward reaching Society of Automotive Engineers (SAE) Level 4 (L4), enabling autonomous control under specific conditions.

In addition to above the data, the market study conducted as part of the SHOW project in deliverable D16.1 [6] allows for a more comprehensive understanding of all the relevant markets for the business idea. They key points from this study that can help the SHOW Marketplace grow are the following:

- The current mobility trend highlights the need for clean, shared automated vehicles, along with the high demand for the digitalization of mobility.

- There is an array of initiatives (e.g., SPACE initiatives[1]) towards automated public transportation, which subsequently includes many potential customers for the SHOW Marketplace.
- In the next 10 to 15 years, technology should provide users with increased flexibility in selecting their preferred modes of transportation when traveling from one location to another.

2.2.1.3 Ansoff Matrix

The Ansoff Matrix [7], also known as the Product/Market Expansion Grid, can be a strong strategic planning tool, which helps businesses determine their growth strategies by analysing the combination of new and existing products and markets. It provides a framework for four growth strategies Figure 1:

1. **Market penetration**: The concept of increasing sales of existing products into the current customer base or capturing a larger share of the current market.
2. **Market Development**: Focuses on selling existing products into new markets or customer segments.
3. **Product Development**: Focuses on introducing new products to an existing customer base or market.
4. **Diversification**: The most ambitious strategy, as it involves entering a new market with altogether new products.

[1] https://www.space-initiatives.com/

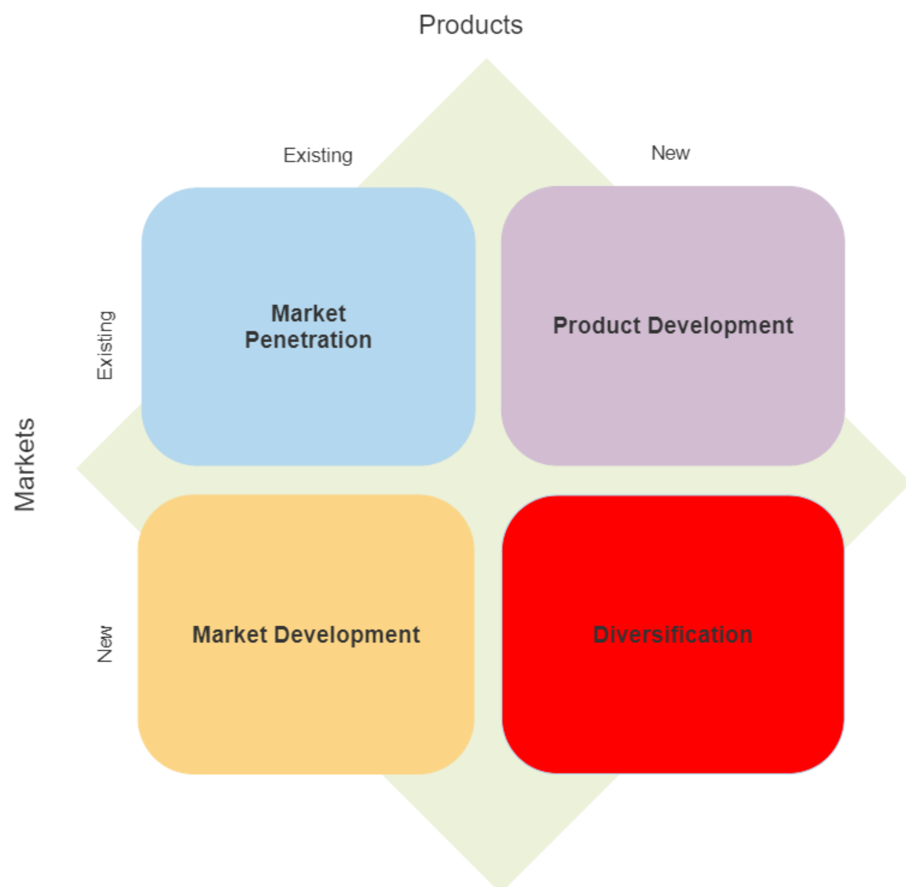

Figure 1: Ansoff Matrix

When it comes to the SHOW Marketplace, a clear business strategy based on the Ansoff Matrix includes the following:

1. **Market Penetration:**

Objective: Increase the share of the current market for the SHOW Marketplace.

Strategies:

- Implement targeted marketing campaigns to attract more users within the existing user/customer base.
- Offer loyalty programs or incentives to encourage current users to make more frequent purchases.
- Enhance the user experience and customer service to retain and satisfy existing users.
- Decreasing prices to attract new customers within the market segment.

2. **Market Development:**

Objective: Introduce the SHOW Marketplace to new geographic regions or customer segments.

Strategies:

- Entering a new domestic market (regional expansion) with similar needs and preferences.
- Tailor the platform to accommodate the requirements of specific customer segments, such as B2B clients or different industries.

3. **Product Development:**

Objective: Create and launch new products or services within the SHOW Marketplace.

Strategies:

- Develop additional features, tools, or functionalities to improve the user experience and add value.
- Introduce new categories of products or services that align with the existing SHOW Marketplace offerings.
- Investing in R&D to develop an altogether new product(s).

4. **Diversification:**

Objective: Explore new markets and products that are not directly related to the current SHOW Marketplace.

Strategies:

- Related Diversification: Where there are potential synergies that can be realized between the existing business and the new product/market.
- Unrelated Diversification: Where it is unlikely that any real synergies will be realized between the existing business and the new product/market.

2.2.1.4 PESTLE Analysis

Table 1 below summarizes the PESTLE Analysis [8] conducted to the SHOW Marketplace.

Table 1: PESTLE Analysis for the SHOW Marketplace

Political factors	Economic factors	Sociological factors
• Government regulations and policies related to the CCAM community. • Funding and support from government and European-wide initiatives and grants. • Political stability in the regions and in the transport sector in general where the marketplace operates.	• Economic conditions affecting the willingness to invest in autonomous mobility services. • Exchange rates, inflation, and currency fluctuations for international operations. • Economic disparities between regions affecting market demand. • Economic impact on traditional transport industries. • Calculating the costs to stakeholders, including	• Changing consumer preferences and attitudes towards autonomous mobility. • Societal acceptance of new mobility technologies and services, including safety and privacy concerns. • Demographic shifts and urbanization affecting transportation needs. • Changes in travel behaviour and patterns, such as

	the affordability of autonomous vehicle services compared to traditional transportation options.	increased reliance on ride-sharing services and reduced car ownership. • Accessibility and integration of autonomous vehicle services for different segments of the population (e.g. PRMs).
Technological factors	**Legal factors**	**Environmental factors**
• Rapid advancements in autonomous vehicle technologies. • Integration of IoT and AI in transportation systems. • Infrastructure requirements to support autonomous vehicles. • Cybersecurity risks and potential vulnerabilities in autonomous vehicle systems.	• Compliance with regulatory frameworks and legal challenges related to autonomous vehicles. • Liability and legal frameworks. • Intellectual property rights and patent issues in autonomous mobility.	• Technological innovations focused on reducing environmental impact. • Integrating autonomous vehicles with sustainable transport systems and infrastructure.

2.2.2 Competitor Analysis

2.2.2.1 Porter's 5 forces

The Porter's 5 Forces Analysis [9] conducted for the SHOW Marketplace is presented below:

1. <u>Threat of New Entrants:</u>

High: The threat of new entrants is high, especially from giant tech companies like Google, Apple and Microsoft, which are investing in services that can be used by autonomous vehicle. Additionally, niche players in connected and autonomous mobility services may emerge, making the industry more competitive.

For the SHOW Marketplace to mitigate this risk is to take advantage of the current customer segments (largely represented by the SHOW consortium members). Utilizing existing network, partnerships, and customer base to strengthen the market position, new entrants will find it difficult to replicate these established relationships. Another solution can be to create high barriers to entry through patents, proprietary technologies, and partnerships with established players.

2. <u>Bargaining Power of Suppliers:</u>

Moderate: Suppliers, such as technology providers like Google and Microsoft, may have a high bargaining power as they can provide numerous software solutions tailored to automated mobility. These tech giants can influence the market with their advanced solutions; however, the SHOW Marketplace can negotiate favourable terms with a diverse set of suppliers, including smaller technology companies.

3. Bargaining Power of Buyers:

Moderate: Buyers, including public transportation operators, technology companies, and academic institutions, among others, may have moderate bargaining power. They have various service providers and platforms to choose from, making competition a factor. However, the SHOW Marketplace can reduce the bargaining power of buyers by offering unique and valuable services.

4. Threat of Substitute Products or Services:

Low to Moderate: The threat of substitutes exists from general service marketplaces and specialized industry platforms. For instance, companies like Uber and Lyft could compete indirectly by expanding into autonomous mobility services. However, for highly specialized connected and autonomous mobility services, the threat may be relatively lower, as the SHOW Marketplace caters to unique needs.

5. Competitive Rivalry:

Moderate to High: Competitive rivalry is moderate to high due to the presence of various competitors, including general service marketplaces, mobility service providers (Uber, Lyft), technology giants (Google, Apple), and industry-specific platforms. The SHOW Marketplace needs to differentiate itself through unique features, a strong brand, and value-added services to compete effectively in this dynamic landscape.

2.2.3 SWOT Analysis

Table 2 below is a SWOT analysis [10] in which a brief summary of the internal and external analysis is taken into consideration.

Table 2: SWOT Analysis of SHOW Marketplace

Strengths	Weaknesses
• The services are covering all AV types (bus, shuttle, car etc.). • Covering passenger, cargo and mixed transport under varying schemes and use cases. • Bringing under one software platform, a variety of different services. • Co-developing and co-applying all solutions with the local ecosystem and societies. • Accelerator for adoption of CCAM services in Europe. • Non commercialized services pool for the research enhancement in the CCAM field. • Managed by a very experienced and strong team; with proven capacity of managing EC projects of this size.	• No market presence in the industry. • High efforts to achieve interoperability and common architecture. • Cash flow will be unreliable in the early stages. • Cost efficiency not yet determined.

• Using AI and big data analytics to develop added value services and a relevant AV enabled marketplace. • Personalized Dynamic Services.	
Opportunities	**Threats**
• One-stop-shop for automated mobility services and products – within & beyond SHOW. • A platform for service promotion that will redirect the interested buyers to the respective URL/platform. • High political and industrial interest in Europe and beyond and link to external initiatives (e.g., AVENUE[2]) multiplies own data and resources. • SHOW Dashboard could also be hosted in the marketplace. • Companies will be able to promote their hardware equipment via the tool module. • UI widgets and single components that could be utilized in different parts of designing an autonomous vehicle system could be uploaded to the SHOW Marketplace.	• Fierce competition in the automotive industry. • Change of priorities and/or policies at local level. • Negative impact to public acceptance of an AV related accident might lead to the abandonment of the SHOW Marketplace solution and its services. • Unsecure financing of mobility services may put future investments at risk. • Challenging data collection and governance. • Slow adoption of AVs

2.2.4 Qualitative and Quantitative Research

A questionnaire has been created to gather valuable feedback and insights from users and stakeholders who have interacted with the SHOW Marketplace. It aims to evaluate the marketplace from both technical and business perspectives. The questionnaire specifically seeks to assess the user experience with the marketplace's technical aspects (registration, uploading, filtering, etc.), and their willingness to engage with the platform. Additionally, it aims to understand the marketplace's relevance and potential value to different user categories and the CCAM community, and to identify potential improvements or additional features.

2.3 Business Overview

2.3.1 Business Opportunity

For the time being, the SHOW Marketplace presents itself as a unique opportunity in the CCAM domain, as -and to the best of our knowledge- no other established business or other EU-funded projects have proposed something that will act as a centralized platform hosting products and services related to autonomous mobility. Thus, the market is currently lacking a solid bridge that can bring together different stakeholders that meets their demands.

Digital technologies have the potential to transform the way we commute, by making it smarter, more efficient, and more environmentally friendly. The SHOW Marketplace will

[2] https://h2020-avenue.eu/

be based on existing, innovative, and newly developed digital technologies; thus, it has the opportunity to become a key player in the industry thus generating revenue in a timely and efficient manner.

On the other hand, and the fact that everything that has been mentioned is still somewhat new, means that the market is not quite established yet. Therefore, there are very few established players, and competition is not an obstacle at the time being. However, given the lack of awareness, a push strategy will be implemented in the initial business stages in order to guarantee that the brand is getting visibility and that people and related companies become acquainted with it.

The differentiating factor for this platform is that it creates a community amongst the SHOW Marketplace users, making it easier for everyone to be able to fulfil their needs. A critical factor to be considered as well is that all fiscal requirements are treated properly and that the idealized solutions are feasible. All these factors mentioned above will be described and analysed with more precision in the next chapters. The financial aspect will also be analysed in detail in the following chapters.

2.3.2 SHOW Marketplace as a brand

The SHOW Marketplace has the potential to become a brand and a serious gamechanger in the new mobility paradigm, as more and more companies, organizations, research projects, academic and research institutes, work towards on developing solutions for fully autonomous vehicles. The proposed Marketplace that already launched in June 2022 envisions the work performed from 70+ partners. In addition, it contains the results of other related projects (AVENUE, NIOVE[3], ULTIMO[4]etc.).

This gives a real competitive advantage, since the unique value propositions of the SHOW Marketplace along with the diverse categories of the developed commercial and free product items, will strengthen its market position after launch. The main message promoted by the brand will revolve around its uniqueness as a platform and the facilitated experience it provides to the users.

The message of the SHOW Marketplace can be envisioned in a slogan, which will represent the key selling point of the business, which is to have available solutions at the distance of a click. The proposed slogan for the platform is *"Cooperative, Connected, and Automated Mobility in one click"*. This slogan conveys the idea that the SHOW Marketplace can become a point of interest for individuals and organizations looking for innovative and convenient mobility options.

Furthermore, the SHOW Marketplace's brand identity is not just about providing products and services; as mentioned multiple times, it aims at fostering a sense of *community* among its users, and also aims at acting as a hub where individuals and businesses can come together, collaborate, and address their mobility needs efficiently and effectively. The marketplace's commitment to addressing fiscal requirements and ensuring the feasibility of idealized solutions reinforces its reliability and trustworthiness.

[3] https://cordis.europa.eu/project/id/833742/reporting
[4] https://ultimo-he.eu/

2.3.3 Business Model

The business model for the SHOW Marketplace was envisioned and presented in the previous version of the deliverable [2]; thus, there is no need to analyse it once again. For that reason, we only present the Business Model Canvas (Table 3) that formulates the key points he key elements of the Marketplace and its activity.

Table 3: Business Model Canvas for SHOW Marketplace

<table>
<tr><th colspan="2">Value Proposition</th><th colspan="2">Main Challenges</th></tr>
<tr><td colspan="2">The SHOW Services Marketplace creates value by serving as a:
▪ One-stop-shop for automated mobility services – within & beyond SHOW.
▪ Non commercialised services pool for the research enhancement in the CCAM field.
▪ Accelerator for adoption of CCAM services in Europe.
▪ Stimulator for passenger familiarisation to new mobility paradigm.
▪ Easy-to-consume overview of available product and data items.</td><td colspan="2">▪ Openness.
▪ User acceptance.
▪ Pricing, affordability, and methods for payment.
▪ Personalization of the SHOW Marketplace.
▪ Lack of business and financing models for each service.
▪ Provide maximum value to each stakeholder.</td></tr>
<tr><th>Customer Segmentation</th><th colspan="2">Distribution channels/Key Activities</th><th>Key Partners</th></tr>
<tr><td>▪ Passenger.
▪ Tier 1 Supplier.
▪ OEMs.
▪ Public or Private Transport Operator.
▪ Public Transport Authority.
▪ Research/Academia.
▪ Technology/Service Provider.
▪ City/Authority.
▪ Traffic Management Centre Operator.
▪ Infrastructure Operator.
▪ Association.</td><td colspan="2">▪ SHOW Marketplace.
▪ SHOW project web page.
▪ National and international conferences.
▪ Events, workshops, and webinars.
▪ Social media campaigns.
▪ Paid advertising.
▪ Email marketing.
▪ Publications.
▪ Search engines optimization.
▪ Offline channels.
▪ Public affairs activities.
▪ Case studies, one-pagers, etc.</td><td>The relevant partners and stakeholders have been thoroughly presented in D6.1 and the SHOW Grant Agreement.</td></tr>
<tr><th colspan="2">Business Revenue Model</th><th colspan="2">Cost Structure</th></tr>
<tr><td colspan="2">▪ Commission-based model (will not be used at the early business stages): Cost per Sale percentage fee.
▪ Revenue from the Licensing pricing models (SaaS or Perpetual license model will be adopted) for the commercialized services.</td><td colspan="2">▪ Initial investment required.
▪ Investment in infrastructure (physical and digital).
▪ Recurring cost of physical and digital infrastructure.
▪ Technical installation.</td></tr>
</table>

▪ Listing Fee model (cannot be used for the duration of the SHOW project and for SHOW stakeholders): a fixed fee for adding a service. ▪ Payment processing fee: charge of a certain amount for every successful transaction.	▪ Personnel costs (operation, R&D, education, etc.). ▪ Marketing and Communication. ▪ Other costs (Business Licenses/Permits/Fees, travel, etc.).

2.3.4 Strategic Objectives

The Strategic Objectives of the SHOW Marketplace are:

1. After the completion of the SHOW project, an organization can take advantage and generate revenue.
2. Take advantage of the synergies created as part of the SHOW project to increase the SHOW marketplace adoption in the CCAM community.
3. Establish the SHOW Marketplace as a trusted and recognized brand in the connected and autonomous mobility sector through effective marketing and communication strategies.
4. Extend the reach of the SHOW Marketplace to new geographic regions and international markets to capture a global audience.
5. Enhance the visibility and adoption from the CCAM community of the SHOW marketplace by building synergies with the EU-funded project FAME[5].
6. Continuously expand the range of products and services offered on the platform to meet the evolving needs of users, including technological advancements and sustainable mobility solutions.
7. Develop strategies to enhance user engagement, satisfaction, and loyalty through personalized experiences, feedback mechanisms, and community-building features.
8. Attain a leadership position in the CCAM marketplace by facilitating collaboration among industry stakeholders and promoting innovation in the field.
9. Actively engage with policymakers and regulatory bodies to shape industry standards and regulations, ensuring a conducive environment for CCAM technologies.
10. Continuously gather and analyse market data and user feedback to stay at the forefront of emerging trends and demands in the autonomous mobility market.
11. Integrate sustainability initiatives and promote the adoption of environmentally friendly mobility solutions within the marketplace, contributing to a more sustainable future.
12. European-wide launch as a company on 2024 after the conclusion of the SHOW project.
13. Reach over 500 registered users in first year of activity.
14. Reach payback before 5th year of activity. The main advantage in regard to that, is that most of the development and infrastructure costs were part of the whole SHOW project. Thus, no further investments are required for that matter.
15. Possibly complete European coverage by 2030 and begin international expansion (not detailed in scope of the Business Plan).

2.3.5 Phases and Development

Every project is usually divided into phases that cover all the relevant actions needed to be undertaken, since the conception of the idea to its launch and the continuous

[5] https://www.ccam.eu/projects/fame/

expansion. Since, the phases related to concept, initiation, definition, planning, and the development of the SHOW Marketplace were envisioned in the Grant Agreement of the SHOW project and since the development phase of the Marketplace is over, there is no need to mention them once again.

For the above reasons, on this section we will focus only on two key phases that follow after the launch and their duration is continuous, which are analysed afterwards:

- **Performance and control – Duration: Continuous**
    - This phase occurs once the platform is launched and is continuous because it measures and assesses the business performance and its evolution. This includes constant review and analysis of the performances of the service providers and attention to the feedback given by users.
    - This encompassing oversight involves regular assessments of the service providers' contributions, ensuring quality and reliability. Furthermore, it places significant emphasis on user feedback, utilizing this input to enhance the overall user experience. Through performance tracking and control mechanisms, the SHOW Marketplace can adapt and innovate in real-time, responding to changing market dynamics and user needs.
- **Expansion – Duration: Continuous**
    - This phase implies the growth into more markets and a broader range of services offered.
    - This phase is not bound by a fixed timeline; rather, it is an ongoing endeavour driven by the vision of reaching new markets and offering an increasingly diverse array of services.
    - Expansion can be geographical diversification to cater to a broader international audience, as well as the introduction of new categories of products and services within the marketplace.
    - By continually exploring new horizons, the SHOW Marketplace can adapt to emerging trends and opportunities in the CCAM sector, ensuring its sustained relevance and competitiveness in an ever evolving and ever-changing landscape.

These two phases constitute pivotal elements of the SHOW Marketplace's objectives beyond its initial launch, ensuring its adaptability, growth, and ability to serve as a dynamic force within the CCAM sector.

2.4 Exploitation, Marketing, and Operating strategies

2.4.1 Exploitation plan

The exploitation plan will be developed regarding the commercialization of the SHOW Marketplace platform and the product items produced during the implementation of the SHOW project. The specific exploitable project results are foreseen as being:

1. **SHOW Marketplace Platform Commercialization:** Launching and monetizing the SHOW Marketplace platform as a centralized hub for connected, cooperative, and automated mobility (CCAM) solutions.
2. **Diverse Product Items:** Commercializing a wide range of products and services related to autonomous mobility, catering to various customer needs.
3. **Unique Value Propositions:** Leveraging the unique position of the SHOW Marketplace.

4. **Community Building:** Creating a sense of community among SHOW Marketplace users to foster cooperation and knowledge sharing in the CCAM domain.
5. **Market Expansion:** Continuously growing into new markets and offering an expanded set of CCAM services to meet evolving customer demands.
6. **Visibility and Awareness:** Establishing a strong online presence and raising awareness about the SHOW Marketplace through various marketing channels, including social media, webinars, and specialized fairs.
7. **Partnership Development:** Forging strategic partnerships with technology and industry vendors to enhance the platform's offerings and promote its exploitation within the CCAM industry.

The SHOW Marketplace has already been introduced to multiple groups of internal and external partners of the SHOW project. In addition to that, the Business and Software Evaluation Questionnaire presented in Appendix can help to further engage the existing users of the SHOW Marketplace. However, to proceed in a European-wide launch and commercialization of the platform, a strong and successful business and marketing strategy needs to be circulated.

2.4.2 Marketing strategy

For the Marketplace to be successful, it is of upmost importance that the platform generates traffic, meaning that service providers and consumers need to become frequent users. For this to take place, it is necessary to develop a communication plan in order to attract these users.

The marketing plan aims at two different targets, the first being directed towards service providers and, later, towards general consumers. The services provided from the SHOW Marketplace must add value to its customers, and in turn, this value should be perceived as such by them. Towards that goal, the marketing plan will help illustrate how this service will be sold, thus motivating the prospective customers to engage with the marketplace and create a further connection and relationship with the brand. By increasing visibility and by raising awareness (which is a main objective of the SHOW Marketplace), it will allow for further growth of the business and increase the perception of added value that the platform intends to offer to its customers and to its sellers.

To develop an efficient marketing strategy, it is important to establish the general direction (mission and vision), positioning and segmentation. The dissemination activities aim to create visibility and promote the exploitation of the concept and achievements of the SHOW Marketplace platform by establishing effective communication channels and appropriate liaisons with all relevant stakeholders. By creating awareness about the outcomes and promoting their adoption, the exploitation of the platform will foster a culture of cooperation in the context of related services and applications. An impact assessment framework will measure the effectiveness of the impact related activities.

The main targets of the marketing strategy are to:

- Promote full visibility of the project’s work and disseminate the results of the SHOW Marketplace to all relevant stakeholders, in Europe and beyond.
- Establish liaisons with related companies and software developers as appropriate, to contribute to the creation of an ecosystem grouping active players in the CCAM domain.
- Create and maintain the platform’s web site and appropriate communication channels to all external related communities/activities.

- Participate and organize specific events for increased and effective liaisons, dissemination of information and engagement of key stakeholders.
- Discover, build and reinforce partnerships with new technology and industry vendors to promote the exploitation of the project's platform.
- Define the impact assessment framework and conduct relevant activities to quantify the expected impacts.
- Create personalised promotional campaigns based on the results of Google analytics

Other promotion tools that will be utilized are:

- *Newsletter*: a periodic newsletter can keep the community updated with the latest developments in the sector, featuring exclusive insights, success stories, and updates about the SHOW Marketplace.
- *Social media*: utilize social media platforms for real-time discussions, engaging content, and industry news.
- *YouTube*: in-depth product showcases, expert interviews, etc., can help increase the SHOW Marketplace visibility.
- *Educational communication*: webinars, workshops, and informative content designed to empower the community with knowledge about cutting-edge solutions.
- *Promotional Material*: brochures, infographics, and detailed documents can provide an in-depth view of the SHOW Marketplace offerings and how they can benefit potential customers.
- *Exhibiting on specialized fairs*: engage with experts, explore product demonstrations, and seize the opportunities shaping the future of mobility.

2.4.2.1 Mission and vision of the SHOW Marketplace

Mission

Become a one-stop shop encouraging participation from the CCAM community to accelerate awareness and to offer innovative CCAM technologies and services.

Vision

To be recognized as a **reference for both services providers and service consumers** in the autonomous mobility industry, **becoming the "go to" option** when searching for automated mobility services.

Values

The key value propositions were presented in the previous version of the deliverable [2]. However, some more are added here, which are the following:

- Promote sense of community and utilize the existing synergies with relevant stakeholders.
- Wider access to different markets, as diverse product items are offered.
- Cooperative, collaborative approach for information sharing and innovation.
- Social and economic impact on the industry sector.

2.4.2.2 Positioning

The positioning refers to creating, in the mind of the customers, a significant or distinct image of the company. The idea behind the SHOW Marketplace is to become the "go to" reference for service providers and service consumers in the CCAM domain. The platform has an attractive design, is intuitive and user-friendly, and also acts as a certified response to consumer needs. There are two basic characteristics important to help determine the positioning of a brand: identification of the product or service and differentiation (Table 4).

Table 4: SHOW Marketplace positioning

Identification	Differentiation
Digital marketplace combining consumers needing a service and suppliers willing and capable to do so.	• Innovative platform. • Easy and fast way to find the desired solution. • Unique in the CCAM domain. • Diverse products and services for a large variety of customers.

To further develop the positioning, the method of the golden triangle of positioning was considered (Figure 2).

Figure 2: Golden triangle of positioning

Customer expectations

The SHOW Marketplace is committed to understanding and exceeding customer expectations. Customers can expect a seamless, user-friendly experience when searching for innovative CCAM technologies and services. Users of the SHOW Marketplace can access diverse markets and enjoy a cooperative, collaborative environment for information sharing and innovation. The SHOW Marketplace values its customers' diverse needs and seeks to address them comprehensively through its easy-to-use feedback mechanism.

Differentiation from competitors

To stand out in the CCAM industry, the SHOW Marketplace embraces innovation as its core differentiator. We offer a unique and innovative platform that simplifies the process of finding desired solutions in the CCAM domain. Our intuitive design and user-friendly interface set us apart, making it easy and fast for users to navigate. The SHOW Marketplace's distinctiveness is underscored by our diverse range of products and services, catering to a wide variety of customers. We prioritize delivering a remarkable, unmatched experience that sets us apart from the competition.

Potential assets

The SHOW Marketplace's potential assets lie in its role as a central hub for CCAM solutions. With over 70 partners and insights from related projects like AVENUE and NIOVE among others, we aim to offer a comprehensive repository of CCAM technologies and services. This extensive network and variety of knowledge provide a significant competitive advantage, facilitating valuable liaisons and partnerships. Additionally, our commitment to fostering a sense of cooperation within the CCAM domain creates a socioeconomic impact that benefits the industry.

2.4.2.3 Segmentation and targeting

Given the characteristics of the SHOW Marketplace, the key customers and their goals and interests are presented in Table 5 below. The following customer segmentation was first introduced in the previous deliverable [2], but it is important to mention it once again as a core component of the overall marketing strategy.

Table 5: Customer segmentation

Role	Goals/Interests
Passenger	Transportation from A to B, comfort, awareness about new solutions coming.
Tier 1 Supplier	Provides solutions for OEMs; revenue and clientele expansion.
Original Equipment Manufacturers (OEMs)	Get benefited of new solutions and services that they can integrate in their new products.
Public or Private Transport Operator	Get aware of SoA solutions in the domain and create synergies with technology providers aiming at sustainable mobility promotion.
Public Transport Authority	Boost the appeal of public transportation through new CCAM solutions of varying readiness level.
Research/Academia	Reinforce R&I in the domain through new elements (get benefited mostly by open-source knowledge shared).
Technology/Service Provider	Offer their solutions to be exploited by different vendors in varying contexts; revenue increase; business synergies.
City/Authority	Increase traffic safety and efficiency, inclusion of all demographic groups, awareness about automation.
Traffic Management Centre Operator	Providers of new CCAM specific traffic management services, as implemented and deployed in SHOW. Get benefited from supporting services provided by technology providers.
Infrastructure Operator	Get benefited from services and solutions that can leverage their infrastructure operation (Digital Twins, Simulation suites, etc.).
Associations (e.g., Mobility Association)	Awareness about new research based and commercial CCAM services and solutions, that after they validate, they can promote to their members and, finally, Cities transport system passengers.

2.4.2.4 7 Ps

The 7Ps strategy [11] that will be used for the SHOW marketplace marketing approach is a marketing model that includes seven key elements to optimize a business's marketing efforts.

1. **Product**: The goods or services offered to meet customer needs.
2. **Price**: The cost customers pay for the product.
3. **Place**: The distribution channels through which the product is sold.
4. **Promotion**: The communication tactics used to raise awareness and generate sales.
5. **People**: The staff involved in delivering the product and customer service.
6. **Process**: The systems and procedures used to deliver the product or service.
7. **Physical Evidence**: The tangible proof or environment that supports the product's existence (e.g., branding, packaging, ambiance).

2.4.3 Operating model

There are four main plans that detail the implementation of the strategy and ideas of the business:

- **IT**: Since the business will rely on the well-functioning of a cloud-based technological platform, our priority is to guarantee that everything within this nature will be reliable and operating smoothly.
- **Marketing** – Development of the mission and vision of the company, definition of the market segments and the most suited target market, setting of the value proposition and explanation of what will be offered to society and its linkage with strategic management, determination of the positioning and differentiation strategy, formulation of the 7Ps – Product, Price, Place, Promotion, People, Process and Physical Evidence.
- **Organization**: It provides an overview regarding logistics matters, such Dimension, Location, Processes and Operations.
- **Implementation Requirements**: This field is related to legal matters, and more specifically it demonstrates the requirements for the company's start and growth under the right conditions and licenses.

2.4.3.1 Organizational strategy

2.4.3.1.1 Capacity, logistics and operations

Location

The nature of the business does not require a physical location for suppliers and consumers to meet, as most of the services are offered as a service. Thus, the size and location of the facilities needed are reduced, which in turn reduces operational costs. Nevertheless, an office space should be established for all administrative staff to work as a team. Therefore, and due to initial financial restraints, the solution at least of the first year of operations it to work from the CERTH premises, in the facilities of which the Marketplace is hosted. These spaces provide the necessary accommodations to help further develop the platform and to continuously improve it. Once the business has grown and it keeps on developing, it will be important to have an own office that is also bigger in order to adapt to an increase in staff.

Operations & Capacity

In an initial phase, the SHOW Marketplace as a company will have to function on minimal costs and to do so it is necessary for job functions and responsibilities to cross over within the team. That is why a priority in the beginning will be to form a dynamic team capable of fast paced environment and flexible to change.

One of the main advantages regarding operations, is that most of the developmental work has been performed as part of the SHOW project, thus the idea to start off small with a limited staff is possible. Over time, the business will develop, and it will be possible and necessary to grow and increase in numbers, but for the initial business stages, the business's organizational chart will be as follows:

2.4.3.2 Implementation requirements

2.4.3.2.1 Legislation

Firstly, registration of the new company is required. This registration - type of company, brand, and name request - can be realized online. The following documents are necessary:

Registration

- Commercial registry.
- Social insurance registration.
- Declaration of activity initiation.
- Certificate of Admissibility.

Other fiscal obligations

- IRS.
- VAT.
- Rate deducted monthly from employees' salaries.

2.4.3.2.2 Company Foundation Requirements

New companies have to meet requirements, especially when trying to participate in financial support programs. The most common are:

- Correctly established and registered.
- License and legal requirements necessary to exert activity.
- Regularized Tax status and social security.
- Prepared accounting and accordingly to the law.

2.5 Financial Plan

2.5.1 Funding Requirements for the SHOW Marketplace

In the context of the SHOW Marketplace, funding requirements refer to the financial resources needed to support its establishment, growth, and ongoing operations. These requirements are essential to ensure the successful implementation and the achievement of its goals. The funding needs for the SHOW Marketplace can be outlined as follows:

- **Startup Capital:** To initiate the development and launch of the SHOW Marketplace, an initial injection of capital is required. This capital will cover expenses related to technology infrastructure, initial marketing efforts, and the establishment of necessary business operations.
- **Operational Expenses:** Beyond the startup phase, the SHOW Marketplace will have ongoing operational costs. This includes expenses such as employee salaries, maintenance of the digital platform, marketing and advertising, customer support, and administrative overhead.
- **Marketing and Promotion:** A significant portion of the funding will be allocated to marketing and promotional activities to attract service providers and consumers to the platform. This includes digital marketing campaigns, social media advertising, and participation in relevant industry events.
- **Technology and Infrastructure:** As a digital platform, the SHOW Marketplace will require continuous investment in technology and infrastructure. This includes website maintenance, server hosting, software updates, and security measures to ensure a seamless and secure user experience.
- **Expansion and Growth:** Funding for expanding the marketplace into new markets, adding new product categories, and accommodating a growing user base. This could involve entering new geographic regions, collaborating with additional service providers, and scaling up operations.
- **Research and Development:** The SHOW Marketplace should allocate resources for ongoing research and development to stay at the forefront of CCAM technologies and services. This includes enhancing existing features, developing new functionalities, and adapting to emerging industry trends.
- **Working Capital:** A portion of the funding will serve as working capital to manage day-to-day financial needs, such as paying suppliers, covering operational expenses, and ensuring the smooth functioning of the platform.
- **Contingency and Risk Mitigation:** It is essential to set aside funds for unforeseen challenges, economic fluctuations, or unexpected obstacles that may arise during the development and operation of the SHOW Marketplace.

The exact funding requirements will depend on the scale, the speed of expansion, and the prevailing market conditions. A well-structured financial plan should provide a detailed breakdown of the funding requirements, specify the sources of capital (e.g., equity, loans, grants), and explain how the funds will be allocated to meet the objectives and milestones outlined in the business plan. Clear and transparent financial projections are crucial for attracting potential investors or securing loans to support the SHOW Marketplace's growth.

3 Service Development

3.1 Introduction

SHOW project aims to support the migration path towards affective and persuasive sustainable urban transport through technical solutions, business models and priority scenarios for impact assessment, by deploying shared, connected, electrified fleets of autonomous vehicles in coordinated Public Transport, Demand Responsive Transport, Mobility as a Service and Logistics as a Service operational chains in real-life urban demonstrations all across Europe.

Energy management plays a crucial role in fulfilling the SHOW project's objectives by optimizing the use of energy resources within the autonomous vehicle fleets, which in turn enhances operational efficiency, sustainability, and cost-effectiveness. Four energy-related solutions have been developed to align with these objectives, each designed to enhance efficiency, sustainability, and the overall mobility experience.

Firstly, the Centralized Platoon Control System is a solution that directly relates to the objective of using deep learning methods for efficient defect and maintenance management. This system enables cooperative driving by synchronizing the movement of multiple vehicles in a platoon formation. By anticipating and predicting potential issues, maintenance can be scheduled effectively, ensuring minimal downtime and enhanced operational efficiency.

Secondly, the Comprehensive Analysis of Electrified Powertrains across Different Driving Scenarios using Real-World Data addresses the objective of collecting and clustering energy and emission profiles for various vehicles. This solution involves an in-depth analysis of powertrain performance across diverse driving conditions, providing valuable insights into energy consumption patterns and emission levels. Such data-driven analysis facilitates the development of strategies to optimize energy use and reduce the environmental impact of vehicular operations.

Thirdly, the Low Carbon Mobility Management system is designed to meet the objective of modelling optimal use of charging infrastructure alternatives to maximize the fleet operating range of Connected and Autonomous Vehicles (CCAVs). This solution measures energy consumption and emissions of a trip via GPS and provides direct feedback to drivers through a dedicated app. By offering real-time insights into energy use and emission levels, this system empowers drivers to make informed decisions that contribute to lower carbon footprints and more efficient energy utilization.

Lastly, the mitigating range anxiety and enhancing battery efficiency in AVs based on SoC forecasting service offers a holistic solution to one of the most pressing challenges in managing AVs—precisely forecasting the State-of-Charge (SoC) of their batteries. This last service is based on statistical and ML methodologies to offer a complete energy related service.

3.2 Centralized Platoon Control System

3.2.1 Introduction

Global traffic transportation, due to significant traffic and congestion increase in urban areas in the last decades, is facing several challenges. That requires innovative solutions to ensure sustainability, safety, and efficiency. One of the solutions is the integration of electrified, connected and autonomous vehicles that can communicate and coordinate with each other to optimize traffic flow, reduce emissions, and improve safety and in consequence increase the acceptance and usage of the passengers in public transportation. A multi-vehicle cooperative control system strategy requires sophisticated algorithms and protocols that enable vehicles to share information about their state and intended trajectory and collaborate on route planning and traffic management.

Traffic congestion in urban areas has increased significantly in recent decades. In the SHOW project, connected autonomous electric vehicles and shuttles are driving and will increase traffic density, decrease energy consumption, and increase safety and comfort. Cooperative driving is one of the technologies that can provide a solution to these challenges in the future. One example of cooperative driving use cases is platooning of trucks on the highway, where heavy-duty trucks drive closely behind each other to reduce air resistance and thus energy consumption. In urban area, platooning can also contribute to increased road capacity and reduce traffic congestion by reducing the distance between vehicles and optimize the traffic flow. For platooning and driving manoeuvre coordination there are centralized or decentralized approaches known. The centralized needs more computational power then the decentralized approach but has a higher impact on energy savings.

For this purpose, a Centralized Cooperative Adaptive Cruise Control (C-CACC) for platooning and merge functions was chosen, developed, implemented, simulated and tested by FEV. This approach combines the automatic longitudinal velocity control with a Vehicle-to-Vehicle (V2V) information exchange through Codha MK5 electronic, such as reliable Vehicle-to-Vehicle communication, to enable a stable cooperative driving strategy in urban area for connected autonomous vehicles (CAV).

Within the SHOW project, FEV is engaged in the development, implementation and real vehicle testing of predictive and cooperative driving functions that incorporates an optimization-based longitudinal vehicle following strategy and merge-in manoeuvre management with an implemented safe, robust and wireless Cooperative Intelligent Transport Systems (C-ITS) V2V communication. Realistic traffic simulations are employed to evaluate the effectiveness of these centralized predictive and cooperative driving functions and control strategy in terms of energy-saving potential. In specific urban traffic scenarios, it has been determined that the implementation of these functions can result in an energy-saving potential of 21 %.

3.2.1.1 Problem Statement

In urban area, the main problem is the increasing traffic and inappropriate driving behaviours, which leads to an increase in energy consumption, pollution, congestions, noise, and accidents and decreasing travel comfort and traffic efficiency. Therefore, a push towards safe, comfortable, reliable, and efficient public transport is necessary.

One approach is to establish new electrified connected autonomous vehicles especially in the urban public transport. The missing acceptance problem of new electrified urban public transportation with autonomous shuttles needs to be solved. Therefore, the respective connected autonomous shuttles must be further developed with safe, comfortable, and optimized driving strategies and with stable V2V communication. A non-optimized control strategy could lead to large distance between vehicles and low average speed to increase safety and traffic efficiency. Besides the energy consumption optimization, the control strategy must deal with sudden changes in acceleration of the leader vehicle due to inappropriate driving, obstacles or neighbouring vehicles and has to ensures speed synchronization of follower vehicles with the leader's variable acceleration.

Another major challenge involves ensuring that the applications can operate during disruptions and failures such as other road users cutting in, communication and sensor failures, etc. These are the challenges that platoons and merge in of CAVs will face in real traffic situations, and they need to be considered.

Vehicle-to-vehicle communications can be unreliable as interference causes communication failures. Achieving reliable communications, which is a key element allowing for the minimal distance coordination and maximum average speed control of the platoon vehicles, might be challenging in case of heavy road traffic. Another problem lays in testing and evaluation of such new safety critical cooperative manoeuvre functions and new C-ITS V2V communication before they can be deployed.

3.2.1.2 Impact

All of the aforementioned aspects lead to the following negative impacts:

- Higher energy consumption and pollution
- Less efficient driving and higher congestion formation
- Less accident prevention
- Less driving comfort
- Less passenger acceptance and usage of cooperative autonomous vehicles in urban public transport

3.2.1.3 Solution

In view of the current state of the art and technology readiness, the combination of ADAS, autonomous driving and V2X offers great problem-solving potential. Nevertheless, the definition of a suitable control system is not often trivial, especially when dealing with multiple-objective problems and dynamics complexity. In this scenario, even though diverse strategies are possible (e.g., Equivalent Consumption Minimization Strategy, Rule-based strategy, etc.), the linear Model Predictive Control (MPC) turned out to be among the most effective ones in solving the aforementioned problems. MPC is highly dependent on the prediction model used. The FEV controller uses the linear MPC framework. Furthermore, multiple models and control inputs are considered throughout the development.

With the rapid development of V2X communication technologies and computational power, the centralized approach is the better option for vehicle merge manoeuvres and platooning focusing on energy consumption reduction. Compared to the decentralized control strategy, a centralized approach has the advantage that the interaction between vehicles can be considered in the control optimization problem and other systems for public transport management can also be integrated. Therefore, FEV chooses a novel solution to utilize centralized linear MPC for a multiple vehicle velocity control strategy, which considers the trade-offs between minimizing energy consumption and maximizing traffic flow under ideal communication conditions.

Within the SHOW project, FEV's problem solution is the development, implementation and real vehicle testing of predictive and cooperative driving functions based on the linear MPC such as C-CACC that incorporates an optimization-based longitudinal vehicle following strategy and merge-in manoeuvre management of a platoon of CAVs. With the usage of proven communication electronic Cohda MK5 and implemented safe, integer and wireless

C-ITS V2V communication, main problems of the V2V challenges can be solved so that not only the energy consumption but also comfort and safety can be improved.

To minimize the problem of testing and evaluation of such new safety critical cooperative manoeuvre functions and new C-ITS V2V communication FEV developed realistic traffic simulations to evaluate the effectiveness and stability of these new predictive and cooperative driving functions and control strategy before starting real drive tests.

To overcome several problems concerning simulation, real testing and safety aspects a comprehensive development process that considers both simulations and real tests was necessary, both to analyze its suitability to different scenarios and to show the real benefits and the acceptance of the users. Therefore, simulations for automated vehicles with the C-CACC algorithm was carried out before FEV integrated this algorithm into real vehicle, combined with standardized C-ITS V2V communication and tested on the ATC proving ground.

For communication each of the entities implement the service “Cooperative Lane Merge” (CLM), and the underlying “Cooperative Manoeuvre Protocol” (CMP). Both, the CLM and the CMP were designed and implemented by based on proposals from the 5GAA. The lower layers (Access, Geo Networking and Basic Transport Protocol (BTP)) are used as provided by the Codha Wireless V2X Module (MK5) the 5th generation On–Board Unit (OBU) and proven ready for large–scale field trials for V2V communication.

3.2.1.4 Approach

A search in scientific publications have also shown that a reduction of 12−17% in energy use can be achieved when a CAV is following a leading vehicle or manoeuvre leader with the specific objective of minimizing accelerations and decelerations. The energy savings will increase with the number of following vehicles. The platoon leader calculates the desired control signals with a linear MPC and sends them to the following vehicles. The trade-offs between minimizing energy consumption and maximizing traffic flow is considered in the optimization problem.

The centralized approach is implemented to optimize the total energy consumption of all vehicles while improving traffic efficiency. To solve a realistic optimal control problem, an additional data-driven velocity prediction model of the vehicle in front of the platoon is used to consider the cutting in of other road users or sudden acceleration changes of the preceding vehicle.

The centralized and cooperative driving functions enable energy efficient, safe, and comfortable merge-in and merge-out manoeuvres and platooning through:

- Utilizing optimization-based algorithm to minimize unnecessary acceleration and deceleration
- Applying a centralized approach for coordination of following, merge in and out manoeuvres
- Utilizing centralized driving manoeuvre management and calculation of the energy-efficient merging position
- Detecting the gap between vehicles earlier, so that the vehicle velocity behind the merging position will be reduced only slightly
- Smooth merging of the vehicle into the group
- Identification and definition of the signals to be exchanged for V2V communication, and integration of the signals into the interfaces

- Defining control and state signals of leading and following vehicles
- Integration of the V2V interface in the automated vehicle control unit (VCU) software
- Implementation of coordination functionalities in the VCU software
- Exploring the energy-saving potential during following drive between 10-22% depending on vehicle position in the group and their driving route
- Testing of vehicles on the ATC proving ground

Besides the energy consumption reduction, the string stability of the whole platoon can be optimized by the simulation with a realistic electric vehicle model in realistic urban scenarios and preceding vehicle simulation. With that, the robustness of the controller could also be simulated and optimized.

3.2.1.5 Benefit for end-users

Automated shuttles with centralized and cooperative driving functions will lead to high travel comfort, a more efficient traffic flow fewer accidents, which could ultimately lead to greater acceptance and use of autonomous public transport.

3.2.1.6 Contribution to SHOW objectives

With the new algorithms we can show the fulfilment of KPI 32, 33 and support of other KPIs (see Table 6).

Table 6: Excerpt of SHOW's KPIs.

Broader category	KPI #	Impact	RQ or target	Demo-sites	Simula-tion	Project targets
Environment and energy efficiency	26	Energy use	How does the introduction of the new mobility system change energy consumption of vehicles?	✓	✓	–
	27	CO_2, PM, NOx emissions	How does the introduction of the new mobility system change the amount of vehicle emissions related to transport in the area of interest?	✓	✓	–
	28	Air quality	How does the introduction of the new mobility system affect the air quality in the area of interest?	–	✓	–
	29	Noise levels	How does the introduction of the new mobility system affect the traffic noise in the area of interest?	✓	✓	–
	30	Reduction in CO_2	90% for CO_2 at city level	–	–	✓
	31	Reduction in noise level	30% reduction	–	–	✓
	32	Reduction in energy consumption	20% for passenger transport, 40% for freight	–	–	✓
	33	Reduction in energy consumption	10% reduction	–	–	✓

The results can also contribute to other KPIs, e.g. CO_2 reduction through energy savings, noise level reduction through traffic efficiency increase, increase in safety through safe V2V communication and surrounding detections, traffic flow increase / traffic congestion decrease through higher average speed, and driving comfort increase through optimization of acceleration and deceleration values.

3.2.2 Implementation

To enable the holistic coordination of interconnected vehicles, a method is developed to optimize multiple vehicle velocity trajectories within a single control problem. The primary objective of this method is to reduce the overall energy consumption for vehicle propulsion. To achieve this, a centralized cooperative driving function, known as Centralized Cooperative Adaptive Cruise Control (C-CACC) is initially tested using a scenario involving the platooning of vehicles on the same lane (see Figure 3).

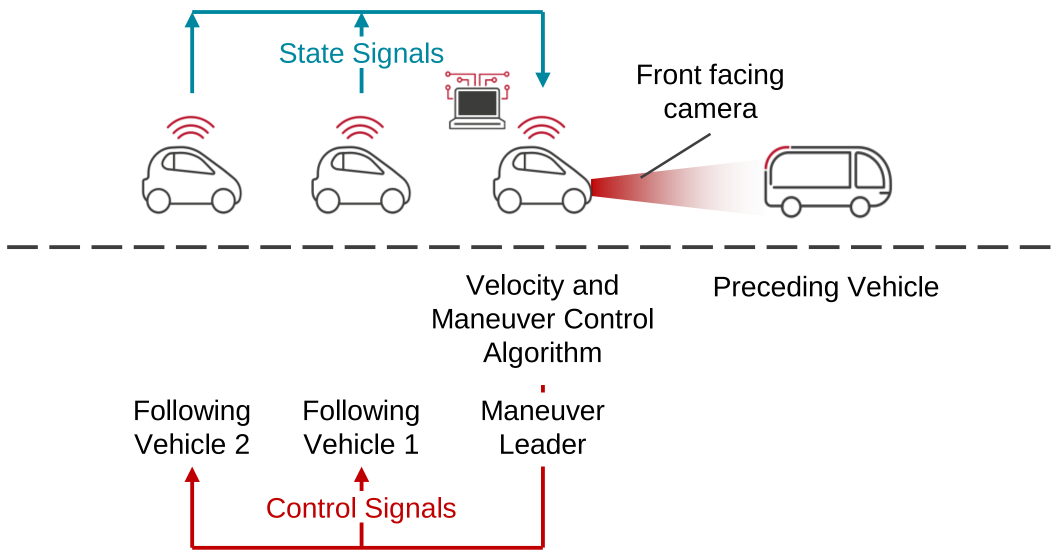

Figure 3: A schematic representation of a centralized platoon control system.

Unlike conventional platooning of trucks, which often prioritize aerodynamic advantages through close following, the centralized platooning control in urban areas pursues a different objective. Here, the goal is to optimize the velocity trajectories of all participating platoon vehicles, reducing unnecessary acceleration and deceleration to minimize the overall energy consumption. For this purpose, a linear MPC algorithm is employed to formulate and solve the optimal control problem (Figure 4).

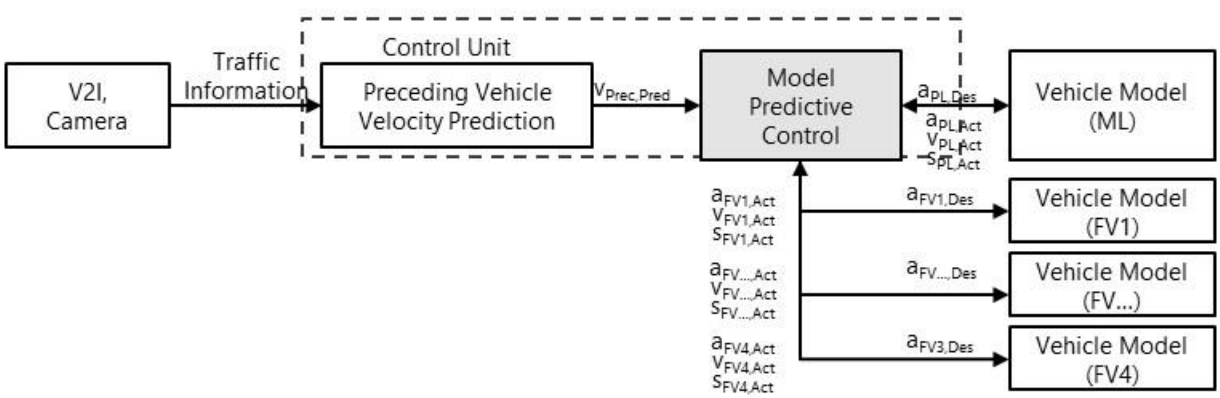

Figure 4: Simulation implementation.

A comparative analysis was conducted to analyse the potential energy savings between the C-CACC and a state-of-the-art adaptive cruise control (ACC) in an urban setting (see Figure 5). The study involved a simulation where a platoon consisting of one manoeuvre leader (ML) and four following vehicles (FV1-4) following a preceding vehicle (bus) with a predefined velocity profile encompassing urban and suburban areas. The speed limits in these areas were set at 50 km/h and 70 km/h, respectively. To evaluate the energy consumption, a battery electric vehicle plant model was employed. In the reference simulation, all vehicles utilized a state-of-the-art ACC algorithm. The simulation results revealed a significant difference in the velocity profile and electrical motor (EM) power between C-CACC and ACC.

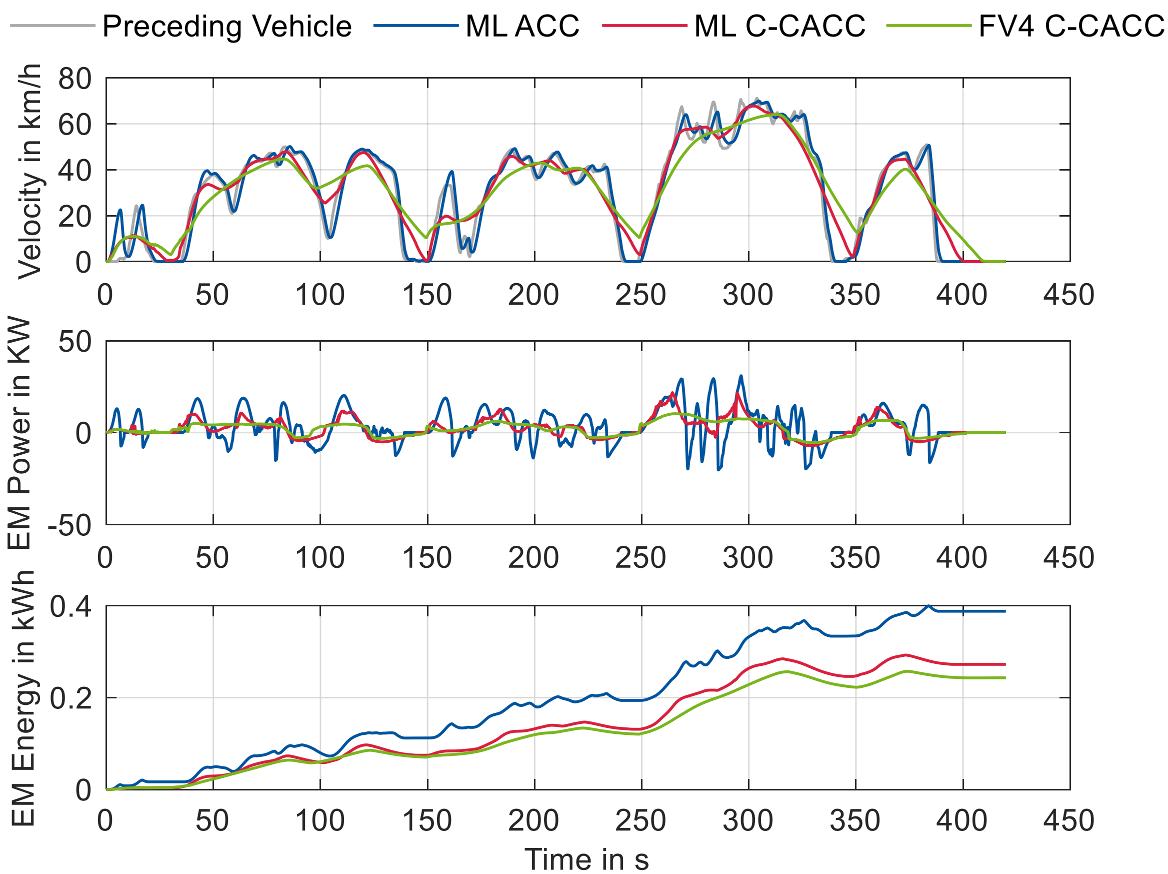

Figure 5: Simulation results of vehicle velocities, EM-power and energy, comparing ML equipped with ACC and C-CACC and FV4 with C-CACC.

By comparing the velocity and EM power profiles of the ML using both C-CACC and ACC, it becomes evident that the amplitude of these profiles is lower with C-CACC compared to ACC. This indicates that C-CACC effectively reduces unnecessary acceleration and deceleration, even in scenarios where the preceding vehicle (bus) frequently changes its velocity. As a result, the total energy demand for traction is reduced, leading to an energy-saving potential of 29% (as shown in Table 7).

Another aspect of the energy-saving potential can be observed by comparing the simulation results of the ML and the FV4, both utilizing C-CACC. FV4 exhibits lower deceleration, occurring earlier than that of the ML, which eliminates any standstill phases for FV4 during the simulation with the selected driving profile. The amplitude of the velocity profile for FV4 is even smaller than that of the ML, consequently affecting the overall EM energy consumption. A comparative analysis indicates an energy-saving potential of 11% when comparing FV4 to the ML.

	Test with ACC	*Test With C-CACC (ML)*	*Test With C-CACC (FV4)*	*Energy Saving Potential (ML C-CACC vs. ACC)*	*Energy Saving Potential (FV4 vs. ML)*
Traction Energy Consumption	13.70 kWh /100 km	9.63 kWh/100 km	8.56 kWh/100 km	29 %	11 %

Table 7: Comparison of traction energy consumption of ML with ACC and C-CACC and FV4 with C-CACC.

To validate the simulation results in real-world conditions, FEV implemented the C-CACC algorithm in a demonstrator vehicle equipped with a Micro-Autobox (MABX) as a prototype controller (VCU). This integration involved incorporating the C-CACC algorithm solely for the ML into the vehicle's control system. Figure 6 illustrates the schematic representation of the software integration of the C-CACC algorithm within the vehicle.

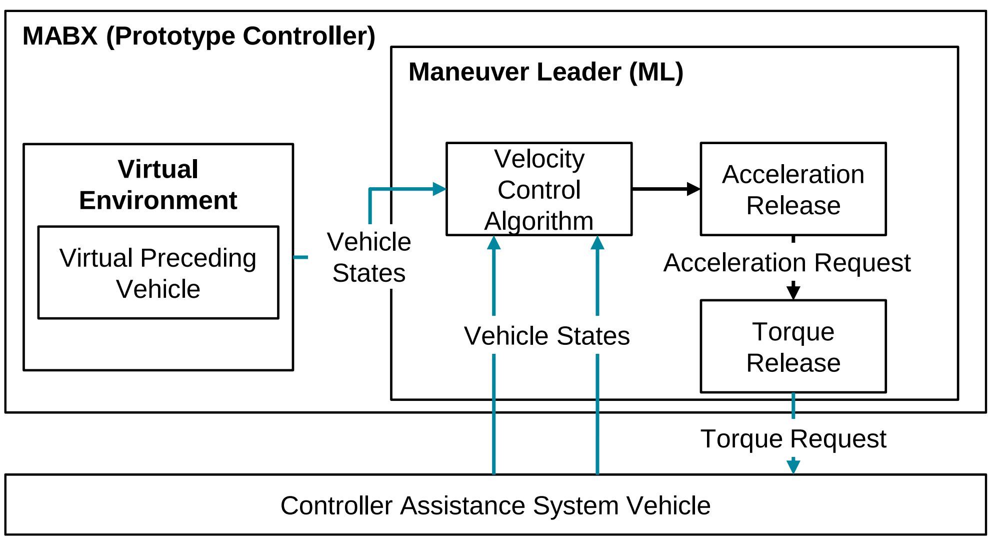

Figure 6: A schematic representation of a software integration of C-CACC algorithm in vehicle.

In a virtual environment, the velocity and position of the preceding vehicle (shuttle bus) are determined based on the predefined velocity profile, similar to the simulation. These preceding vehicle (shuttle bus) states are then transmitted to the velocity control algorithm (C-CACC) implemented in the ML. Additionally, the real-time vehicle states of the ML, such as its current velocity and acceleration, are also fed into the velocity control algorithm through the vehicle controller assistance system.

Using the optimization results obtained from the C-CACC algorithm, the acceleration profile of the ML is calculated. Based on this acceleration profile, the corresponding torque request is generated and transmitted to the vehicle controller assistance system. The vehicle controller assistance system then utilizes this torque request to facilitate the actual vehicle movement and propulsion, enabling the ML to move forward according to the desired velocity and acceleration determined by the C-CACC algorithm.

In urban traffic environments, driving scenarios can become more complex due to factors such as varying driving destinations, different driving behaviours, and interactions between passenger cars and public transportation, such as automated electric shuttle buses. These situations often involve various types of manoeuvres, including joining, merging in, and merging out. In the context of the SHOW project, FEV specifically focused on the merging manoeuvre, as represented by the merge-in vehicle in Figure 7.

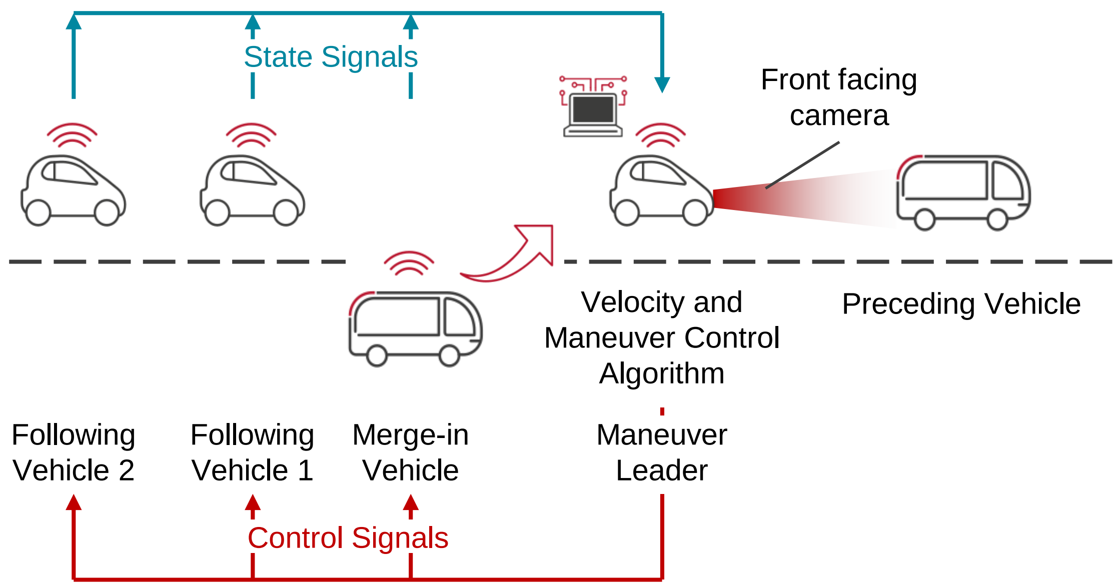

Figure 7: A schematic representation of a centralized platoon control system with merge-in vehicle.

If a merge-in vehicle (MV), such as a shuttle bus, departs from a bus station and intends to merge into a platoon, it can send a merge request to the ML using V2V communication. Upon receiving this merge request, the manoeuvre controller algorithm in the ML is activated. The manoeuvre controller then utilizes optimization-based calculations to determine an energy-optimized merging position for the MV. Simultaneously, the ML takes over the velocity control of the MV. Once a sufficient gap between two vehicles is detected, providing enough space for the MV to merge in while maintaining a safe distance, the ML sends a merge enable signal to the MV. Upon receiving this signal, the MV is authorized to perform the lane change and execute the merging manoeuvre.

To facilitate testing in real vehicles, FEV demonstrated a second vehicle equipped with another MABX (VCU) (Figure 8). In both vehicles, a MK5[6] module is integrated to enable vehicle-to-vehicle (V2V) communication. Furthermore, in the virtual environment, additional following vehicles are simulated. In the ML, the MK5 module is responsible for transmitting the acceleration request of the following vehicle 1 (FV1). This acceleration request is received in FV1 and then transmitted to the MABX (VCU) in FV1. Based on the requested acceleration, the corresponding torque is calculated and sent to the vehicle controller assistance system to facilitate the desired vehicle movement.

[6] MK5: Cohda Wireless' 5th generation On–Board Unit (OBU), [MK5 OBU - Cohda Wireless]

The vehicle states of FV1 are collected within the MK5 module in FV1. Then, these vehicle states are sent back to the MK5 module in the ML for further processing and coordination. This exchange of information between the MK5 modules in both vehicles enables the cooperative driving and coordination between the manoeuvre leader and the following vehicle.

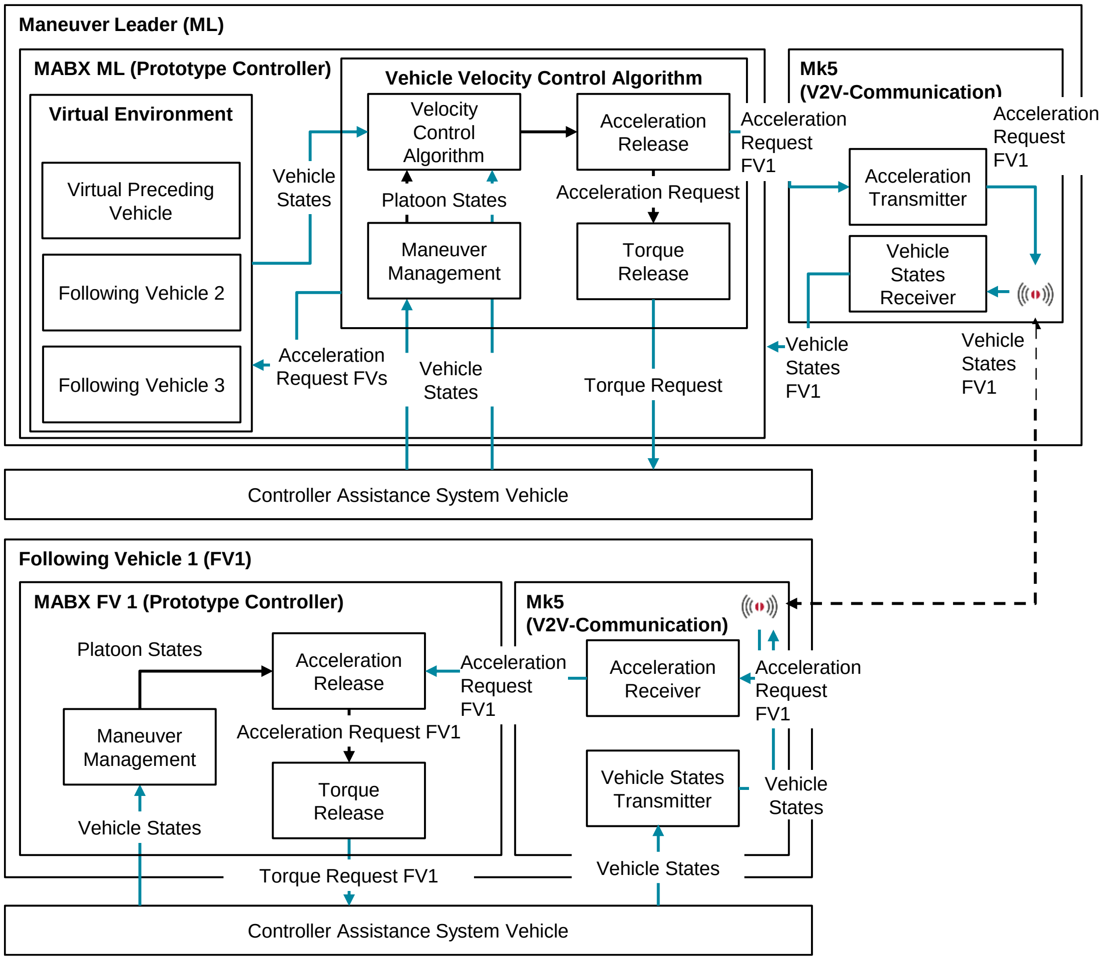

Figure 8: A schematic representation of a software integration of C-CACC algorithm in vehicle ML and FV1.

3.2.2.1 Vehicle-to-Vehicle (V2V) Communication

Through Vehicle-to-Vehicle (V2V) communication, inter-vehicle communication, and high-precision sensors, multi-vehicle cooperative control makes the driving process safer. It not only reduces traffic accidents caused by human errors but also provides greater safety and efficiency compared with stand-alone autonomous driving technologies that rely heavily on sensor performance.

For the cooperative following and merge manoeuvres as described the shuttle bus driver (preceding vehicle) triggers execution of a co-operative manoeuvre. The entities in the system of vehicles, control module and communication modules interact by means of direct Vehicle-to-Vehicle (V2V) communication. The communication entities take different roles for the manoeuvre cooperation: manoeuvre initiation, manoeuvre coordination and manoeuvre control.

The “Bus” (preceding vehicle) is the initiator of the manoeuvre request, the “Manoeuvre Lead” (ML) takes the coordination and control, and “Follow Vehicles” are as platoon members centrally controlled by the ML (Figure 9). Note that the ML and the Platoon Lead (PL) are the same vehicle in this setup. The ML coordinates and controls the manoeuvre and hosts the C-CACC Software Module. For communication, each of the entities implement the service “Cooperative Lane Merge” (CLM), and the underlying “Cooperative Manoeuvre Protocol” (CMP).

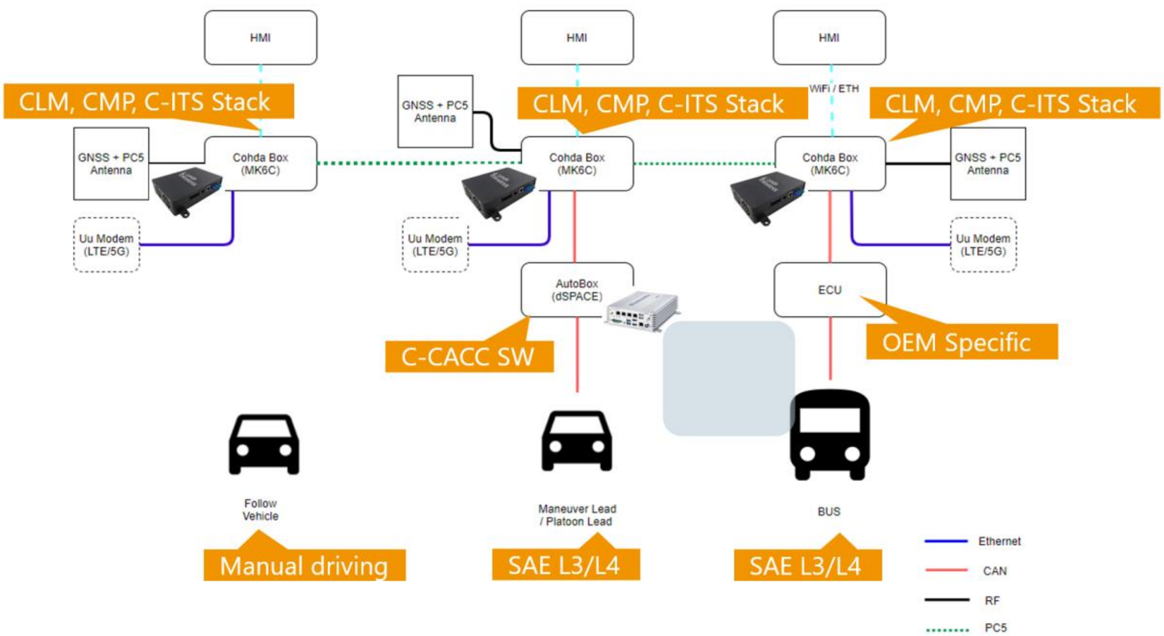

Figure 9: System Architecture – CLM=Cooperative Lane Merge; CMP= Cooperative Manoeuvre Protocol; SAE L3/4 = Driving Automation Level 3 or 4.

Both, the CLM and the CMP where designed and implemented by FEV.io GmbH, based on proposals from the 5GAA [7]. The communication protocol stack is depicted in Figure 10: The lower layers (Access, Geo Networking and Basic Transport Protocol (BTP)) are used as provided by the *Codha Wireless* V2X Module (MK5 or MK6). Those Layers are standardized by C-ITS standards[8]. The standard services of the *Facility Layer* and *Application Layer* are enhanced by the new FEV.io proprietary services “CMP” on the Facility Layer level and the “CLM” on Application Layer level.

Generally, for layered communication, architectures *services* of a lower layer are offered through Service Access Points (SAPs) to higher level services. Concretely, for the given implementation the CMP for example uses the (standard) services of the BTP layers (SAP_{BTP}) and offers its own services to the CLM (SAP_{CMP}). The protocol stack on the right-hand side of Figure 10, i.e. the MQTT Service on top of TCP/IP is used for simulation purposes as a Software in the Loop (SiL) system. In such a system the MQTT message broker service is used instead of the BTP service.

[7] Ref: 5GAA White-Paper “C-V2X Use Cases Volume II”
[8] Ref: C-ITS-Brochure-2020-FINAL.pdf (itsstandards.eu)

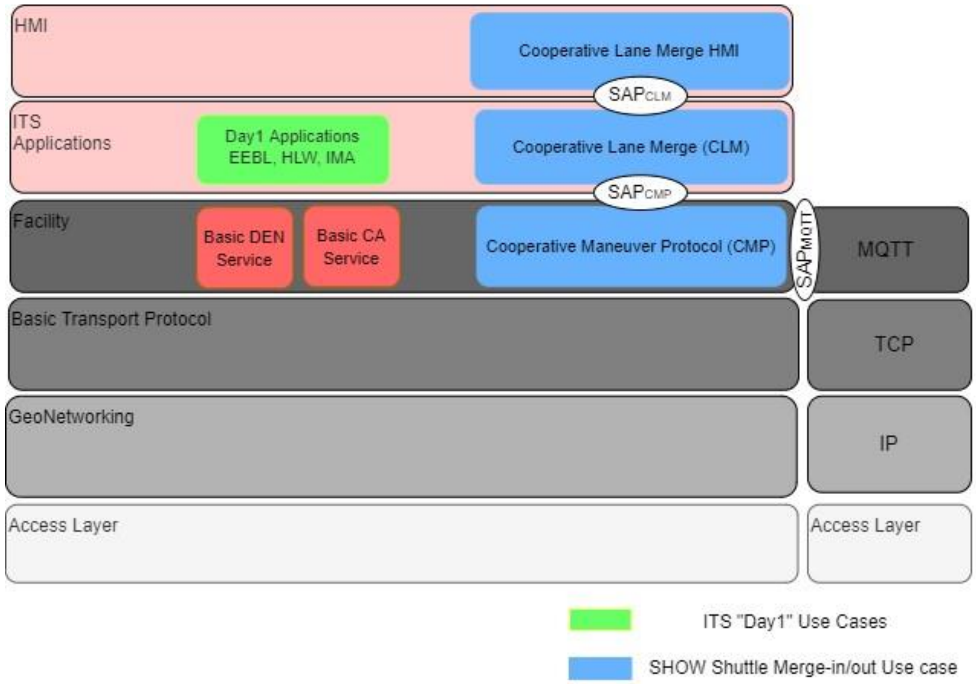

Figure 10: Enhancements of the C-ITS Protocol Stack to realize a Cooperative Manoeuvre Use Case and communication.

3.2.2.2 The Protocol Sequence

The communication protocol used for the SHOW project is illustrated in the Sequence Diagram in Figure 11. The first phase, the “Connection Establishment” phase is initiated by the bus driver who would like to enter or leave the ongoing traffic. This event triggers the build and send of the *Manoeuvre Intent Request* (MIR) message, which transports the manoeuvre intent, the type of manoeuvre some vehicle information to the target vehicles. The collaborative manoeuvre is acknowledged in a three-way-handshake: Manoeuvre *Intent*, Manoeuvre *Feedback* and Manoeuvre *Confirmation*.

After the decision for the common manoeuvre, the ML/PL takes the control over the platoon members and sends the desired vehicle acceleration and/or deceleration values in a regular manner. After all, the bus driver can stop the manoeuvre any time with either an explicit “Manoeuvre Stop Request” or by any manual override of a vehicle function.

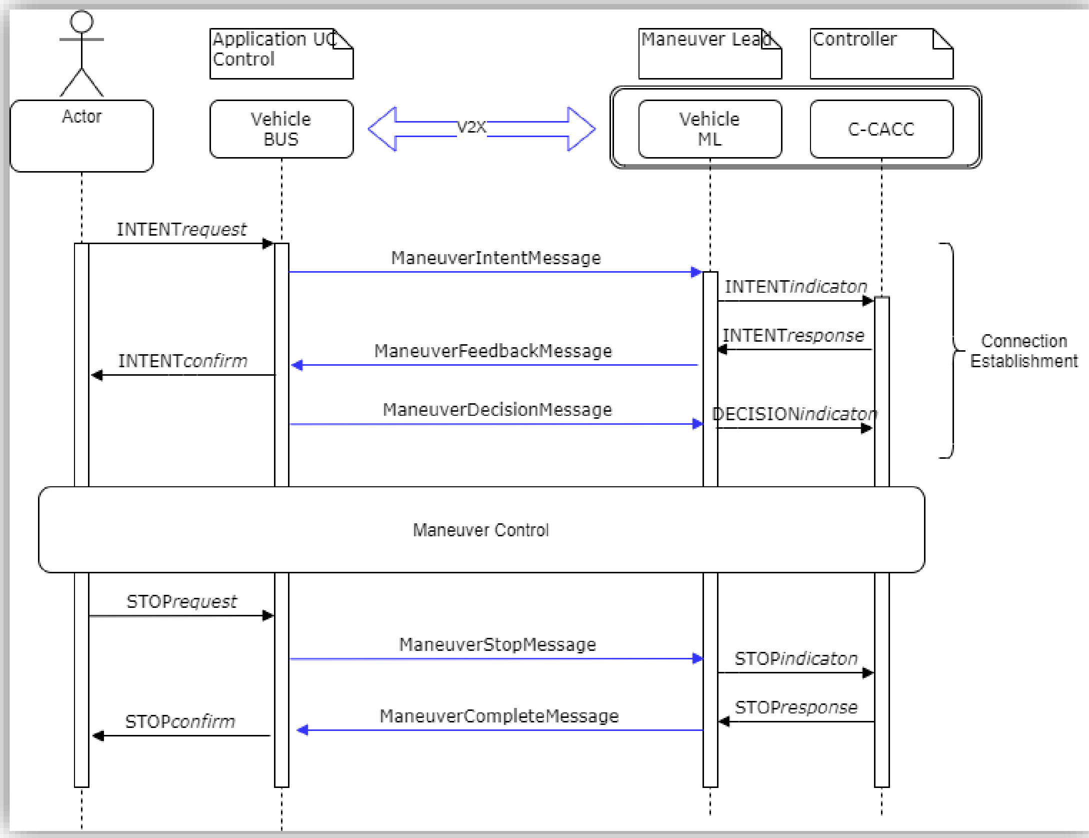

Figure 11: Sequence Diagram for the Cooperative Manoeuvre Protocol (CMP).

3.2.2.3 Limitation and Challenges

During the integration and testing of C-CACC in two demonstrator vehicles with V2V communication, we have encountered the following limitations and challenges:

1. The accuracy of the positions of all vehicles within a platoon can impact the results of the algorithm.
2. The effectiveness of C-CACC heavily relies on reliable and low-latency V2V communication.
3. Integrating C-CACC into a larger scale transportation system requires significant computational power to handle the coordination and communication between vehicles.

3.2.3 Integration

3.2.3.1 Use Cases

The main use case of FEV is UC1.4

- **UC1.4: Energy sustainable automated passengers/cargo mobility in Cities:** With the simulation, driving results, and fulfilment of KPI 32 and 33, FEV was able to show that by using an energy sustainable operation, the CAV operation (passenger or cargo) can cover the same services than conventional vehicles and even more.

- **UC1.1: Automated passengers/cargo mobility in Cities under normal traffic & environmental conditions:** By using centralized and cooperative driving functions in real traffic simulation, FEV was able to support the improvement of efficiency as well as driving comfort in normal speeds and cutting in vehicles and contribute therewith also slightly to UC1.1.

- **UC1.6: Mixed traffic flows:** By using centralized and cooperative driving functions in real traffic simulation FEV was able to support the improvement of road safety and efficiency as well as driving comfort and contribute therewith also slightly to UC1.6.

- **UC1.8: Platooning for higher speed connectors in people transport:** By using centralized and cooperative optimized driving functions in real traffic simulation of platoons, FEV was able to support and show the improvement of energy efficiency, traffic flow, and higher average speeds and could contribute therewith also to UC1.8.

- **UC3.4: Automated services at bus stops:** By using centralized and cooperative optimized driving functions in real traffic simulation and C-ITS V2V communication of platoons, FEV was able to support and show the improvement of automatic handling bus stop approach and merging and could contribute therewith also slightly to UC3.4.

3.2.3.2 Integration speed trace from LCMM-System of Frankfurt shuttle

For further investigation of real energy-saving potential in the SHOW project, by using SHOW data, the recorded speed profiles of the Frankfurt shuttle bus were used. The SHOW data were used in the multi-vehicle C-CACC simulation environment as the preceding vehicle's driving profiles. The centralized and cooperative optimized driving functions in real traffic simulation with the novel solution of using centralized linear MPC for a multiple vehicle velocity control strategy considers the trade-offs between minimizing energy consumption and maximizing traffic flow under ideal communication conditions. A segment of the driving profiles is depicted in the following Figure 12.

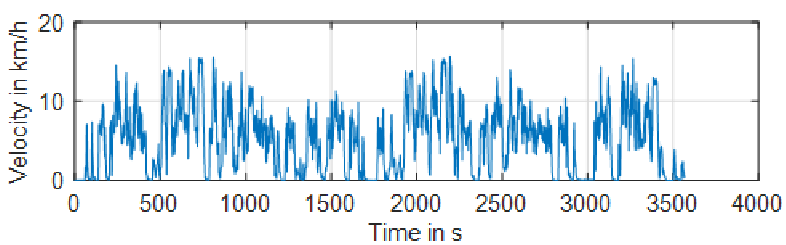

Figure 12: A segment of the Frankfurt shuttle driving profiles.

The traffic scenario includes a driving route with a bus stop and a preceding vehicle driving in the same lane as the ML vehicle. The velocity profile of the preceding vehicle is selected from real measurement data from FEV data base. Figure 13 presents a schematic diagram of the merge-in manoeuvre. A centralized adaptive Cruise Control (CACC) function controls the velocity of the ML. Through the front facing sensor, the FVs can measure the distance and relative velocity of the preceding vehicle. The acceleration of the preceding vehicle is sent to the respective following vehicle via C-ITS V2V communication. Utilizing a three-layer cascaded control loop: a distance, a speed, and an acceleration controller, which are all designed as proportional-integral (PI) controller, the desired torque at the wheel can be calculated and forwarded to the vehicle model. With the help of this C-CACC functionality, during the whole simulation the distances between vehicles remain stable.

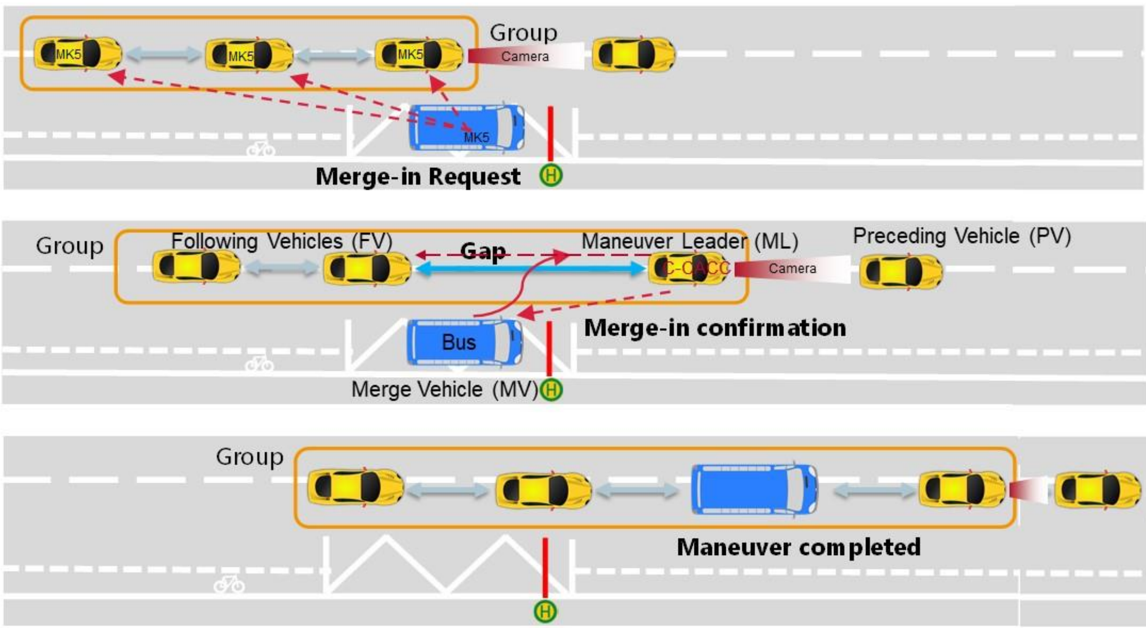

Figure 13: Merge manoeuvre overview.

- Manoeuvre Leader (ML) is driving at a defined speed behind the preceding vehicle (PV)
- Bus (Merge vehicle - MV) and following vehicle (FV) are driving at the same speed with a constant safety distance
- Bus (MV) intents to serve an upcoming bus stop and communicates this intention together with the planned deceleration or velocity profile to the ML of the formed vehicle group earlier than the merge manoeuvre is actually performed.
- Bus (MV) initiates bus stop manoeuvre
- ML and following vehicles (FV) optimize their velocity with regards to the upcoming stop of the bus, a safe distance and energy efficiency
- MV performs the bus stop service
- Passengers depart and enter the shuttle
- MV finishes the bus stop service and communicates the intention to depart including the planned acceleration or the planned velocity profile to ML of the formed vehicle group
- MV initiates the bus stop departure manoeuvre
- ML and FV optimizes their velocity with regards to the departure of the MV and with regards to energy efficiency and maximum safe traffic flow

Compared to the preceding vehicle, the amplitude of acceleration and the velocity of all vehicles in the platoon are smaller than those of the preceding vehicle. For each vehicle in the platoon, these values are also smaller than for its own preceding vehicle. The distance between the vehicles remains almost the same except at gapping during merge manoeuvres, which means that the rule-based C-CACC algorithm can keep the platoon string stable, and the algorithm is well-designed and can be used as the baseline for the evaluation of the developed C-CACC algorithm.

3.2.4 Summary

After the adaptation, compilation and integration of the C-CACC software into the MABX prototype controller the implementation and integration of the MABX was done first with one automated demonstration vehicle. The results show that adopting the C-CACC system in a five-vehicle platoon substantially decreases fuel consumption and emissions compared with the ACC system and manually-driven vehicles. Furthermore, it reduces the driving volatility and reduces the risk of rear-end collision which consequently improves safety. The results of the merging scenario showed that during the cooperative merging manoeuvre, the system slightly reduces the driving inconsistency, the energy consumption and emissions decreases because of less dynamic accelerations of C-CACC vehicles compared with ACC vehicles but maximizing the average speed of the platoon. Moreover, the results demonstrated that the C-CACC system can improve energy economy and safety compared with the ACC system. The advantage is that the optimization problem can find a solution with the best benefit between vehicle acceleration, or rather energy efficiency and string stability. The real vehicle test was carried out at the Aldenhoven Testing Center (ATC), during which measurements of the actual DC Link voltage and current were taken. Like the simulation setup, the velocity profile, EM power, and energy consumption of the ML using both ACC and CACC were plotted in Figure 14.

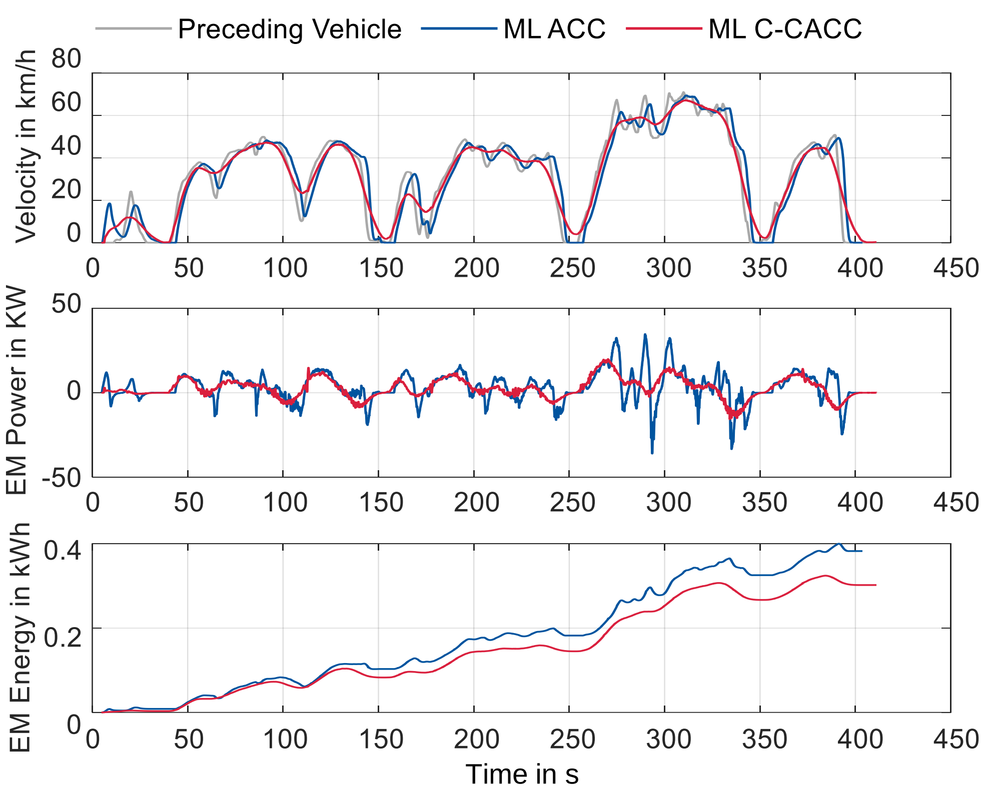

Figure 14: *Vehicle test results of vehicle velocities, EM-power and energy, comparing ML equipped with ACC and C-CACC.*

Similar to the simulation results, the amplitude of the velocity and EM power profiles of the ML using C-CACC is lower when compared to ACC. This reduction in amplitude leads to a decrease in traction energy consumption. Table 8 presents the traction energy consumption of the ML using both ACC and C-CACC. The ML using ACC exhibits a traction energy consumption of 10.7 kWh/100 km, whereas the ML Using C-CACC achieved a lower traction energy consumption of 8.4 kWh/100 km. This indicates an energy-saving potential of 21% during the real vehicle test with the predefined velocity profile of the preceding vehicle (bus). During real vehicle tests, drivability and comfort was evaluated by different passengers. With reduced acceleration and deceleration, the driving experience could be improved with C-CACC in comparison to ACC only. The driving experience leads to a much more pleasant and smoother behaviour and a higher level of acceptance.

Table 8: Comparison of traction energy consumption of ML with ACC and C-CACC.

	Test with ACC	*Test With C-CACC*	*Energy Saving Potential (ML C-CACC vs. ACC)*
Traction Energy Consumption	*10.7 kWh /100 km*	*8.4 kWh/100 km*	***21 %***

It can be observed that the energy-saving potential differs between simulation and real vehicle testing. This discrepancy is attributed to the differences in vehicle parameter settings between the vehicle model used in the simulation and the real vehicle used on the ATC. The vehicle model has also different behaviours compared to a real vehicle, leading to variations in the energy-saving potential.

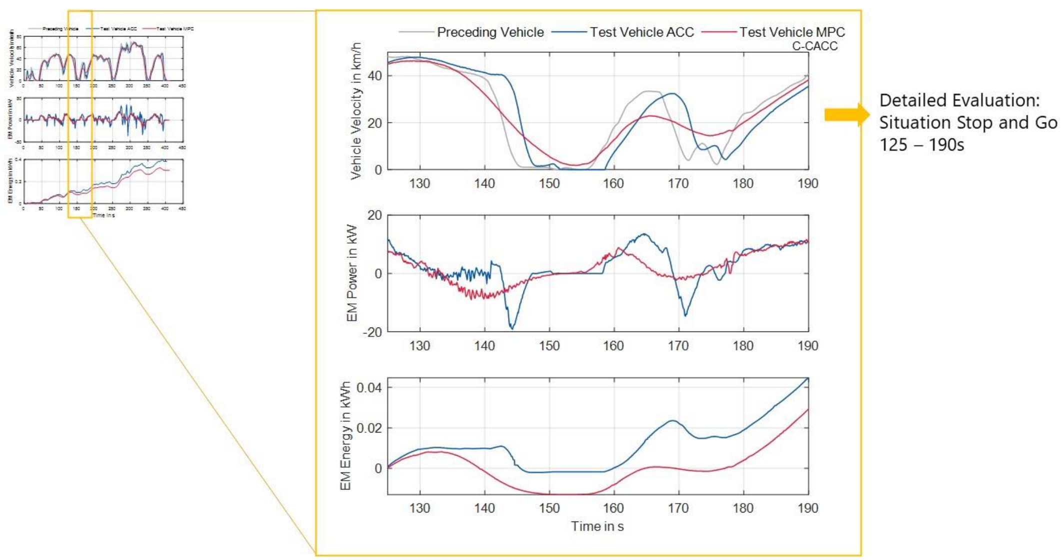

Figure 15: Vehicle test results of vehicle velocities, EM-power and energy, comparing ML equipped with ACC and C-CACC of Stop and Go situation (125s – 190s).

Detailed investigation in Stop and Go situation showed a reduced stop time and lower amplitude of the velocity and EM power profiles of the ML using C-CACC when compared to ACC. This reduction leads to a decrease in traction energy consumption. Table 3 presents the traction energy consumption of the ML using both ACC and C-CACC in the detailed Stop and Go situation. The ML using ACC exhibits a traction energy consumption of 10.4 kWh/100 km, whereas the ML using C-CACC achieved a significant lower traction energy consumption of 6.9 kWh/100 km. This indicates an energy-saving potential of 34%

during the real Stop and Go vehicle test with the predefined velocity profile of the preceding vehicle (shuttle bus).

Table 9: Detailed comparison of traction energy consumption of ML with ACC and C-CACC in Stop and Go situation.

	Test with ACC	*Test With C-CACC **(125s – 190s)***	*Energy Saving Potential (ML C-CACC vs. ACC)*
Traction Energy Consumption	*10.4 kWh /100 km*	*6.9 kWh/100 km*	***34 %***

The energy saving potential in stop and go urban traffic is up to 30% (KPI 32 and 33). Along with the aforementioned, the results can also contribute to other KPIs e.g. CO2 reduction through energy savings, noise level reduction through electric CAV use, increase in safety through safe V2V communication and surrounding detections, traffic flow increase / traffic congestion decrease through higher average speed, and driving comfort increase through optimization of acceleration and deceleration values.

As a continuation the European Program "Horizon 2020" the Hi-Drive[9] Project is one of the successors of SHOW (in this respect). We as FEV.io GmbH are a project member of the Hi-Drive project. The communication technology (i.e. protocol stack code libraries) from SHOW can be re-used and enhanced for the Hi-Drive context. The anticipated principle for the communication protocol stack is outlined in Figure 16.

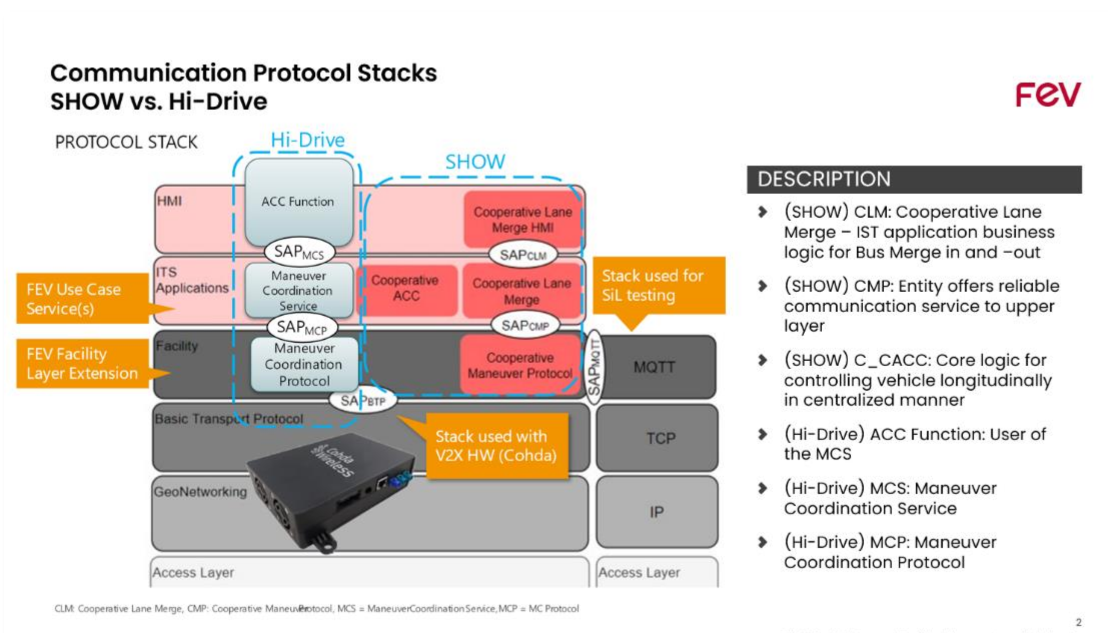

Figure 16: Re-use and enhancement of the SHOW code base for the Hi-Drive project.

[9] Hi-Drive Deployment of Higher Automation

3.3 Low Carbon Mobility Management

3.3.1 Introduction

In today's world, where environmental sustainability is more critical than ever, every individual and organization must contribute to reducing their carbon footprint. Transportation is a major source of greenhouse gas emissions. With innovative technologies, there is the power to make significant changes. "Low Carbon Mobility Management" (LCMM) is a smartphone application, developed by T-Systems, designed to analyze trip-data and give real-time driving behaviour feedback as well as post-trip calculations for emissions and fuel consumption. The calculations are based on the ISO-23795 standard.

3.3.1.1 Problem

Transportation accounts for nearly one-quarter of global CO_2 emissions. To achieve the necessary deep cuts in emissions, transportation must play a significant role. State-of-art calculations are based on the vehicle information given by the manufacturer, which is not taking into account the driving behaviour or routing aspects. Other solutions, such as on-board-units are rather expensive and therefore not used in bigger fleets.

Additionally, the European Union has established stringent regulations to reduce carbon emissions, including the EU Green Deal, which sets ambitious targets for emissions reductions across various sectors, including transportation. Compliance with these regulations is crucial for achieving the desired environmental outcomes. Additionally, the European Emission Trading System imposes financial costs on distributors who exceed their emissions allowances. This creates an economic incentive for transportation companies to adopt more efficient and less polluting technologies and practices.

3.3.1.2 Impact

The information currently provided by manufacturers primarily focuses on the technical specifications of vehicles. However, this data often does not account for real-world variables such as driving behaviour and routing choices, which can significantly impact fuel consumption and emissions. The lack of consideration for these factors presents a substantial gap in accurately assessing and mitigating transportation-related emissions.

The current state-of-the-art solutions for monitoring and managing vehicle emissions are predominantly based on On-Board Units (OBUs). These devices collect data on vehicle performance and emissions, providing insights into fuel efficiency and CO_2 output. However, these solutions are often prohibitively expensive, limiting their widespread adoption, particularly among smaller fleets and independent operators.

3.3.1.3 Solution

The LCMM algorithm is based on Newtonian physics and makes driving behaviour measurable. The solution measures acceleration and braking via GPS-equipped smartphones, creates speed profiles, and gives drivers instant feedback on their driving. The LCMM application provides information on the impact of fuel consumption and CO_2 emissions, resulting in a sustainable improvement of the customer's carbon footprint. Fuel consumption and emissions were reduced significantly in a three-year pilot phase in China, conducted with taxi, bus, and logistics companies. Since 2019, the suggested algorithm is ISO- standardized, giving the customer even better transparency on the calculation of consumption and emission.

3.3.1.4 Benefit for the end-users

Anticipatory driving techniques coupled with the direct feedback from the (LCMM) smartphone application benefits several different fleet operators (logistics, public transportation, etc.) but also private users. Higher traffic safety is achieved through the application's real-time monitoring and feedback mechanisms, which help drivers adopt safer driving practices, thereby reducing the likelihood of accidents. Improved driving techniques promoted by the app also lead to lower vehicle maintenance costs due to decreased wear and tear. The application provides drivers with timely, actionable insights into their driving habits.

Environmental benefits are substantial, including lowered CO_2 emissions and reduced pollutants in the ambient air, contributing to better overall air quality. Additionally, anticipatory driving helps decrease noise pollution, creating a quieter and less disruptive environment. The cumulative effect of these improvements is related to fuel and cost savings, further incentivizing the adoption of the LCMM application. By promoting more responsible behaviour in road traffic, the app ensures that drivers are more conscious of their impact on both safety and the environment. The integration of these technologies represents a comprehensive approach to achieving sustainability and efficiency in transportation.

3.3.2 Implementation

The fuel/ energy consumption and emission output determination is achieved by extracting trip data and speed profiles from the Global Navigation Satellite System (GNSS) receiver of a nomadic device (ND), by sending it via mobile communication to a database server and by calculating the deviation of the mechanical energy contributions of:

a) aerodynamics,

b) rolling friction,

c) acceleration/braking,

d) slope resistance and

e) standstill,

relative to a given reference driving cycle in %. As the mechanical energy consumption of the reference cycle is known by measurement with a set of static vehicle configuration parameters, the methodology enables drivers, fleet managers or logistics service providers to calculate and analyse fuel consumption and CO_2 emissions per trip by simply collecting trip data with a GNSS receiver included in an ND inside a moving vehicle. In addition to the on-trip and post-trip monitoring of energy consumption (fuel, CO_2), the solution also provides information about eco-friendly driving behaviour and road conditions for better ex-ante and ex-post trip planning. Therefore, the solution also allows floating cars to evaluate the impact of specific traffic management actions taken by public authorities with the objective of achieving GHG reductions within a given road network.

3.3.3 Integration

To obtain information about the energy behaviour per trip, a low-cost solution called Low Carbon Mobility Management (LCMM) cloud platform architecture has been developed and applied in a number of pan-European logistics projects. This solution considers the economic constraints felt by most logistics companies and their difficulties in investing in the introduction of new technologies. A plug-&-play solution is adopted, where GPS data provided by the HDVs are sent to a database, elaborated, analysed, mapped and then given back in a simplified version to drivers and dispatchers.

The process is as follows: primary GPS data about vehicles derives from a mobile phone installed in the truck. Such data, which include time, latitude, longitude, speed and altitude, are transmitted every fifteen seconds to the server platform. Since the average duration of a mobile phone with GPS turned on is four hours, which is a short period in comparison to the average daily tour of a truck, the mobile phone is equipped with an external battery that extends the duration of the battery to the duration of the entire trip. With this system, the driver needs to turn the device on or off only once a day and can use the smart phone as a telephone or mobile internet device during the day without losing any information.

Before the beginning of each trip, all users need to register their vehicle configuration according to a predefined database and register some user information including the average payload of the specific trip. Data is transmitted to the LCMM platform, which includes three main technical components:

1) A nomadic device with GNSS satellite receiver, e.g. GPS.

2) The radio data transmission to connect device and cloud server.

3) An Internet of Things (IoT) or ICT back-end platform to receive trip data and manage the device.

4) A web-interface to give fleet-operator or others access to the trip data.

The collected GPS data are analysed and evaluated within the database server by any programming language: in the piloted projects, PHP was used. Inside the server, the percentage deviation relative to reference cycle, nowadays WLTP, is calculated and used as a basis for determining fuel consumption and CO_2 emissions.

3.3.3.1 Front End

On-trip visualization for drivers is limited by safety concerns and involves nothing more than a short glance at the colour coding to acquire some feedback on driving eco-mode or not. The positive learning effect for drivers is rather linked to remembering the principles of eco-mode driving by using inertia forces and smart braking or choosing the right speed on motorways according to traffic flow and trip planning. The ex-post evaluation then clarifies details of positive or negative impact on energy demand linked to certain driving manoeuvrers.

Whenever trip recording needs to be stopped, drivers press a stop button to terminate trip recording. Before shutting down the LCMM APP, drivers are informed about some general evaluation results of the recorded trip. These include CO_2 emissions, ranking inside the fleet of users, trip costs or savings, as well as indications for improvements in percentage.

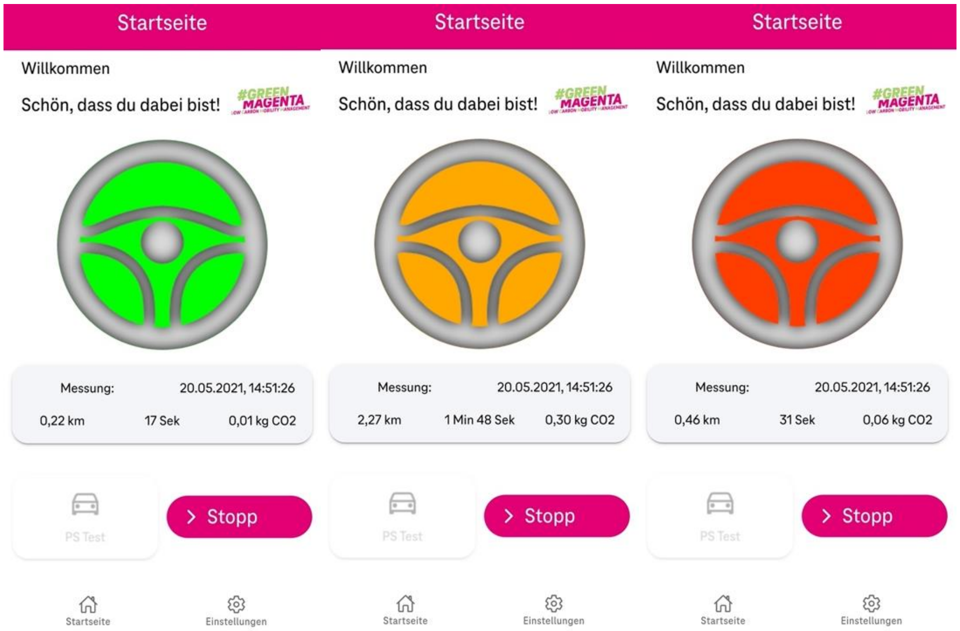

Figure 17: Frontend visualization of LCMM

3.3.3.2 Backend

The LCMM back-end offers several possibilities for online-monitoring and reporting functions. Feedback on driving performances is provided back to freight transport operators through the website platform (for post-trip evaluations and tour planning of the fleet manager), or through the front-end Android application (for real-time evaluations) mentioned in Figure 17. The website platform provides detailed information about the time of the trip listed as well as the duration of trip, distance travelled, average speed, energy behaviour in percentage relative to reference cycle from during the field trial the European Driving Cycle (Urban UDC and Extra-Urban EUDC).

An example of the appearance of the website evaluation of recorded trips for fleet operators can be found in Figure 18 showing an LCMM recorded trip with a private passenger car in Sweden. At the top of Figure 18, the trip ID, vehicle model, date and time are listed together with some basic energy evaluations, i.e. the normalized energy performance index (EPI) in units of cl/t×km, which was found to be effective when comparing vehicle and load influence during the fleet operation in logistics.

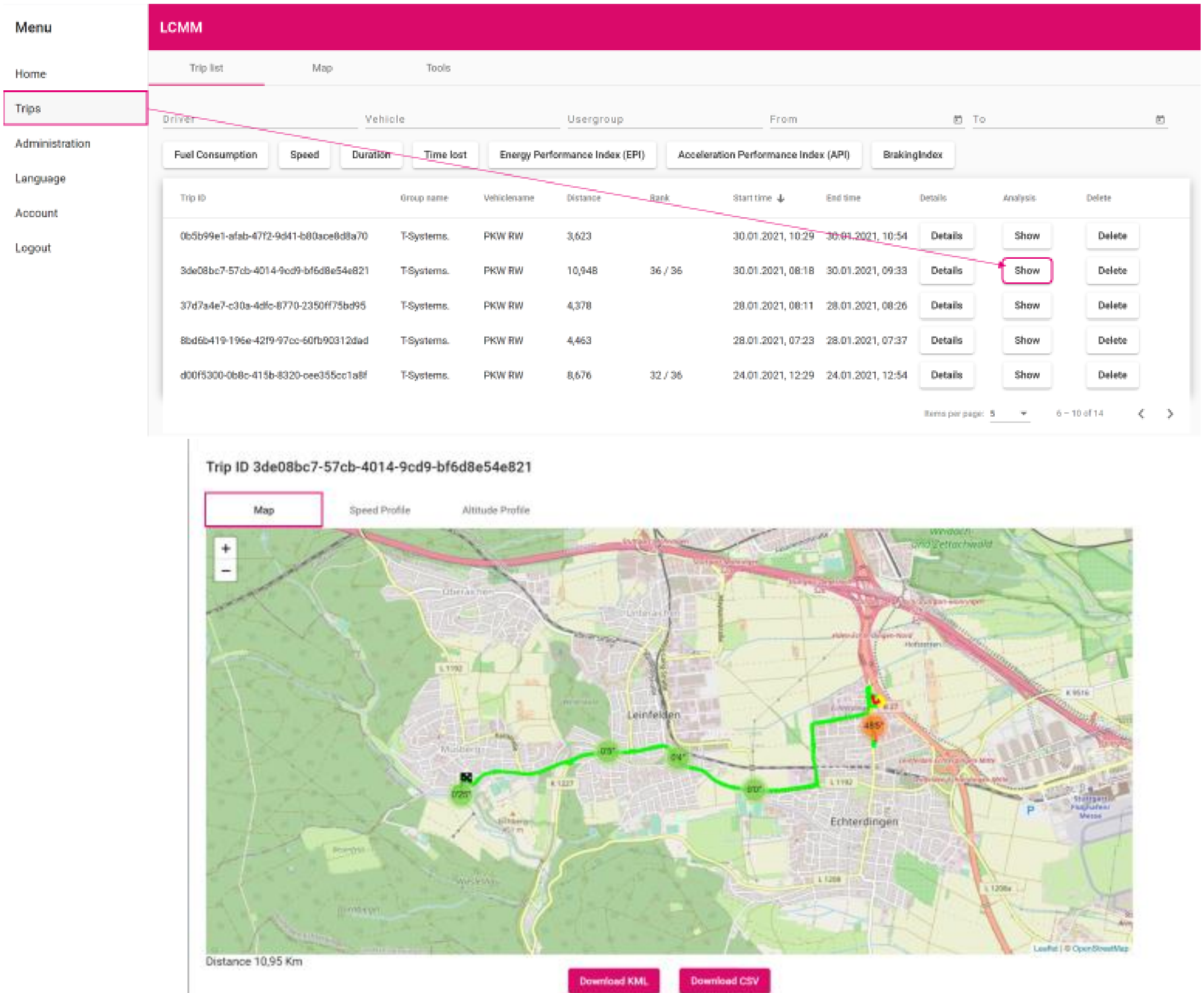

Figure 18 - Backend and post trip analysis

3.3.3.3 Integration with SHOW Use Cases

The LCMM solution was proved to be immensely beneficial for visualizing road conditions and analysing trip data essential for KPI reporting in the SHOW project, especially after the modifications to the German pilot site and the integration of the cities Monheim am Rhein and Frankfurt. During the trials, the application was utilized to report critical trip data, such as kilometres travelled, with a particular emphasis on speed profiles. The application was then made available on the marketplace of the SHOW project, offering multiple PTOs the opportunity to test the application for their use cases.

3.3.4 Summary

The LCMM solution can evaluate a comprehensive set of KPIs crucial for transportation analysis. These KPIs include the duration of the trip, the total distance travelled, the average speed of the vehicle, the average emissions, and the energy behaviour, which is expressed as a percentage relative to a predefined reference cycle. This robust evaluation capacity enables a detailed assessment of transportation efficiency and performance and can be used for private passenger vehicles, as well as fleet providers or buses.

Developing and implementing more comprehensive and cost-effective solutions is critical for the transportation sector to meet its emissions reduction targets and contribute effectively to global climate change mitigation efforts. The LCMM solution has demonstrated its broad applicability in this context, particularly in analysing trips of public transport operators. It has proven to be equally effective when utilized in buses as it was in its initial development phase for logistic fleet providers. This versatility underscores the LCMM solution's potential to enhance operational efficiency and sustainability across various segments of the transportation industry.

3.4 Comprehensive Analysis of Electrified Powertrains across Different Driving Scenarios using Real-World Data

3.4.1 Overview

Automated fleets contribute to solving ecological problems by optimizing routes, reducing idle time, and minimizing unnecessary mileage, leading to lower fuel consumption and emissions. Beside the still widespread of Internal Combustion Engine Vehicles (ICEV), they often adopt Battery Electric Vehicles (BEV) or hybrid vehicles, e.g. Plug-In Hybrid Electric Vehicle (PHEV). Furthermore, alternative fuels, and eco-driving algorithms further reduce their environmental impact. Additionally, automated fleets facilitate shared mobility services, encouraging more efficient use of transportation resources and reducing congestion and emissions associated with individual vehicle ownership. In this context, where the promise of efficiency and convenience converges with the imperative of ecological responsibility, traditional metrics for assessing operational costs face a paradigmatic shift. Historically, the calculus of total operations costs for vehicle fleets has been primarily defined by fuel expenditures. However, as the need to reduce carbon emissions is getting more urgent and ecological footprints are becoming increasingly central to societal discourse, new "currencies" or additional indirect costs emerge to redefine the contours of decision-making. For example, the limitation of particulate matter pollution, power grid capabilities or CO_2 emission in general. The latter one example is the advent of carbon pricing mechanisms, injecting environmental considerations directly into the economic calculus and biasing decision-making towards more sustainable alternatives. Accordingly, KPIs need to be extended or reconsidered. Operational costs are no longer solely defined by fuel costs, the metrics now encompass a broader spectrum of ecological and operational considerations:

- **Tank-to-wheel energy consumption (Wh/km):** Energy consumed during the operation, assuming that the energy is already stored in the vehicle in forms of liquid fuel or electricity.
- **Well-to-wheel energy consumption (Wh/km):** Every carrier of energy must be created, transported & provided to the vehicle and be consumed in order to create kinetic energy. There are several steps between the well and the wheel which define the overall efficiency. This includes the kind of energy harvesting but also the power train of the vehicle.
- **Well-to-wheel CO_2 emissions (g/km):** Vehicles labelled as “CO_2 emission free” are frequently used to highlight that a vehicle does not produce CO_2 during operations. However, this is quite misleading, as electricity can origin from nuclear, coal-fired power plants or photovoltaic panels with different intensity of CO_2 emission during the generation of the energy.

- **Estimated electric range (km):** For BEV, the battery capacity utilization is intended to be maximized, expressed in terms of the vehicle range with one charge. For PHEV, the range is “infinite” as the combustion engine is available but favorized to utilize the battery the best way.
- **Total operating costs (€/km):** For the sake of comparison, the above aspects need to be considered when the total costs per kilometers are computed.

Crucially, the different powertrain systems respond divergently to variations in conditional parameters such as temperature, velocity, and traffic flow. This variability necessitates a nuanced understanding of how each powertrain option performs across a spectrum of real-world conditions. The following simulations implemented by AVL/DE investigate the impact on the aforementioned variables for different power train systems by employing a vehicle model which have been dedicatedly developed for these kind of simulations. Self-explaining, the driving behaviour has a huge impact on the overall results. Therefore, real velocity profiles from vehicles operating on the Linköping test site serve as input. The results help to understand the impact of the environmental conditions and supports the fleet operator in long-term decision-making but also enables to react adequately on changing demands on short-terms.

3.4.1.1 Problem

Traditional metrics for assessing operational costs of vehicle fleets, primarily defined by fuel expenditures, are facing a paradigmatic shift due to the imperative of ecological responsibility. The emergence of new "currencies" or additional indirect costs, such as limitations on particulate matter pollution, power grid capabilities, and CO_2 emissions, is redefining decision-making contours in fleet management.

3.4.1.2 Impact

This shift in operational cost metrics encompasses a broader spectrum of ecological and operational considerations. It necessitates the extension or reconsideration of key performance indicators (KPIs) to include factors beyond fuel costs. Fleet operators must navigate the complexities of different powertrain systems, which respond divergently to variations in conditional parameters like temperature, velocity, and traffic flow. Understanding these dynamics is crucial for effective long-term decision-making and adapting to changing demands in the short term. Ultimately, this influences the ecological footprint and efficiency of automated fleet.

3.4.1.3 Solution

Developing and utilizing advanced metrics and KPIs that incorporate a broader spectrum of ecological and operational considerations beyond traditional fuel expenditures. Implementing sophisticated simulation models to assess the impact of different powertrain systems across various real-world conditions, including temperature, velocity, and traffic flow. Leveraging real velocity profiles from vehicles operating in specific test sites to inform decision-making and adapt fleet strategies both in the long term and in response to short-term demands. This solution solves the aforementioned problems in the following ways:

Advanced Metrics and KPIs: By developing and utilizing advanced metrics and KPIs that go beyond traditional fuel expenditures, fleet operators can better understand the ecological and operational impacts of their decisions. This comprehensive assessment enables more informed decision-making, ensuring that environmental considerations are integrated into fleet management practices.

Sophisticated Simulation Models: Implementing sophisticated simulation models allows fleet operators to assess the impact of different powertrain systems under various real-world conditions. By understanding how different factors such as temperature, velocity, and traffic flow affect the performance of these systems, operators can optimize fleet strategies to minimize environmental impact while maintaining operational efficiency.

Utilization of Real Data: Leveraging real velocity profiles from vehicles operating in specific test sites provides valuable insights into actual driving conditions. By incorporating these real-world data into decision-making processes, fleet operators can make more accurate assessments and adjustments to their strategies, ensuring alignment with ecological responsibilities.

3.4.1.4 Benefit for the end-users

Environmental Impact Reduction: By implementing advanced metrics, simulation models, and investing in research and development for more sustainable powertrain systems, the solution directly contributes to reducing the environmental footprint of automated fleets. This translates to lower emissions, cleaner air quality, and a healthier environment for communities where these fleets operate.

Cost Savings: Although there may be initial investments required for implementing advanced technologies and practices, the long-term benefits include reduced operational costs. By optimizing routes, minimizing unnecessary mileage, and improving fuel efficiency through better powertrain systems, fleet operators can save on fuel expenses and maintenance costs, ultimately leading to cost savings that can be passed on to customers or reinvested into further sustainability initiatives.

Improved Efficiency and Reliability: Through the utilization of sophisticated simulation models and real-world data, fleet operators can make more informed decisions that enhance the overall efficiency and reliability of their services. This translates to better service quality for end-users, with more accurate arrival times, reduced waiting periods, and overall smoother transportation experiences.

Alignment with Values and Preferences: As environmental sustainability becomes increasingly important to consumers and businesses alike, the adoption of eco-friendly fleet management practices aligns with the values and preferences of end-users. This can lead to increased brand loyalty, positive public perception, and enhanced reputation for businesses that prioritize sustainability in their operations.

Health and Well-being Benefits: By reducing emissions and improving air quality, the solution contributes to better health outcomes for individuals living and working in areas served by automated fleets. Reduced exposure to pollutants can lead to lower rates of respiratory illnesses, allergies, and other health issues, ultimately improving the overall well-being of communities.

3.4.2 Implementation

3.4.2.1 Vehicle Model

The basis for the simulations is a physical vehicle model, which can be switched between:

- Internal combustion engine vehicle (ICEV)
- Battery electric vehicle (BEV)
- Plug-in hybrid electric vehicle (PHEV)

The main components of the vehicle powertrain are:

- the engine
- the battery,
- the electric motor and
- the transmission.

Driveline

The transmission model takes into account the gear ratio, the efficiency and the inertia of the transmission. The transmission efficiency is a function of the transmission output power. The final drive efficiency and the clutch inertia are kept constant.

Internal combustion engine

The engine is the main component of the ICEV and one of the components of the PHEV. The engine is connected to the wheels through the clutch, the transmission and the final drive. The speed ranges from 750 to 5500 rpm. According to the target maximum power, the most suitable engine map is selected and scaled to the target power. The scaling factor affects the following parameters: engine displacement, inertia, maximum torque, maximum tractive power and drag power, fuel consumption and efficiency. The raw engine maps have been obtained from the manufacturer as a list of triples: speed, torque and fuel consumption values.

Electric motor

The electric motor is the main component of the BEV and one of the components of the PHEV. The electric motor is connected to the wheels through the transmission and the final drive. The scaling technique is similar to the one used for the engine. The scaling factor affects the following parameters: inertia, maximum torque and power, efficiency. The raw electric motor maps have been obtained from the manufacturer as a list of triples: speed, torque and power loss values.

Battery

The battery is the main component of the BEV and one of the components of the PHEV. The battery is connected to the electric motor through the inverter. The battery efficiency is a function of the battery power and the battery state of charge (SOC). The battery is designed to meet the power and energy requirements of the vehicle. The maximum power is determined by the maximum electric power required by the electric motor, scaled up by the inverters efficiency. The energy capacity is determined by the distance to be covered and the average energy consumption of the vehicle (250 Wh/km). A medium-size set of different battery cells is then analyzed to find the most suitable one for the vehicle.

3.4.2.2 Vehicle powertrain model

Powertrain layouts

The schematic representation below represents the ICEV layout. The engine is connected to the transmission through the clutch and provides the demanded power to the vehicle with two torque-multiplying components: the transmission and the final drive.

Figure 19: ICEV layout

The schematic representation below represents the BEV layout. The battery-powered electric motor is connected to the transmission and provides the demanded power to the vehicle via the transmission and the final drive.

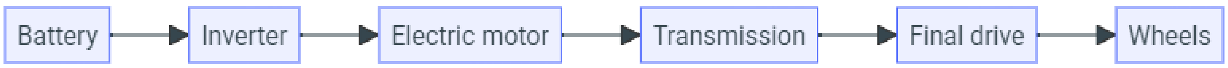

Figure 20: BEV layout

The schematic representation below represents the PHEV layout. It combines the ICEV and BEV layouts by connecting the engine and the electric motor to the transmission through the clutch and the fixed gear ratio, respectively. The battery is designed to provide enough power and energy to the electric motor to cover a certain distance. It is suitable to be used in the city, where more stringent emission regulations are in place.

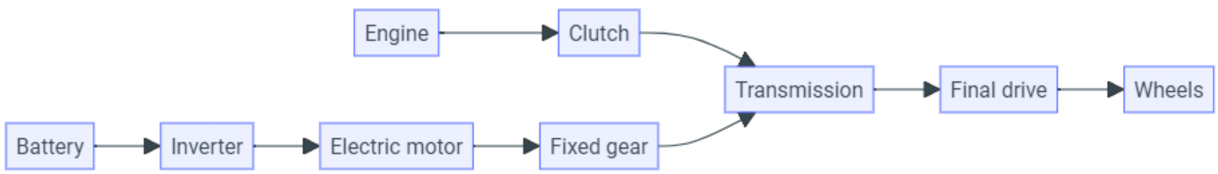

Figure 21: ICEV layout

3.4.3 Integration

The vehicle model was applied to the data collected at the Linköping site, which are available via the SHOW Data Management Platform. The driving dataset consists of 560 GPS traces. Each trace contains the following columns: timestamp, latitude, longitude, altitude, speed. The Figure 22 shows the main characteristics of the driving data. The key driving parameters, i.e. the average vehicle velocity, the mean positive acceleration, the distance and the positive power demand, range from a minimum value to a 3 to 5 times higher maximum value. This wide range of values allows for a comprehensive analysis of the impact of the environmental and situational conditions on the vehicle performance.

The first step of the pipeline is to clean the data. Each file is kept if it contains at least 10 GPS points, the maximum speed is at least 1 km/h, the maximum acceleration is at least 0.1 m/s^2, and the covered distance is at least 2 km. The data are then resampled to a time step of 0.5 second.

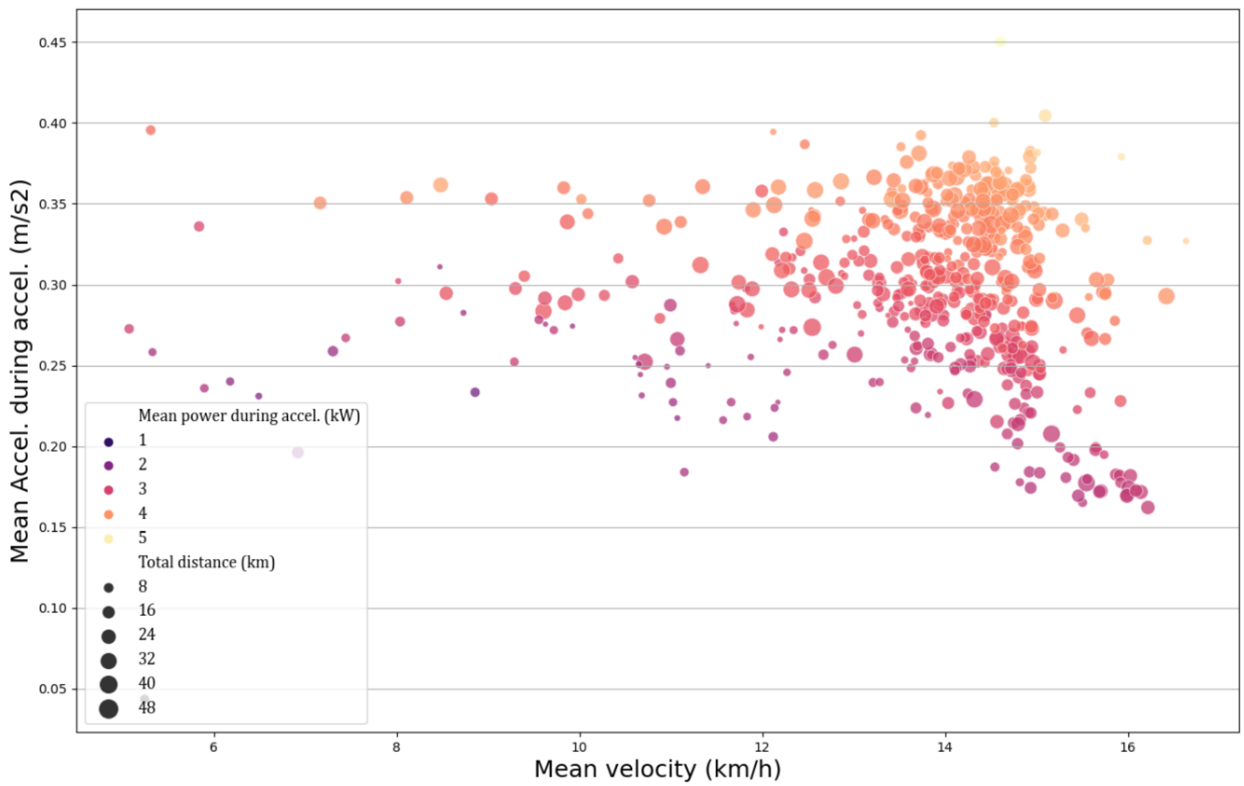

Figure 22: Graphical representation of the used trip data from Linköping site.

This cleaned data set (see Figure 22) is used for three different scenarios:

- Scenario #1: Impact of Ambient Temperature
- Scenario #2: Impact of Vehicle Velocity
- Scenario #3: Impact of Traffic Flow

3.4.4 Scenario #1: Impact of Ambient Temperature

3.4.4.1 Motivation

The vehicles may operate at various ambient temperatures, given by the regional and seasonal conditions, but also due to the day and night temperature variation. The temperature impacts the different power trains at different aspects

Combustion engine: Extreme temperatures, both hot and cold, can affect the efficiency of fuel combustion. In colder temperatures, fuel may not vaporize as easily, leading to incomplete combustion and reduced efficiency. Conversely, in extremely hot temperatures, the air may become less dense, affecting the air-fuel mixture ratio and combustion efficiency.

Electric vehicle battery: Extreme temperatures can also affect the the vehicle's battery capacity. In cold weather, the chemical reactions within the battery slow down, reducing its ability to provide the nominal capacity

The following simulations will address the temperature depending questions:

- How do the operational costs change?

- What is the utilizable distance of my battery?
- Is there a temperature dependent best-choice of the powertrain?

3.4.4.2 Approach

The simulations have been conducted for the different powertrains (ICEV, BEV and PHEV) for variations of ambient temperature. The temperature range has been set from -30°C to 30°C. The driving data has been taken from the Linköping test site. For the sake of computation time, only 20 trips have been sampled that could represent statistically the different driving conditions.

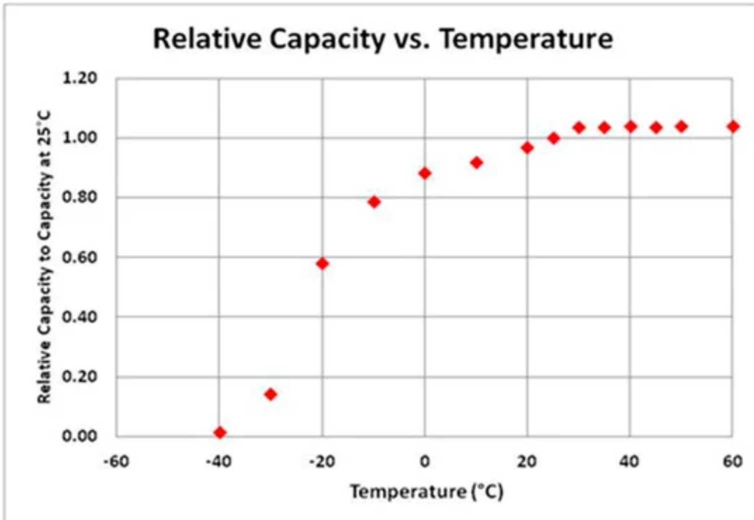

Figure 23: Relative Capacity for Lithium-Ion Battery w.r.t. to the temperature.[10]

3.4.4.3 Results

The vehicle model has been used to simulate the different powertrains under the given conditions. The total operating costs, the well-to-wheel energy consumption, the well-to-wheel CO_2 emissions and the estimated electric range have been computed for each trip and each powertrain (see Figure 24).

[10] Pesaran, A.; Santhanagopalan, S.; Kim, G.-I. Addressing the Impact of Temperature Extremes on Large Format Li-Ion Batteries for Vehicle Applications. In Proceedings of the 30th International Battery Seminar, Ft. Lauderdale, FL, USA, 11–14 March 2013. Google Scholar ↩

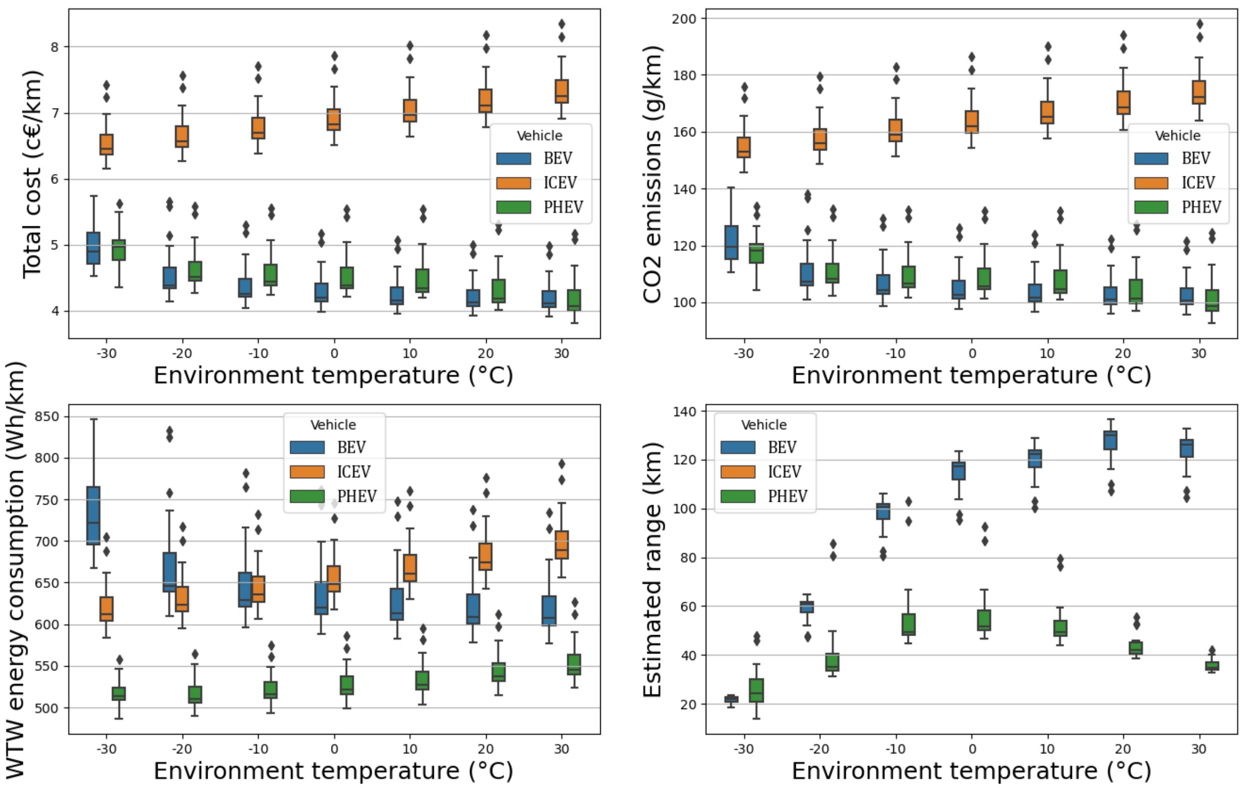

Figure 24: Impact of temperature on the selected indicators.

The results showed that the operational costs, CO_2 emissions and WTW energy consumption trends match one another for ICEV and BEV. That is due to the linear correlation between those metrics and the fuel consumption (ICEV) and the battery consumption (BEV). The full temperature range (-30°C to 30°C) causes an 12.4% increase in all metrics for the ICEV and a 15.3% decrease for the BEV. The PHEV, however, shows a different trend. The operational costs and CO2 emissions are higher at lower temperatures (15-16% more), while the WTW energy consumption is higher at higher temperatures (7%). This is due to the fact that the PHEV uses the combustion engine more at lower temperatures, leading to higher costs and emissions. The BEV, on the other hand, is more efficient at lower temperatures, leading to lower costs and emissions. The ICEV shows a similar trend to the PHEV, but the effect is less pronounced.

The estimated range trend of the BEV is strongly correlated with the battery capacity variation with temperature. The PHEV shows an increasing-decreasing trend, with the maximum point at -10°C. The drop in the estimated range at lower temperatures for the PHEV is mitigated by a more efficient combustion engine. The vehicle is therefore capable of covering more distance with the same amount of fuel and battery energy. Conversely, the estimated range decreases when the temperature exceeds 0°C, as the combustion engine becomes less efficient, despite an increment in battery capacity.

3.4.4.4 Summary

The main findings of the first scenario are:

- The operational costs, CO_2 emissions and WTW energy consumption decrease and increase with decreasing temperature for ICEV and BEV, respectively. The

BEV is however more convenient than the ICEV at any temperature. The PHEV shows a similar trend and values to those of the BEV, but it is more constant over the -20°C to 10°C range.

- The WTW energy consumption trends of BEV and ICEV cross at -10°C. The ICEV is more efficient at lower temperatures, while the BEV is more efficient at higher temperatures. The PHEV is consistently more efficient than the ICEV and BEV at all temperatures.
- The estimated range of the BEV decreases with decreasing temperature, while the estimated range of the PHEV increases at lower temperatures and decreases at higher temperatures.

3.4.5 Scenario #2: Impact of Vehicle Velocity

3.4.5.1 Motivation

The second scenario refers to the situation where the velocity of the vehicle changes. This may happen if e.g., the speed limitation is lifted, a faster delivery is desired or energy needs to be saved.

3.4.5.2 Approach

The three powertrains have been compared across different velocity profiles. Only 20 trips have been sampled that could statistically represent the Linköping test site driving conditions. To ensure a broader comparison, the velocity profiles have been scaled to different levels, ranging from 0.75 to 2.25 times the original velocity profile. That leads to a total of 140 different velocity profiles. The maximum power demand and force demand have been kept constant at 30 kW and 3 kN, respectively.

One important aspect of the driving data is the maximum speed of the vehicle. A speed scaling technique is applied to the speed values to ensure that the maximum speed reaches a certain value. The scaling is performed by multiplying the speed values by a scaling factor and by dividing the time values by the same scaling factor, so that the distance covered remains the same. The new time and speed values are resampled to a time step of 0.25 second to ensure a smooth speed profile and set as the target profile to be followed by the vehicle.

Even though a certain maximum speed is attainable, the vehicle might not be able to closely follow the speed profile due to extreme accelerations or decelerations. A dynamic vehicle model is used to determine the speed profile that the vehicle can follow, given the scaled-up speed profile. The force demand is calculated for each time step based on the speed profile and the vehicle model.

3.4.5.3 Results

The vehicle model has been used to simulate the different powertrains under the given conditions. The following figure shows the impact of the velocity scaling on the different metrics: costs, CO_2 emissions, energy consumption and estimated range. The results have been grouped into five quantiles: (4.8-7.2 km/h), (7.2-9.3 km/h), (9.3-12 km/h), (12-14.5 km/h) and (14.5-17.9 km/h). Each group contains aggregated results from 28 different velocity profiles, out of the 140 total profiles (see Figure 25)

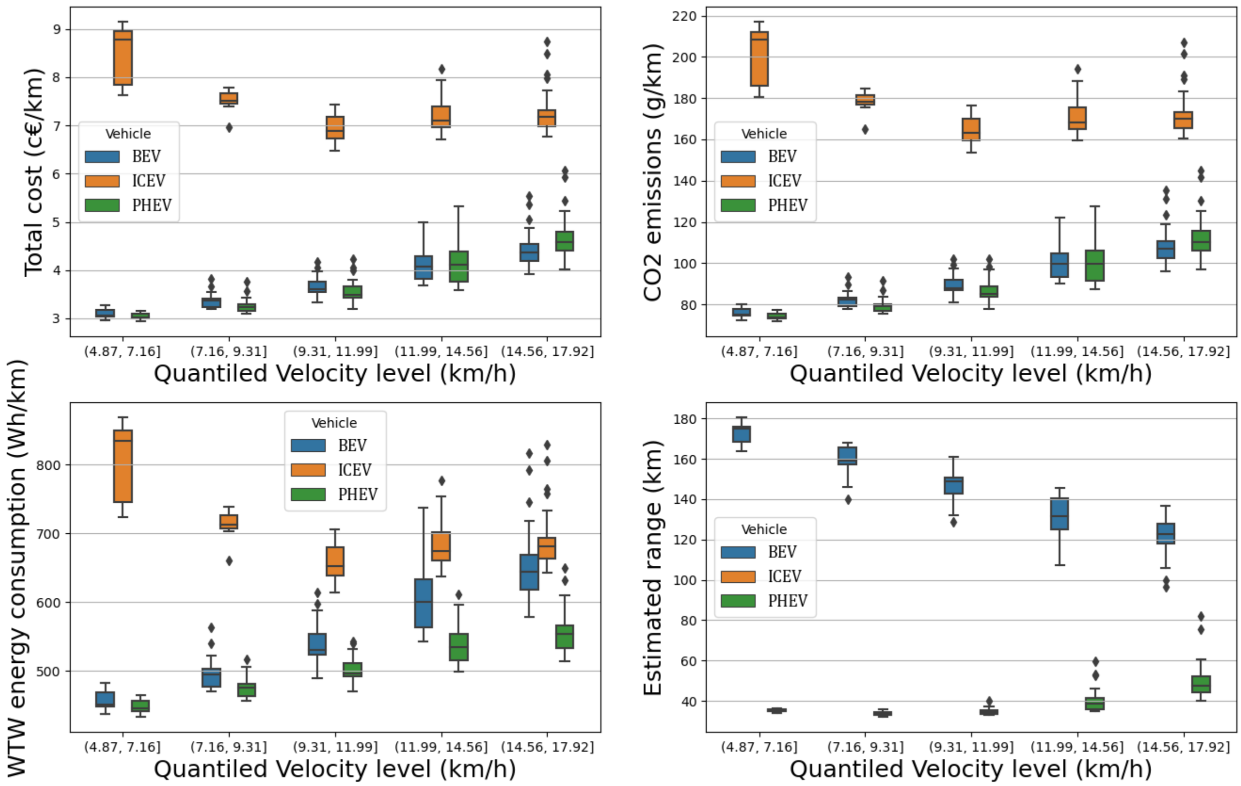

Figure 25: Impact of vehicle velocity.

The results clearly showed that the metrics increase with increasing velocity for BEV and PHEV. The reason is that the power demand increases quadratically with the velocity, while the electric motor and battery efficiency do not vary significantly in the average power range of 1-5 kW. The ICEV, on the other hand, shows an asymmetrical parabolic trend with a minimum at 11 km/h. The reason is that the engine efficiency is extremely low at low velocities and power levels. The BEV and PHEV perform similarly in terms of costs and CO_2 emissions. However, the PHEV being more efficient at higher velocities in terms of WTW energy consumption due to a more efficient combustion engine. The estimated range of the BEV decreases with increasing velocity, while the estimated range of the PHEV increases at higher velocities as the combustion engine is more often employed. The following table shows the percentage variation of the different metrics across the velocity spectrum.

Table 10: Percentage variation of the different metrics across the velocity spectrum

Powertrain	Costs (%)	CO2 emissions (%)	WTW energy consumption (%)	Estimated range (%)
ICEV	-15	-15	-15	-
BEV	43.1	43.1	43.1	-29.7
PHEV	53.1	50.6	24.3	41.5

3.4.5.4 Summary

The main findings of the second scenario are:

- The operational costs, CO_2 emissions and WTW energy consumption increase with increasing velocity for BEV and PHEV. The ICEV shows an asymmetrical parabolic trend with a minimum at 11 km/h.
- The estimated range of the BEV decreases with increasing velocity, while the estimated range of the PHEV increases at higher velocities.
- The PHEV is comparable to the BEV in terms of costs and CO_2 emissions, but it is more efficient at higher velocities in terms of WTW energy consumption.

3.4.6 Scenario #3: Impact of Traffic Flow

3.4.6.1 Motivation

The previous scenario has considered various but linearly scaled velocity profiles. This scenario investigates dynamic changes of the velocity due to the traffic flow i.e., the impact of stop-and-go events and adherent deceleration-acceleration of the vehicle.

3.4.6.2 Approach

The three powertrains utilized in this analysis have been compared across 100 different driving profiles, which can statistically represent the Linköping test site driving conditions with respect to the traffic flow impact.

3.4.6.3 Results

The vehicle model has been used to simulate the different powertrains under the given conditions. The following two figures show the impact of two traffic-related features, i.e., the number of stop-and-go events (see Figure 26) and the average positive acceleration (see Figure 27), on the different metrics: costs, CO_2 emissions, energy consumption and estimated range.

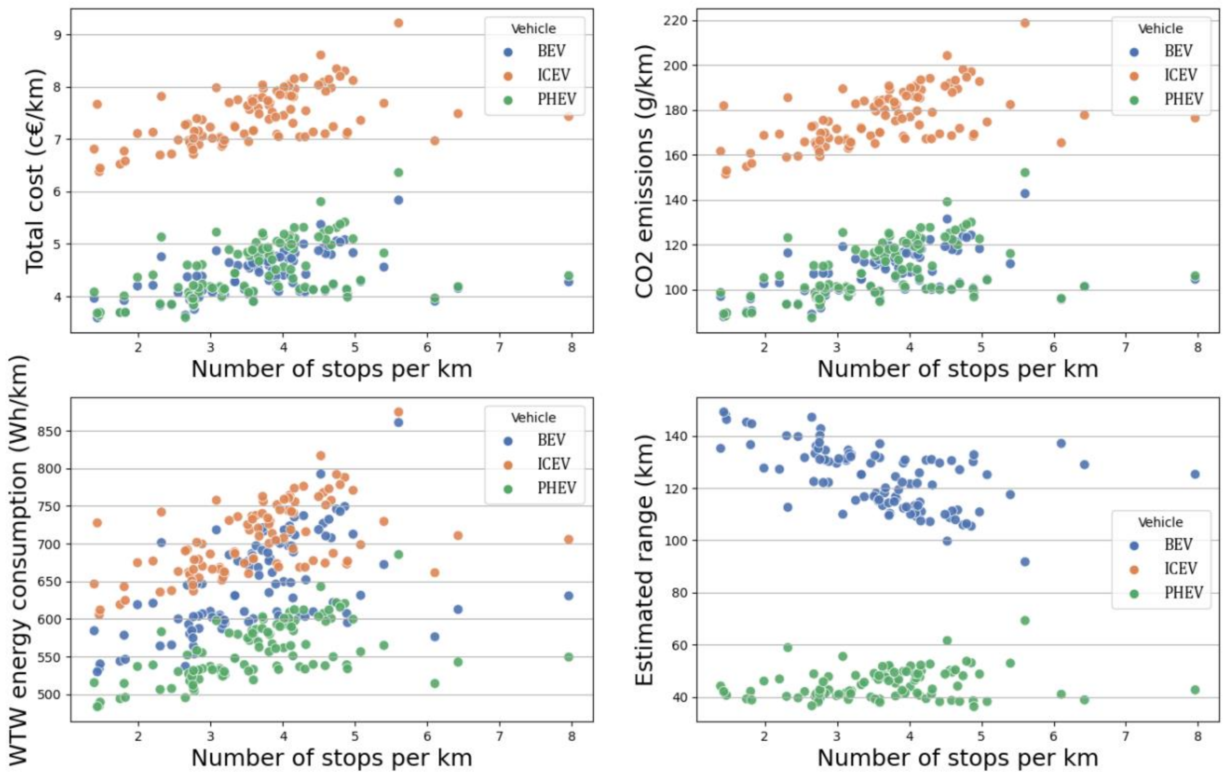

Figure 26: Impact of number of stops per kilometer.

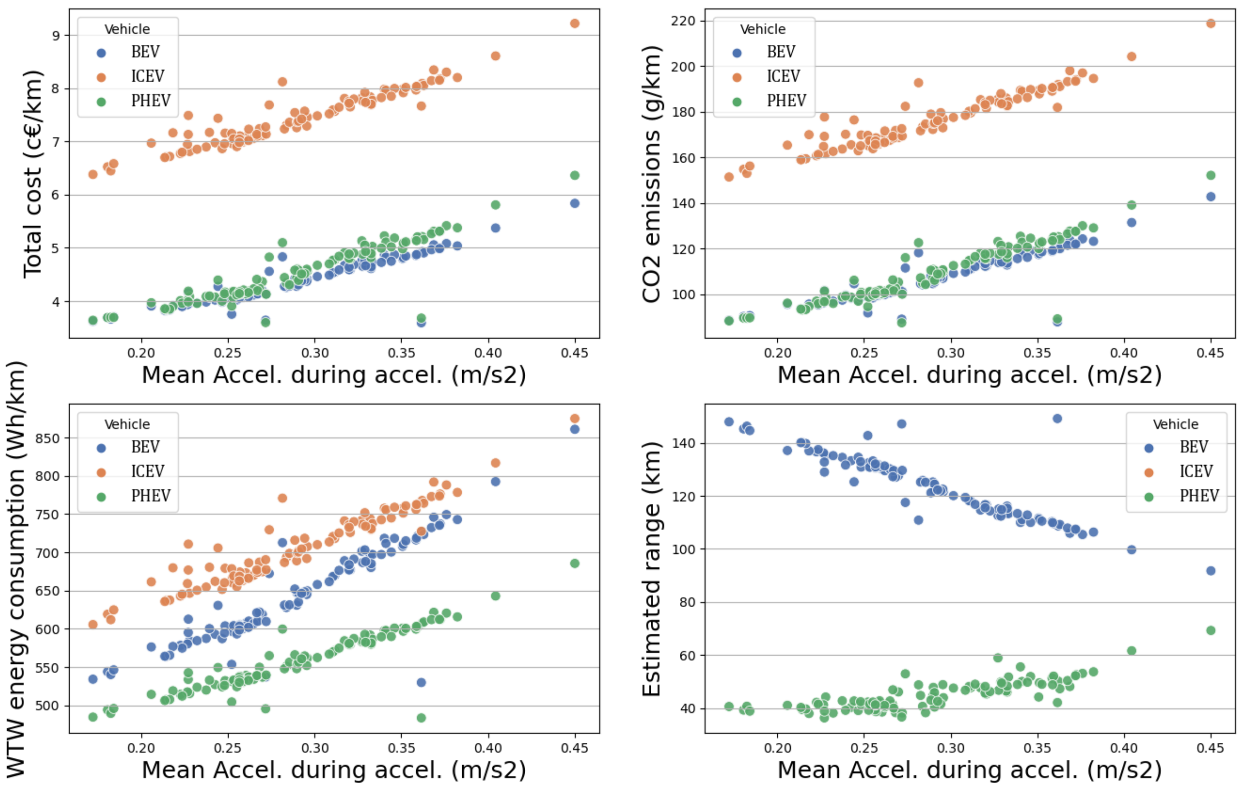

Figure 27: Impact of mean acceleration during an acceleration phase.

The two trends highlight how more aggressive conditions lead to higher costs, CO_2 emissions and energy consumption, but also to a lower estimated range, except for the PHEV as it switches to the combustion engine more often. The linear correlation between the metrics and the acceleration is more pronounced and less scattered than the correlation with the number of stop-and-go events. The driver behaviour between two consecutive stop-and-go events is not necessarily negatively affected by an increasing occurrence of such events. The average acceleration is a more direct measure of the power demand and therefore of the energy consumption. The out-of-trend points at the lower and higher end of the acceleration range are due to the fact that the vehicle powertrain efficiency changes with the power level.

The Figure 28 shows the former results grouped into five quantiles: (0.16-0.25 m/s^2), (0.25-0.27 m/s^2), (0.27-0.3 m/s^2), (0.3-0.34 m/s^2) and (0.34-0.45 m/s^2). Each group contains aggregated results from 20 different velocity profiles, out of the 100 total profiles.

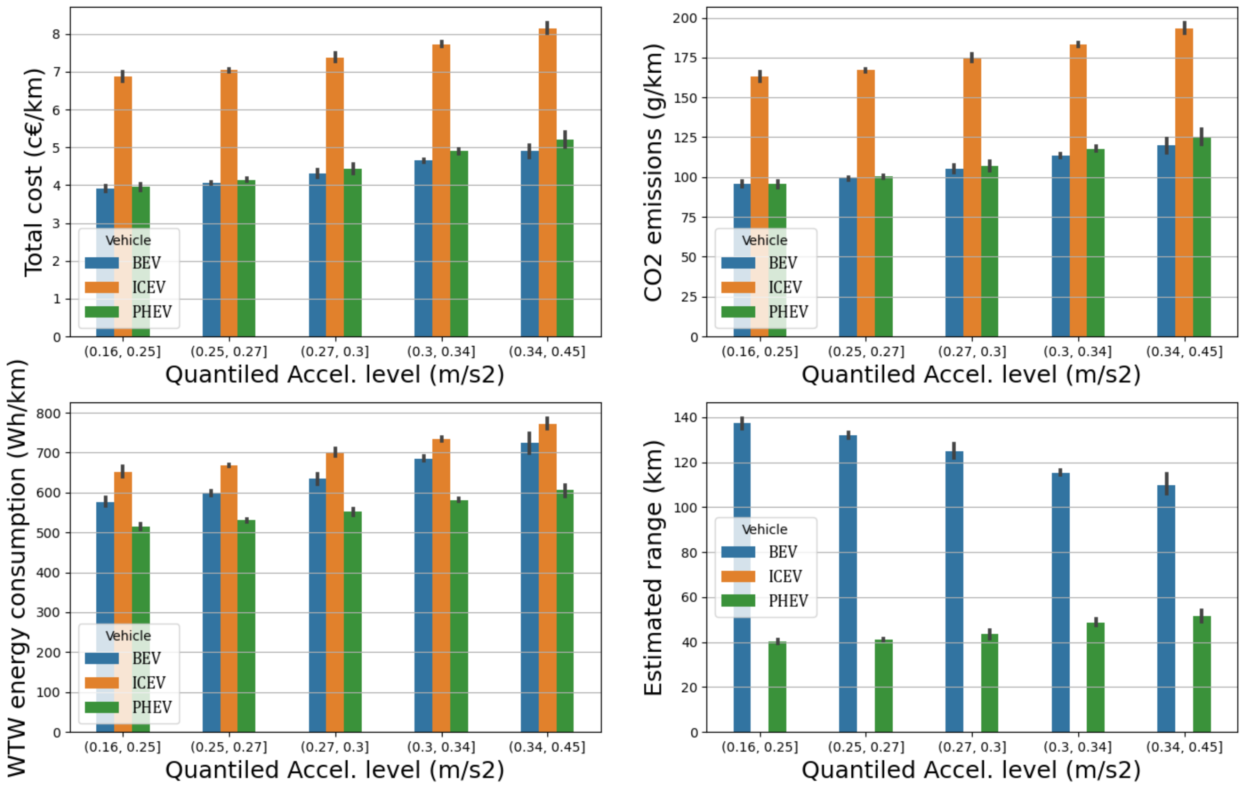

Figure 28: Quantiled velocity profiles.

The table below shows the percentage variation of the different metrics across the acceleration spectrum. The ICEV metrics vary less than those of the BEV and PHEV, except for the PHEV WTW energy consumption.

Table 11: Percentage variation of the different metrics across the acceleration spectrum

Powertrain	Costs (%)	CO2 emissions (%)	WTW energy consumption (%)	Estimated range (%)
ICEV	18.3	18.3	18.3	-
BEV	25.7	25.7	25.7	-20
PHEV	31.9	30.8	17.5	27.5

3.4.6.4 Summary

The main findings of the third scenario are:

- The operational costs, CO_2 emissions and WTW energy consumption increase with increasing acceleration for all powertrains.
- The estimated range of the BEV decreases with increasing acceleration, while the estimated range of the PHEV increases at higher accelerations.
- The PHEV is comparable to the BEV in terms of costs and CO_2 emissions, but it is more efficient at higher accelerations in terms of WTW energy consumption.

- The ICEV is less affected by the acceleration than the BEV and PHEV.
- The acceleration is a more direct measure of the power demand and therefore of the energy consumption.
- The number of stop-and-go events has a less pronounced effect on the metrics than the acceleration.

3.4.7 Summary and Outlook

The solution provides an approach towards enhancing both the ecological footprint and operational efficiency of fleet management through the integration of ecological metrics, advanced simulation models, and the use of real-world data. This strategy not only facilitates informed decision-making by transcending traditional metrics like fuel expenditure but also empowers fleet operators to tailor their strategies under diverse real-world conditions, significantly mitigating environmental impacts while simultaneously improving reliability and service quality.

The key to optimizing fleet performance lies in the tuning of powertrain components, enabling a balance between power output and fuel or energy consumption. Such optimization not only promises an enriched driving experience but also contributes to environmental well-being by minimizing emissions and optimizing energy use. Alongside operational enhancements, the approach brings forth a plethora of benefits to end-users, ranging from the tangible, such as cost savings and improved efficiency, to the intangible, including alignment with environmental values, enhanced brand loyalty, and contributions to public health and well-being. By reducing emissions and optimizing operations, the solution not only tackles immediate operational challenges but also addresses broader societal concerns, offering a pathway to cleaner air quality and a healthier environment.

Looking towards the future, this blueprint for sustainable fleet management underscores the necessity for continuous refinement of technologies and practices in response to the evolving landscape of automated fleets. The trajectory points towards more intricate simulation models, a deeper integration of real-world data, and innovations in sustainable powertrain systems, all while keeping pace with the shifting environmental values of consumers.

Furthermore, this approach is in direct alignment with the SHOW KPIs/objectives, focusing on strategic planning, vehicle scheduling based on forecasted demands, energy constraints, and categorization of energy and emission profiles. This structured methodology not only achieves the goals of reducing emissions and optimizing energy use but also sets the groundwork for a progressive, sustainable future in automated fleet management. As the sector continues to innovate, adopting these sustainable practices will not only address immediate operational challenges but contribute significantly towards broader societal goals of environmental responsibility and enhanced community well-being.

The work presented can be easily extended by exploring the influence of design parameters. Optimizing powertrain components through precise tuning of their sizing presents a significant opportunity to enhance overall vehicle performance and efficiency. When manufacturers meticulously adjust the dimensions and capacities of elements such as the engine, transmission, batteries (in the case of electric vehicles), and other ancillary systems, they can achieve an ideal balance between power output and fuel consumption or energy use. This optimization process is crucial not only in improving the driving experience by ensuring smoother acceleration and responsiveness but also in reducing the environmental impact of vehicles by minimizing emissions and maximizing fuel or energy efficiency. Furthermore, by tailoring the powertrain components to the specific needs and characteristics of the vehicle, engineers can also address issues such as weight distribution and space utilization, leading to a better-designed vehicle overall. In essence, the focused effort on optimizing the sizing of powertrain components is a key factor in the push towards creating more sustainable, efficient, and enjoyable vehicles.

3.5 Mitigating range anxiety and enhancing battery efficiency in AVs based on SoC forecasting

3.5.1 Overview

The rapid adoption of Electric Vehicles (EVs) in the quest for energy efficiency and carbon neutrality has been gaining attention in the recent years. Nevertheless, studies highlight the considerable carbon footprint of EV battery production, usage and recycling. In this direction, the need for advanced strategies to enhance operational stability and mitigate the carbon footprint of these vehicles has intensified. This service developed by CERTH-ITI presents a comprehensive approach to addressing one of the most critical challenges in the management of Automated Vehicles (AVs)—accurately forecasting the State-of-Charge (SoC) of their batteries. The proposed approach leverages real-life data from automated minibuses in Gothenburg, Sweden, to develop a machine learning (ML) pipeline for SoC forecasting. The primary goal is to predict the battery's SoC several minutes ahead, thereby addressing key issues such as range anxiety, grid overloading and energy efficiency, which are crucial for the sustainable operation of AVs.

The research introduces a structured methodology that includes data preprocessing, feature selection, and model training using various ML techniques such as Linear Regression, Ridge Regression, Lasso Regression, and Elastic Net Regression. The study's results demonstrate the efficacy of the proposed approach, with the best-performing model achieving a significant improvement in forecasting accuracy over baseline models. This work underscores the importance of data preprocessing and model selection in developing effective SoC forecasting models, offering valuable insights into future research directions and potential deployment strategies. The parameters extracted from the aforementioned dataset are described in Table 12.

Table 12 Parameters measured in Gothenburg's AVs

Parameter	Category	Description
acceleration value	numerical	Real-time acceleration value in m/s^2
battery state	numerical	Real-time battery status (%)
vehicle mode	categorical	Vehicle mode (in use/standby)
bearing value	numerical	Real-time bearing value in radians
blinkers state	categorical	Blinkers status (warning/right/left)
door state	categorical	Door state (closed/open)
geoPosition high	numerical	Real-time GPS altitude data
geoPosition lat	numerical	Real-time GPS latitude data
geoPosition lon	numerical	Real-time GPS longitude data
mileage value	numerical	Cumulative kilometers traveled
robot mode	categorical	Robot mode (automated/manual)
service mode	categorical	Service mode (on-demand/public transport)
steeringAngle value	numerical	Real-time steering angle in radians
temperature	numerical	Real-time outside vehicle temperature in Celsius
brakeLight state	categorical	Brake light state (true/false)
reverseLight state	categorical	Reverse light state (true/false)
speed value	numerical	Real-time speed in m/s
steeringRate value	numerical	Real-time steering rate in radians
hitRatio value	numerical	Real-time hit ratio (%)

3.5.2 Implementation

The implementation consists of several components to prepare the data, generate insights and create the forecasting models, these components are described in the subsections below.

3.5.2.1 Data Preparation

Data preparation involved cleaning and organizing the raw dataset, collected over 63 days from automated minibuses in Gothenburg, Sweden. The first step was filtering out irrelevant data, specifically focusing on periods where the vehicle was in use and the battery was discharging. Missing values were addressed using forward filling, linear interpolation, or zero filling, depending on the feature's characteristics. The dataset was then resampled to a five-minute interval, which effectively captured meaningful changes in the State-of-Charge (SoC) without introducing excessive noise. Finally, the data was segmented into individual discharge cycles, representing complete trips, which provided the necessary temporal sequences for model training. An example of such an individual segment is provided in Figure 29.

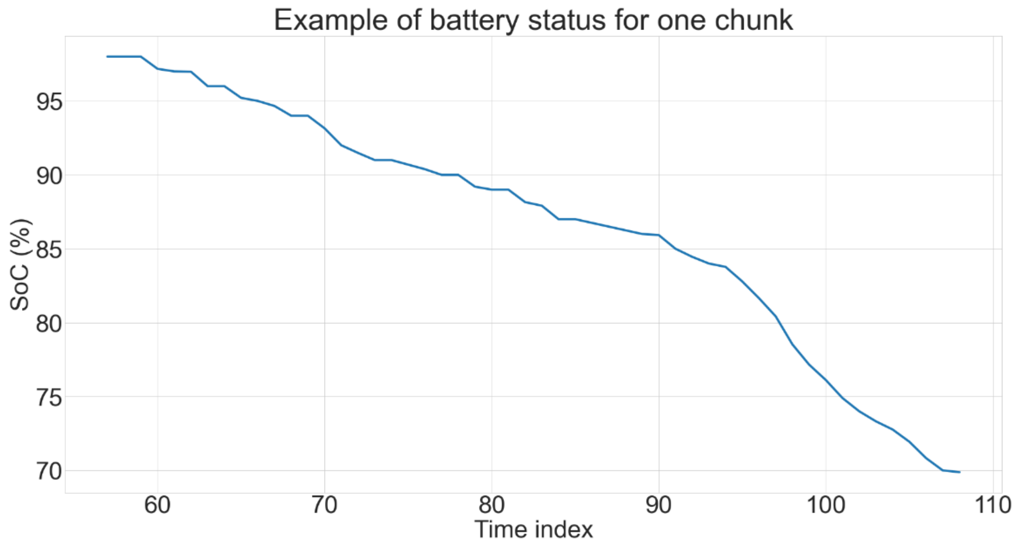

Figure 29 Example of the battery discharge during a single trip segment data chunk

3.5.2.2 Feature Selection

An important step in timeseries forecasting feature generation, is to understand the behaviour of the Auto-Correlation Function (ACF) of the target feature. This can create insights on how much of the past is important in predicting the feature values, namely how many lags should be used during modelling python, an CF plot can be generated with the statsmodels[11] library. Figure 30, demonstrates the ACF plot for a single trip segment, where we can observe 5-6 significant lags. The rest of the segments demonstrate a similar behaviour with important lags ranging between 4 and 10. In this context, the choice was made to lag all input features by 5 lags compared to the target feature for the remaining steps of pre-processing. During modelling, a more exhausting grid searching approach was followed.

[11] https://www.statsmodels.org/stable/index.html

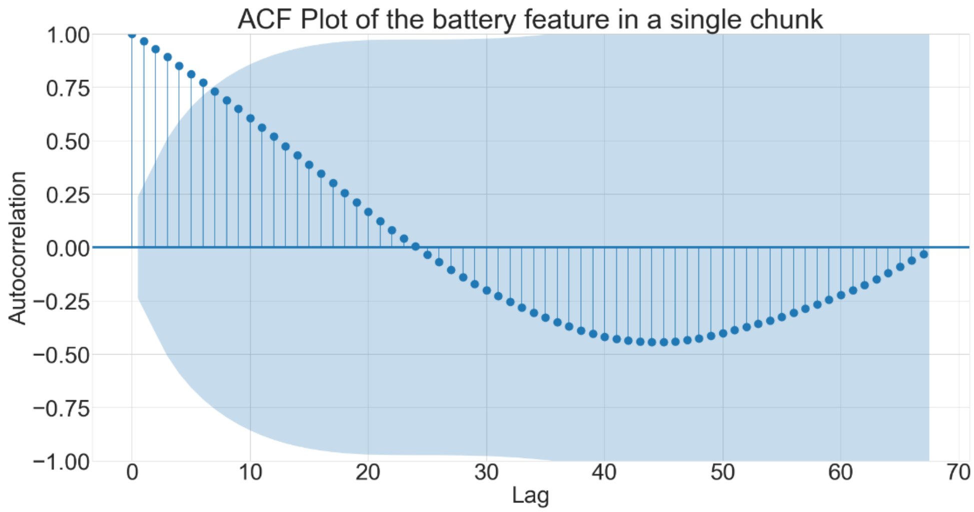

Figure 30 ACF plot of the battery status time-series, for one trip segment

Feature selection was crucial for identifying which variables most effectively predicted the SoC, thus enhancing the model's accuracy and efficiency. This process included an analysis using Pearson correlation coefficient to assess linear relationships between each feature with SoC and Random Forest (RF) to rank features by importance, depicting non-linear relationships. A hybrid approach was then applied, combining insights from both methods to discard low-importance features and refine the selection to those that were most predictive. The final feature set included variables such as battery state, vehicle speed, blinkers state, and hit ratio, which were found to be strong predictors of battery discharge behaviour. Table 13 shows the importance and correlation scores for each feature. Later on, during the modelling approach, a more robust selection step was implemented, testing all possible combinations of these pre-select4ed features and extracting the best one.

Table 13 Correlations and RF-importance scores of lag-5 features compared to SoC

Features	Correlation	RF-importance
mileage value	-0.98	0.13
temperature	-0.76	0.04
acceleration value	-0.26	0.01
geoPosition lon	-0.26	0.01
geoPosition lat	-0.26	0.01
bearing value	-0.20	0.01
steeringAngle value	-0.06	0.01
reverseLight state	0.01	0.00
door state	0.03	0.01
steeringRate value	0.06	0.01
brakeLight state	0.10	0.01
service mode	0.22	0.01
robot mode	0.24	0.01
blinkers state	0.25	0.01
hitRatio value	0.27	0.01

Features	Correlation	RF-importance
speed value	0.28	0.01
geoPosition high	0.29	0.00

3.5.2.3 Model Training

The model training process involved applying various linear regression models to predict the SoC, with each model being trained on the discharge cycles extracted during data preparation. A naïve, persistence model, served as the baseline model, while Linear Regression (LR) Ridge Regression (RR), Lasso Regression, and Elastic Net Regression were employed to address issues like multicollinearity and feature selection. The choice of these algorithms is targeted, due to their ability to avoid over-fitting even when a few data are exploited, like it is the case with individual trip segments. In python, these algorithms can be easily accessed through the scikit learn library[12]. A cumulative training approach was used, where models trained on individual data chunks were combined to update a cumulative model. This cumulative model was refined iteratively, incorporating data from each new trip segment and applying temporal weighting to give more importance to recent data, thus accounting for potential changes in battery behaviour over time. The best performing model was an RR, with an input window of 4 lags which exploited,” blinkers state”,” speed value” and” hitRatio value” as inputs. On the whole forecasting horizon of 6-time steps (half an hour) the model scored an average Mean Absolute Error (**MAE**) of **0.924** significantly outperforming the naïve model which scored an average MAE of 1.6. Figure 31, depicts the actual versus the forecast SoC values for one of the testing trip segments within the data, while Table 14 shows the MAE per forecasting step for both the best-performing linear model and for the naive model.

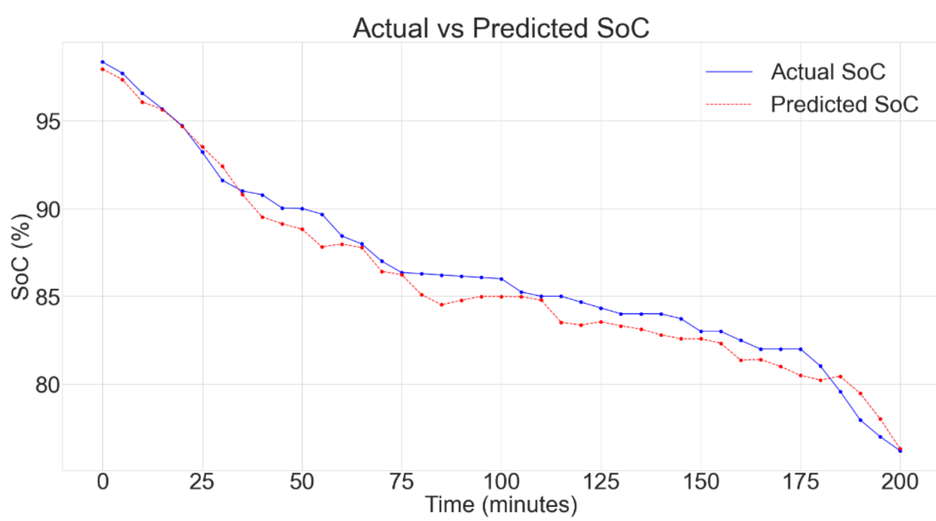

Figure 31 Actual versus forecasted values for a single trip segment

Table 14 Per forecasting step, MAE of the naive and the best performing model

time step (minutes)	Naive MAE	Best MAE

[12] https://scikit-learn.org/stable/

5	0.44	0.31
10	0.89	0.54
15	1.36	0.78
20	1.83	1.04
25	2.00	1.31
30	2.78	1.56

3.5.3 Integration

Related to integration of the proposed service, first some analysis is carried out to establish the rigidity and adaptability of the proposed service, and then a high-level architecture to is proposed to carry out the proposed methods.

3.5.3.1 Rigidity and adaptability

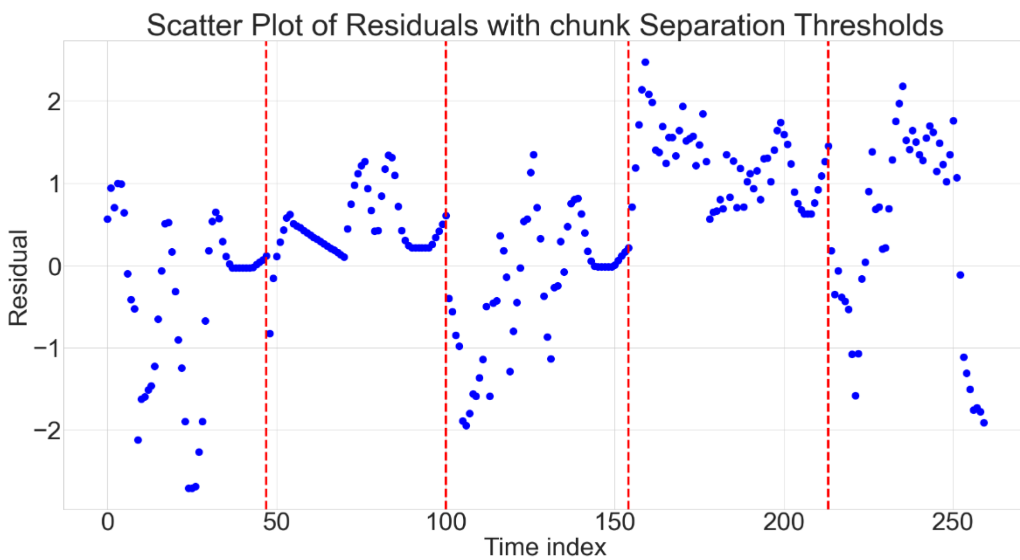

Figure 32: Residuals of the best-performing model.

Figure 32 shows the residuals of the best-performing model across the five testing data chunks. Although the model performs slightly better on some chunks, there is no consistent pattern or trend in the residuals, indicating that the model has achieved a certain degree of stability. To assess the adaptability of this online learning approach, which updates a cumulative model by training on individual data chunks, the model's performance as new data chunks are incrementally introduced is analysed. This process is illustrated in Figure 33, where additional data chunks were progressively used for training, leading to updates in the cumulative model. The results clearly show that the proposed pipeline quickly surpasses the naive model after processing just two trip segments, with a rapid improvement observed within the first 17 chunks before reaching a performance plateau.

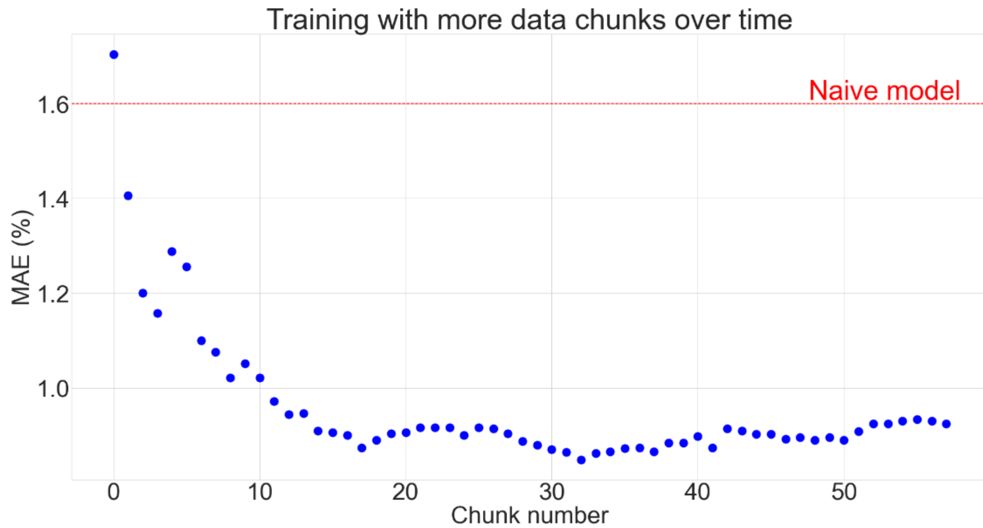

Figure 33 Plot depicting the MAE of the cumulative model, when data chunks are made incrementally available for training

While theoretically, this could help identify the optimal number of trips needed to train an effective model, in reality, battery degradation over time alters consumption profiles. This implies that relying on a static model trained with a fixed number of chunks may become ineffective over time, as its performance could deviate from the plateau and become suboptimal. Although it may not be necessary to update the cumulative model after every single trip, the online learning approach remains the most robust option for the proposed pipeline.

3.5.3.2 High level architecture for online learning

Figure 34 demonstrates a flow diagram for realizing the proposed SoC forecasting service in an online learning fashion. Various sensors are used to monitor battery related features in an EV which are stored in a database. From there the data are accessed through the cumulative model component which produce forecasts for the EV operators. At the same time, this component, checks whether the EV trip has been completed, in which case it updates the cumulative model by re-training on every stored trip. The architecture could either be exploited by remote or on-board processing systems, since the proposed linear models are of low complexity requiring low computational power for training.

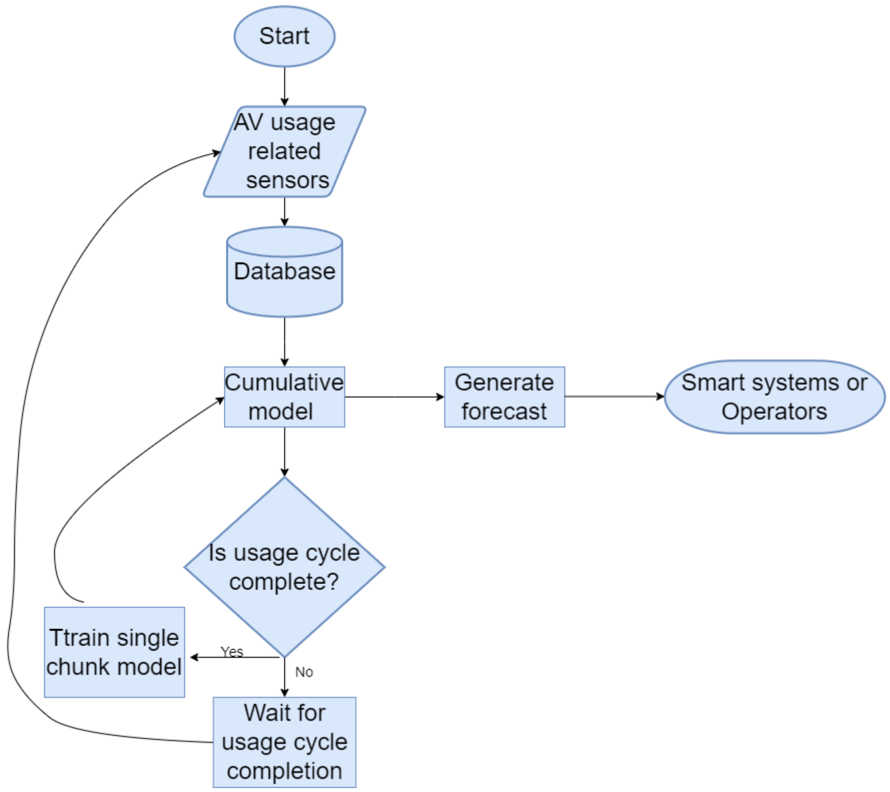

Figure 34: Proposed flow diagram for realizing an online learning SoC forecasting service

3.5.4 Summary

In summary, this service suggested a robust and adaptable ML-based pipeline for forecasting the SoC of AV batteries, leveraging real-life data to address critical challenges in the management of AVs. The study emphasizes the importance of data preprocessing, feature selection, and the use of linear models for time-series forecasting in a dynamic and discontinuous data environment.

Exploiting data from a SHOW pilot in Gothenburg demonstrated that the proposed service could outperform baseline models in forecasting SoC within a half hour horizon by factors up to 42.5%. The key milestones of this service are summarized as follows:

- The rigidity of cumulative model update using LR models trained on individual data chunks, with suitable data preparation.
- The importance of feature selection (in EV usage features) toward improving model performance in SoC forecasting. Vehicle speed demonstrated particularly significant prediction power
- The adaptability of online learning methods in SoC forecasting

4 Integration of new products to marketplace

4.1 State of Charge forecast for electric vehicles

The “State of Charge forecast for electric vehicles” solution derives from CERTH-ITI and the integration into the SHOW Marketplace is shown in Figure 35. For a more detailed explanation, please refer to Section 3.

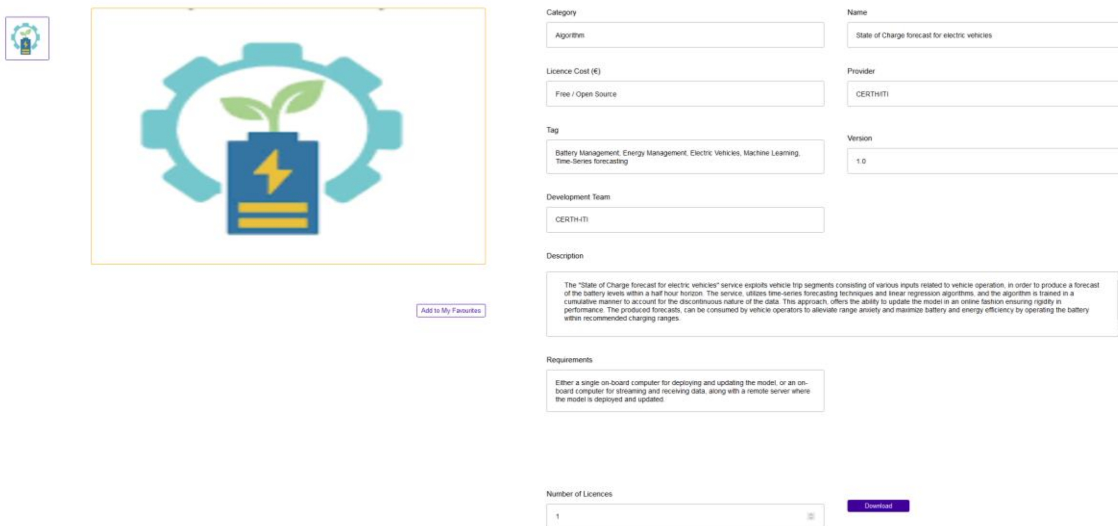

Figure 35: State of Charge forecast for electric vehicles on SHOW Marketplace

4.2 AVL Fleet Monitoring

The integration of the “AVL Fleet Monitoring” service into the SHOW marketplace is depicted in Figure 36. It is a practical tool for effective fleet management that offers clear visualization, providing a quick overview of the entire fleet.

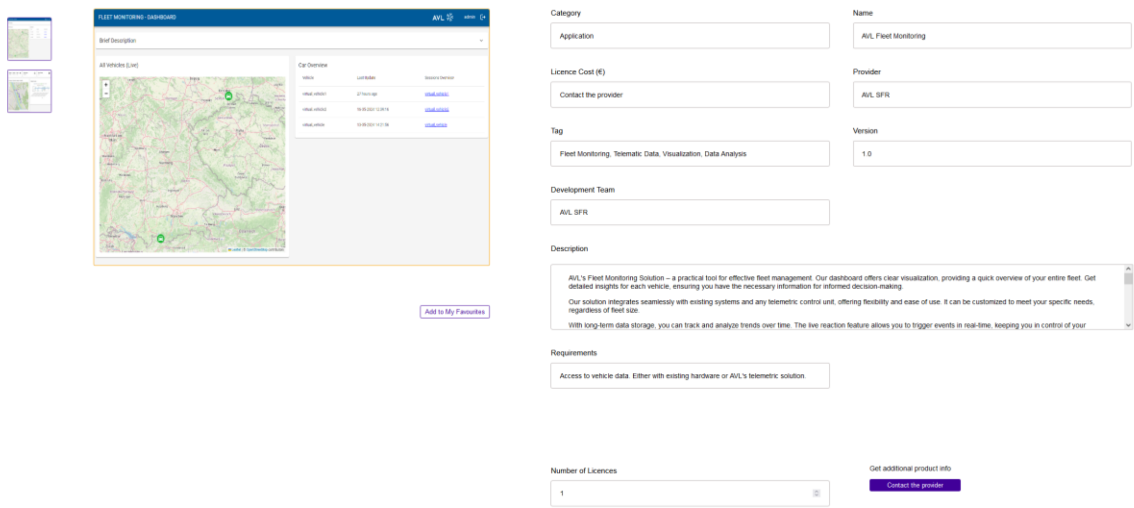

Figure 36: AVL Fleet Monitoring on SHOW Marketplace

4.3 Analysis and Impact of Different Driving Scenarios

The "Analysis and Impact of Different Driving Scenarios" service is available into the SHOW Marketplace as can be observed in Figure 37. A comprehensive breakdown of the service is provided in Section 3.

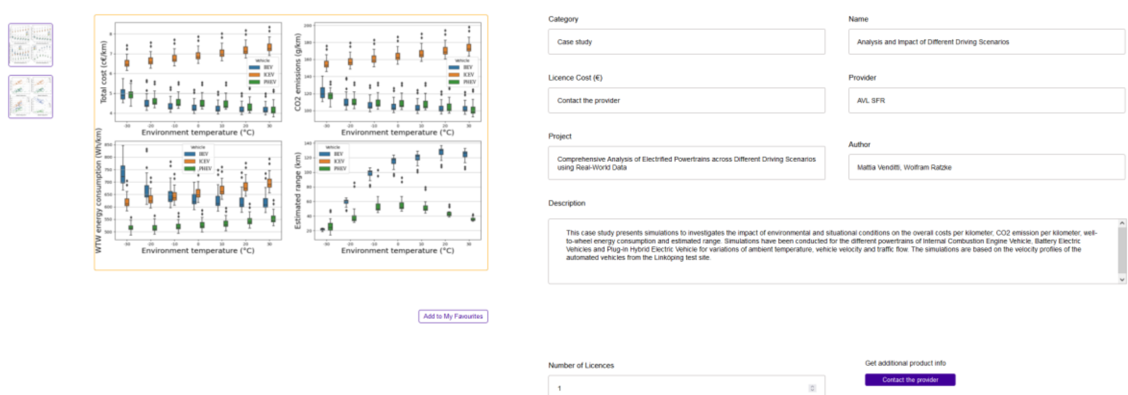

Figure 37: Analysis and Impact of Different Driving Scenarios on SHOW Marketplace

4.4 Mobility Pattern Recognition

"Mobility Pattern Recognition" product item has been uploaded to the SHOW marketplace as can be displayed in the Figure 38. Further details about the service can be found in deliverable D5.4 [17].

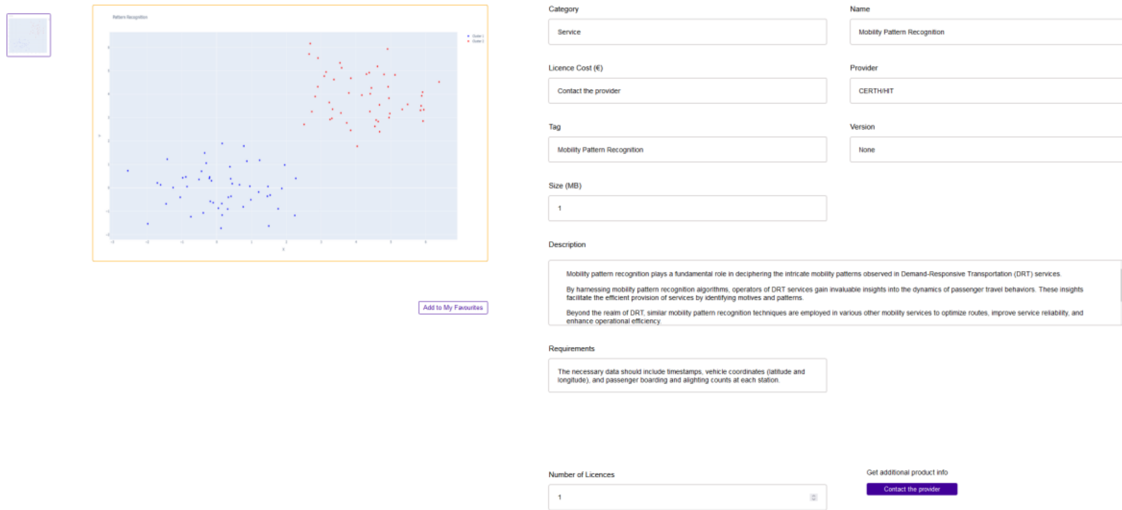

Figure 38: Mobility Pattern Recognition on SHOW Marketplace

4.5 Efficient Transfer & Storage of sensor based AD-data

This service, developed by Salzburg Research, enables efficient transfer and storage of autonomous vehicle data. It includes a Protocol Buffers-based format and Java-based encoding/decoding implementation for real-time and historical data management. “Efficient Transfer & Storage of sensor based AD-data” is another solution which is integrated to the SHOW Marketplace as depicted in Figure 39.

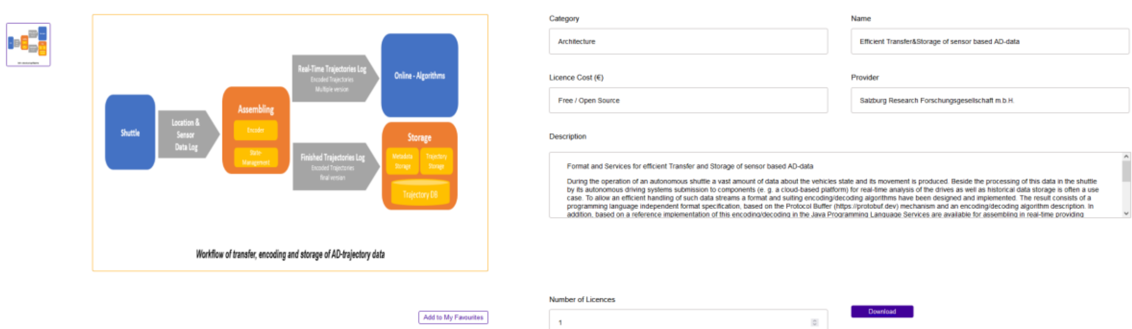

Figure 39: Efficient Transfer & Storage of sensor based AD-data on SHOW Marketplace

4.6 Process model: AD-shuttles on public roads

The generalized process model for deploying and operating autonomous shuttles, developed also by Salzburg Research, outlines nine key activities organized into five phases for autonomous shuttle trials. It builds on existing models and lessons from trials in Austria, offering a framework applicable to other regions as well. The “Process model: AD-shuttles on public roads” service has also been uploaded to the SHOW Marketplace. An instance of this integration is displayed in Figure 40.

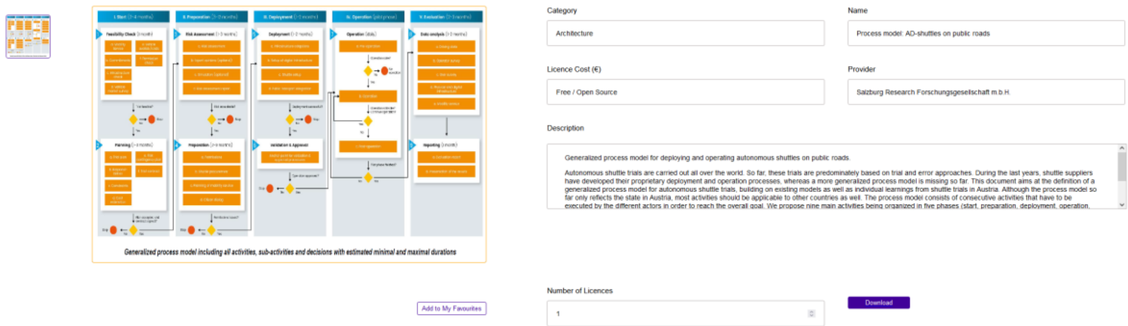

Figure 40: Process model: AD-shuttles on public roads on SHOW Marketplace

4.7 Route Optimizer for Pickup and Delivery

The route planner, developed by AVL SFR, uses a combination of standard local search and a novel genetic algorithm to optimize routes efficiently. It adapts to various user needs, such as providing accessible buses, ensuring better and faster route solutions. The “Route Optimizer for Pickup and Delivery” has been uploaded to the SHOW Marketplace. The aforementioned integration can be observed in Figure 41.

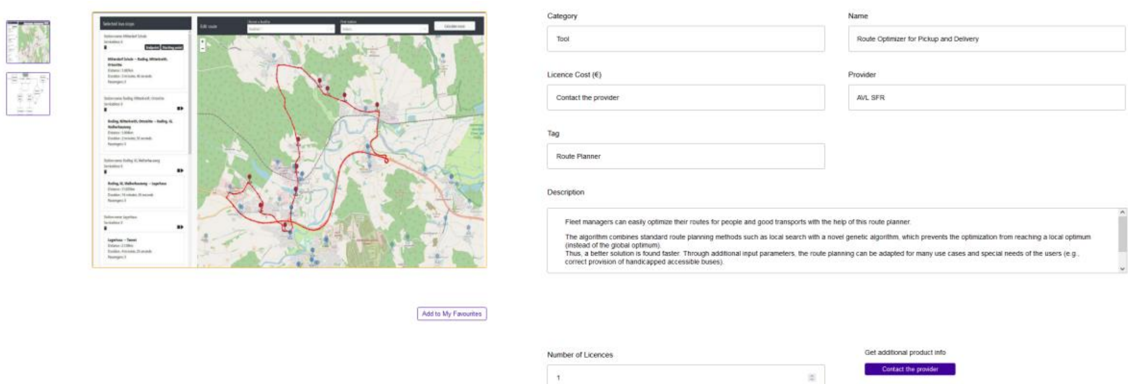

Figure 41: Route Optimizer for Pickup and Delivery on SHOW Marketplace

4.8 Low Carbon Mobility Management

Another service, developed by T-System that has been integrated into the SHOW Marketplace is the “Low Carbon Mobility Management”. The depiction of this service into the SHOW Marketplace is illustrated in Figure 42. A detailed overview of the service is presented in Section 3.

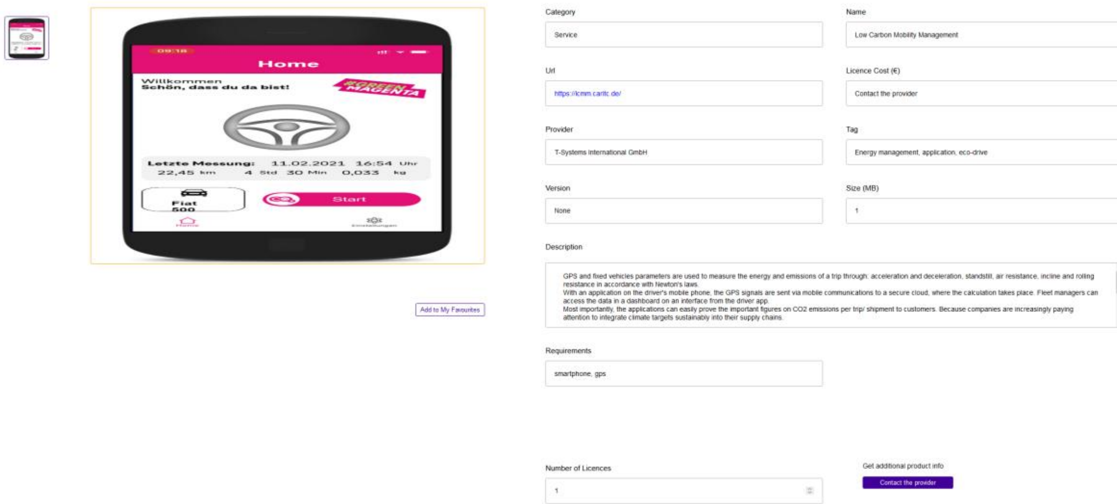

Figure 42: Low Carbon Mobility Management on SHOW Marketplace

4.9 Green Priority

In Figure 43, it is possible to see how “Green Priority” product, developed by SWARCO, has been represented on the SHOW Marketplace platform. Additional information about the service is available in deliverable D6.1 [1].

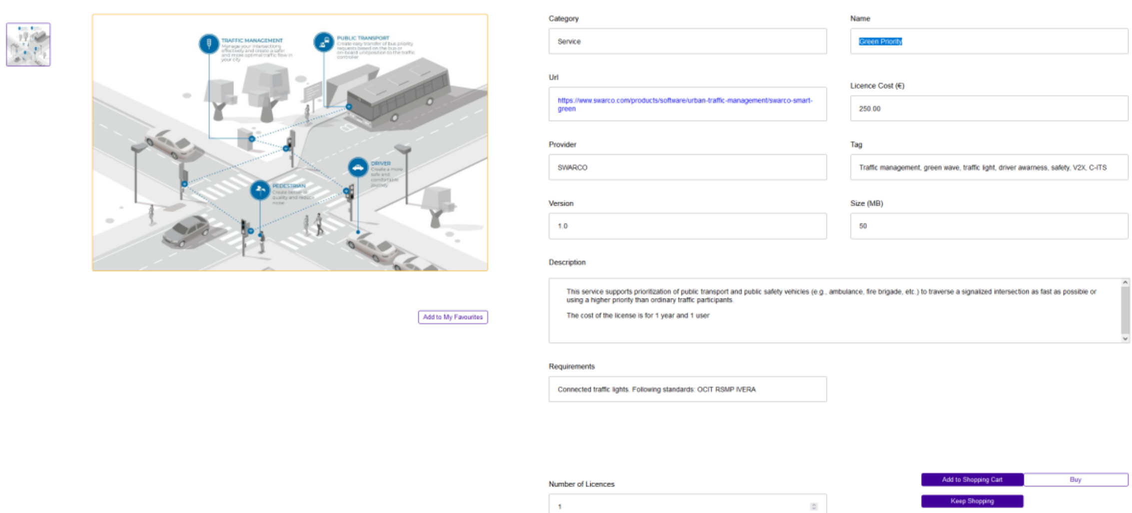

Figure 43: Green Priority on SHOW Marketplace

4.10 Building Automated Drive Demonstrator

Virtual Vehicle Research GmbH offers a service for drive-by-wire vehicle interfaces, sensor setup, E/E integration of sensors, and sensor software integration. The integration of the “Building Automated Drive Demonstrator“ service into the SHOW marketplace is depicted in Figure 44.

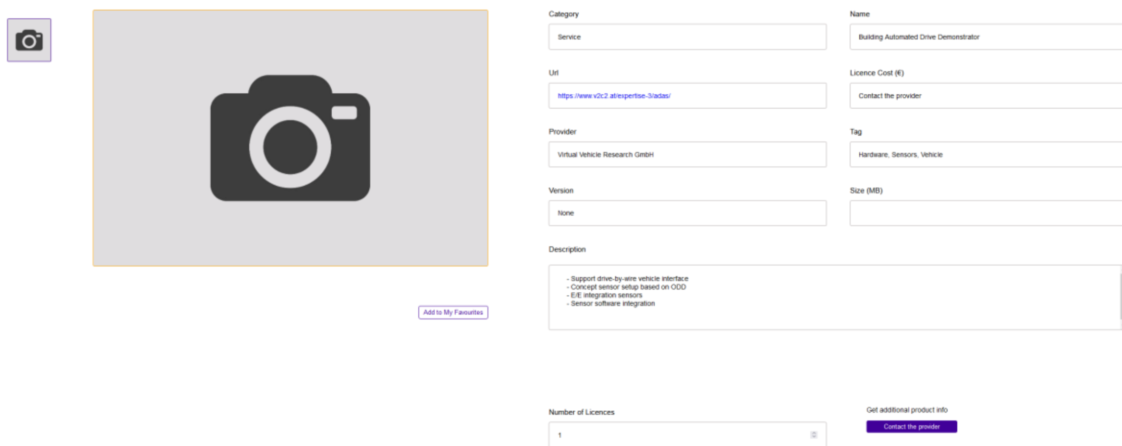

Figure 44: Building Automated Drive Demonstrator on SHOW Marketplace

4.11 Merge-in / -out at bus stops

FEV provides a platooning approach, presented in Section 3, for shuttle and follower vehicles aimed at minimizing energy consumption during merge-in and merge-out scenarios at bus stops. The incorporation of the "Merge-in / -out at bus stops" service into the SHOW marketplace is illustrated in Figure 45.

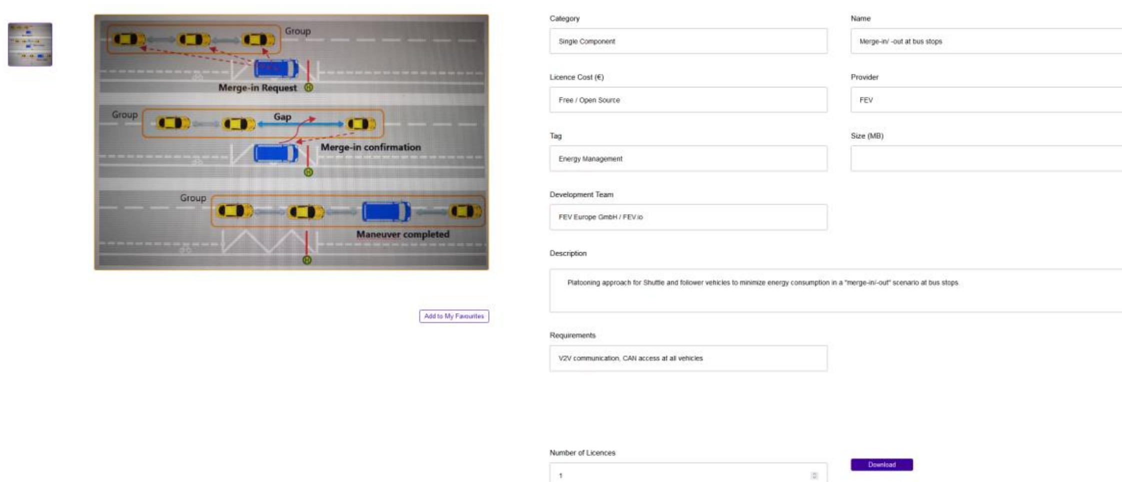

Figure 45: Merge-in / -out at bus stops on SHOW Marketplace

4.12 Public Transportation Demand Forecasting

Figure 46 presents a detailed illustration of how the "Public Transportation Demand Forecasting" algorithm, developed by CERTH-ITI, has been integrated into the SHOW marketplace. Further insights into the service are provided in deliverable D5.4.

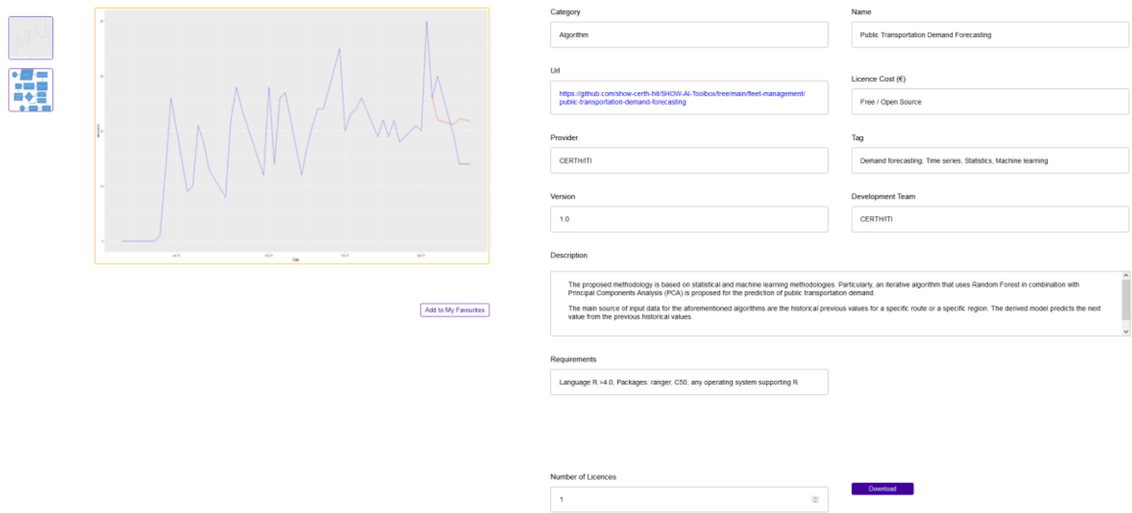

Figure 46: Public Transportation Demand Forecasting on SHOW Marketplace

4.13 Estimated time of arrival prediction

The "Estimated time of arrival prediction" service, developed by DTU, is another product item that has been integrated into the SHOW Marketplace. Its integration into the platform is shown in Figure 47. More in-depth information about the service can be found in deliverable D5.4.

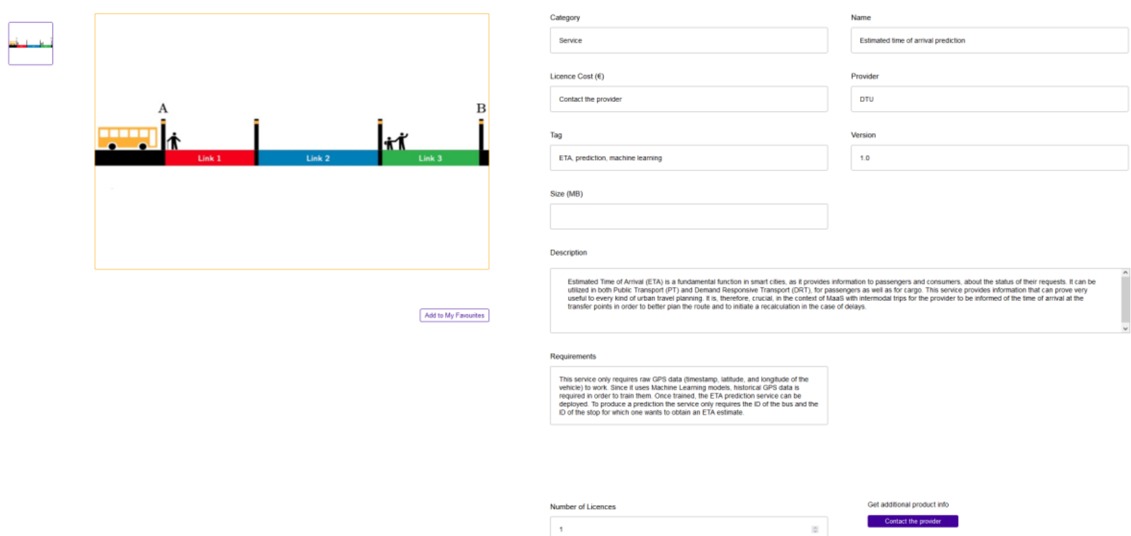

Figure 47: Estimated time of arrival prediction on SHOW Marketplace

4.14 Passenger demand prediction

The "Passenger demand prediction" service, developed by CERTH-ITI, has also been added to the SHOW Marketplace. An example of this integration can be seen in Figure 48. Additional details regarding the service are included in deliverable D5.4.

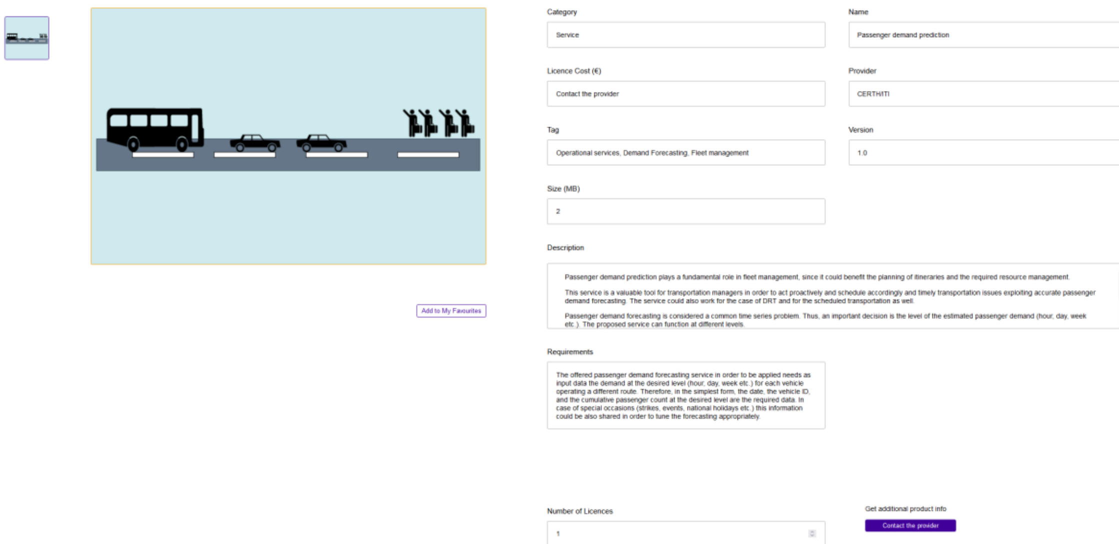

Figure 48: Passenger demand prediction on SHOW Marketplace

4.15 Traffic Light Assistance

Another solution, created by SWARCO and featured in the SHOW Marketplace is the "Traffic Light Assistance" as shown in Figure 49. Detailed information about this service, developed by SWARCO, is provided in deliverable D6.1.

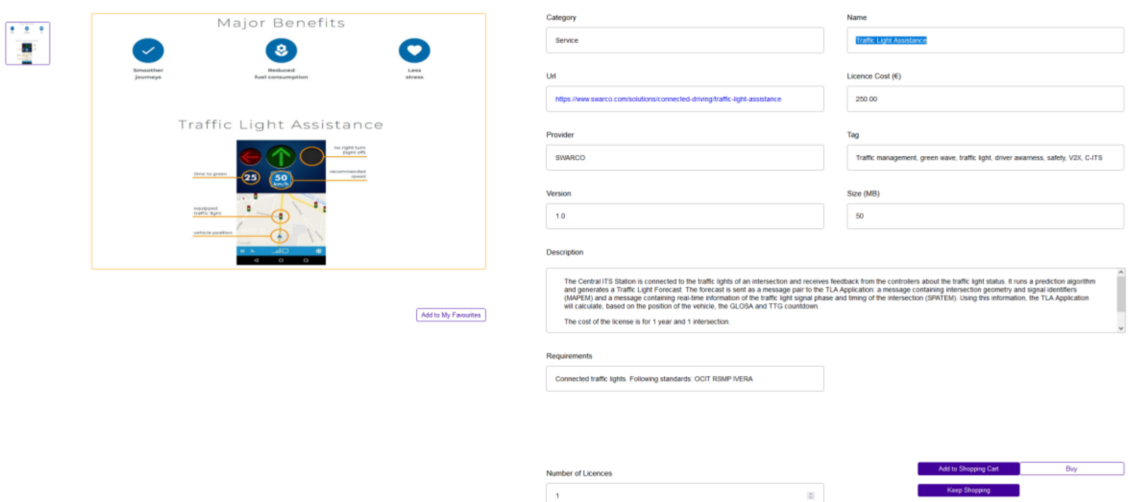

Figure 49: Traffic Light Assistance on SHOW Marketplace

5 Overview of the SHOW marketplace product items

To this date, the SHOW marketplace hosts 28 different products owned by 12 different providing organizations. Figure 50, shows the proportion between internal products that were developed within the purposes of the SHOW project and external products that were integrated to the marketplace. The majority of the products is internal, but the difference is not significant, a fact that highlights the marketplace's impact beyond the SHOW project.

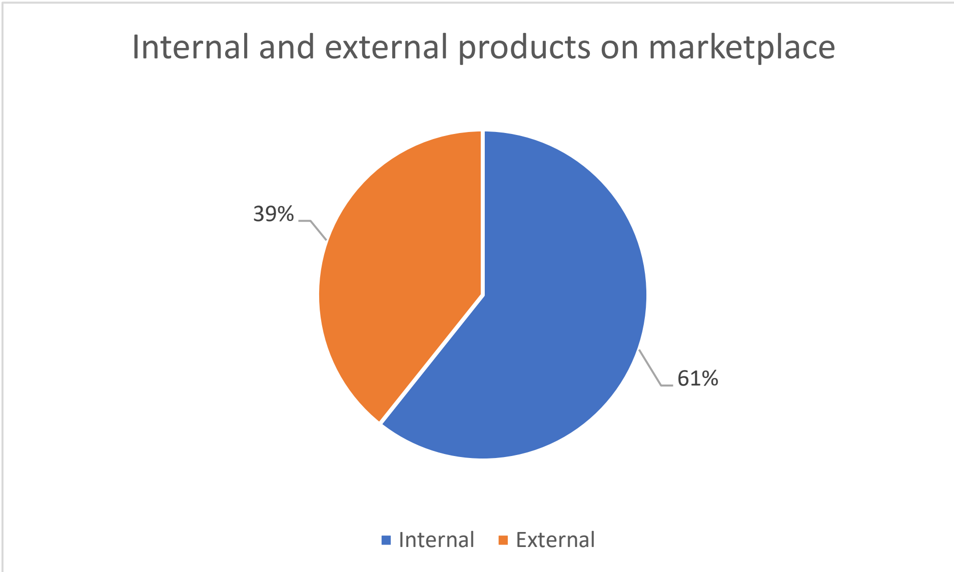

Figure 50: Pie chart of internal and external products in SHOW marketplace

In a different note, Figure 51 demonstrates the number of products owned by each provider. It is clear that CERTH/ITI, as the developing organization of the marketplace has also integrated the most products. Nevertheless, the solution has started to gain popularity between other organizations, like AVL SFR with five products in the SHOW marketplace.

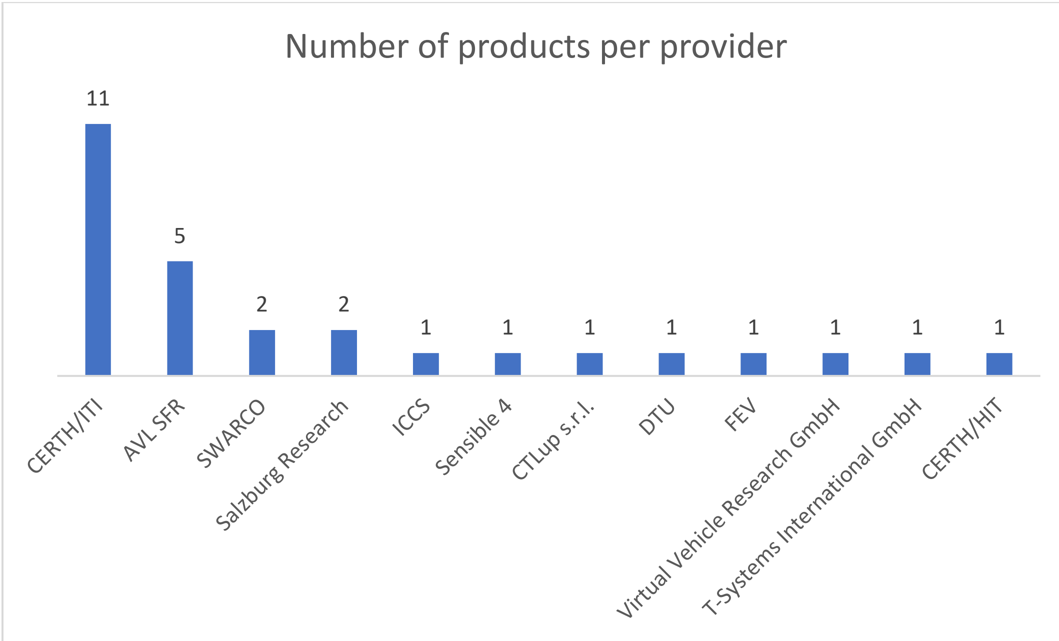

Figure 51: Barplot of number of products per provider in SHOW marketplace

Finally, Figure 52 depicts the occupation of different categories in the SHOW marketplace. The vast majority of the products are developed services, while a considerable amount are proposed software architectures. It is worth noting that a whole group of categories that falls under the software component umbrella, namely UI widgets, dashboards and data models, are still left unoccupied in the marketplace, highlighting a future direction towards targeted products that would further enhance the value of the marketplace.

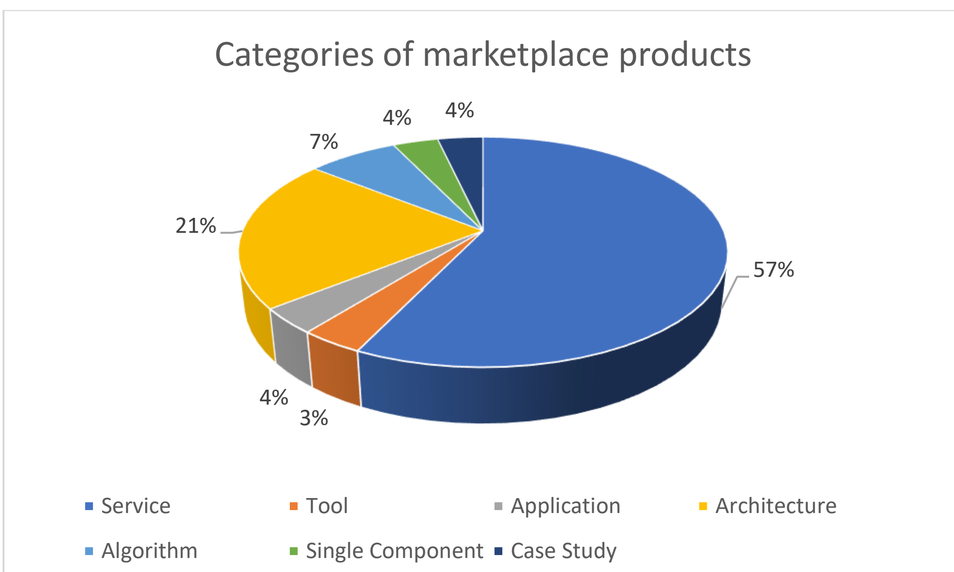

Figure 52: Pie chart of the different product categories in SHOW marketplace

6 Evaluation of the SHOW marketplace

he evaluation of the SHOW marketplace was conducted by interviewing **18 experts** who engaged with the platform, both from within and outside the SHOW project. An overview of the questionnaire that these people were requested to fill is attached in Appendix. As it can be seen in Figure 53, the population originates from different industries, with the majority of them working at research. The vast majority of the population utilized the marketplace through a laptop or desktop computer. Only three of them reported using a mobile phone.

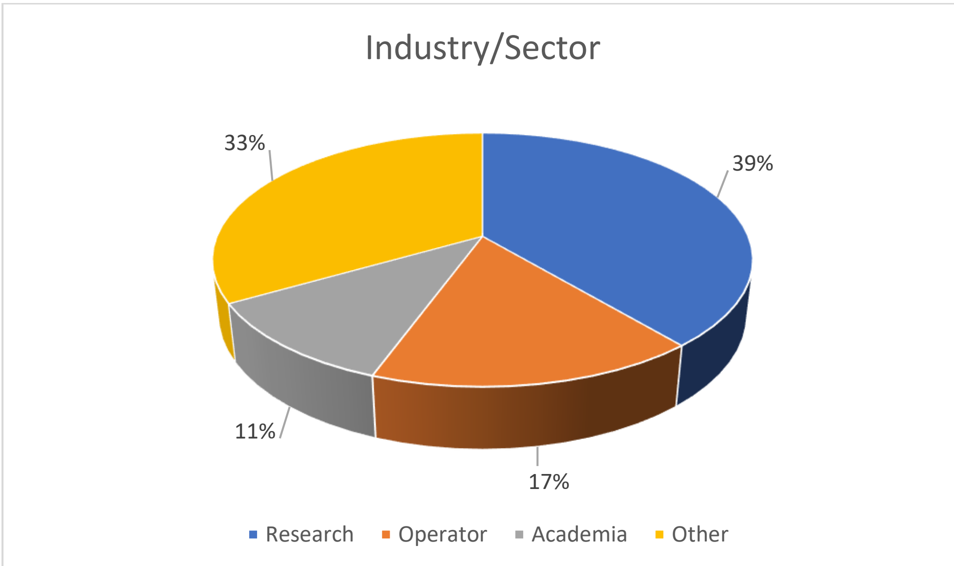

Figure 53: Working sector of the interviewed population

A general impression of the acceptability that the marketplace platform has gained, comes to light with the examination of Figure 54 and Figure 55. Even though 78% of the population, reports rarely using online marketplaces in their business transactions, an 89% declares confidence in sharing their work through the SHOW marketplace. As a high-level overview, this states that not only did people with little preference and possibly experience in marketplace solutions manage to effectively utilize the SHOW marketplace, but that they were also able to do it without particular concerns or difficulties. Following, a more in-depth evaluation analysis, highlights the strengths and weaknesses of the developed solution.

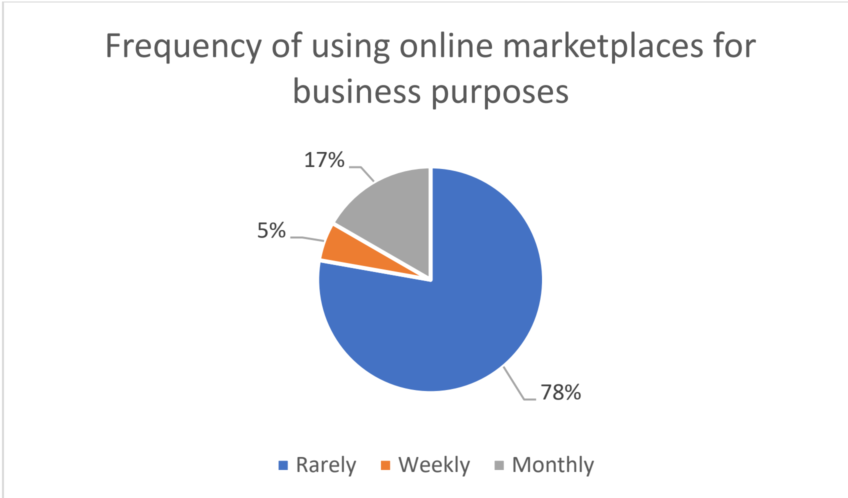

Figure 54: Frequency at which interviewed people use online marketplace for business purposes

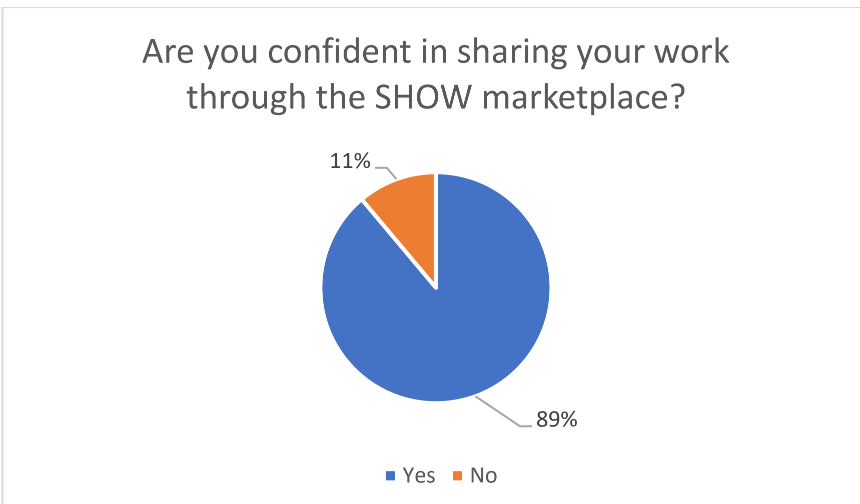

Figure 55: Willingness of interviewed people to share their work through the SHOW marketplace

In order to evaluate the marketplace in a numerical way, the set of possible answers to several questions within the questionnaire, were matched to a rating number. This analogy is demonstrated in Table 15.

Table 15: Answer sets used in the questionnaire, and their matched rating score for analysis

First answer set	Second answer set	Third answer set	Rating
Strongly Disagree	Very Dissatisfied	Not Likely	1

First answer set	Second answer set	Third answer set	Rating
Disagree	Dissatisfied	Somewhat Likely	2
Neutral	Neutral	Likely	3
Agree	Satisfied	Very Likely	4
Strongly Agree	Very Satisfied	-	5

As a first step of the analysis, specific questions that corresponded to some key aspects of the marketplace platform like user experience and security, were analysed. These are the four questions listed below:

- The layout and organization of the marketplace's interface were easy to navigate. (first answer set)
- The registration process was straightforward and easy to follow. (first answer set)
- How satisfied are you with the loading time of each feature of the marketplace? (second answer set)
- Do you believe that all the security measures are in place to guarantee the sound and safe sharing of your product? (first answer set)

For each of the above questions, the average score was extracted and is listed in Table 16. The 4 components rank closely, with an average score of 3.82/5 depicting a **positive overall evaluation**. Security appears to be the strongest attribute of the marketplace.

Table 16: Average user rating for key aspects of the SHOW marketplace

Marketplace feature	User Rating (1 to 5)
UI navigation	3.77
Registration process	3.77
Loading times	3.83
Security	3.94

In a more detailed evaluation of the user experience in the SHOW marketplace, the population was requested to answer questions addressed to specific operations related with uploading a product. These questions were answered with the second answer set and can be grouped together to compare individual components of the UI. This comparison is demonstrated in Figure 56, where it can be seen that most components are given an overall positive score. The users were mostly content with the clarity of guidelines and customization options. A feature that could be possibly further enhanced is the ability to add contents like images videos.

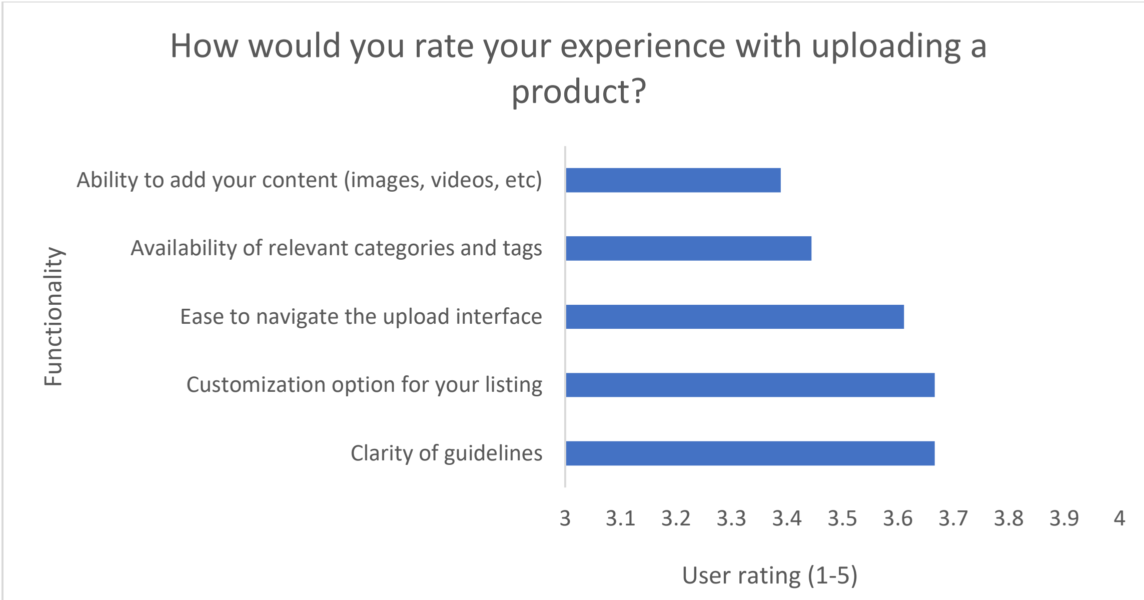

Figure 56: Average rating of different functionalities in the marketplace (1: Very dissatisfied to 5: Very satisfied)

Additionally, the users were asked to determine, which of the product categories they were most likely to interact with, a group of questions that is answered with the third answer set. By averaging the score of each category, a bar plot visualization was created (Figure 57). It can be seen that tools and applications are the most famous options with datasets and dashboards the least famous ones, highlighting the need for autonomous systems that can be used as plug and play solutions by the various stakeholders.

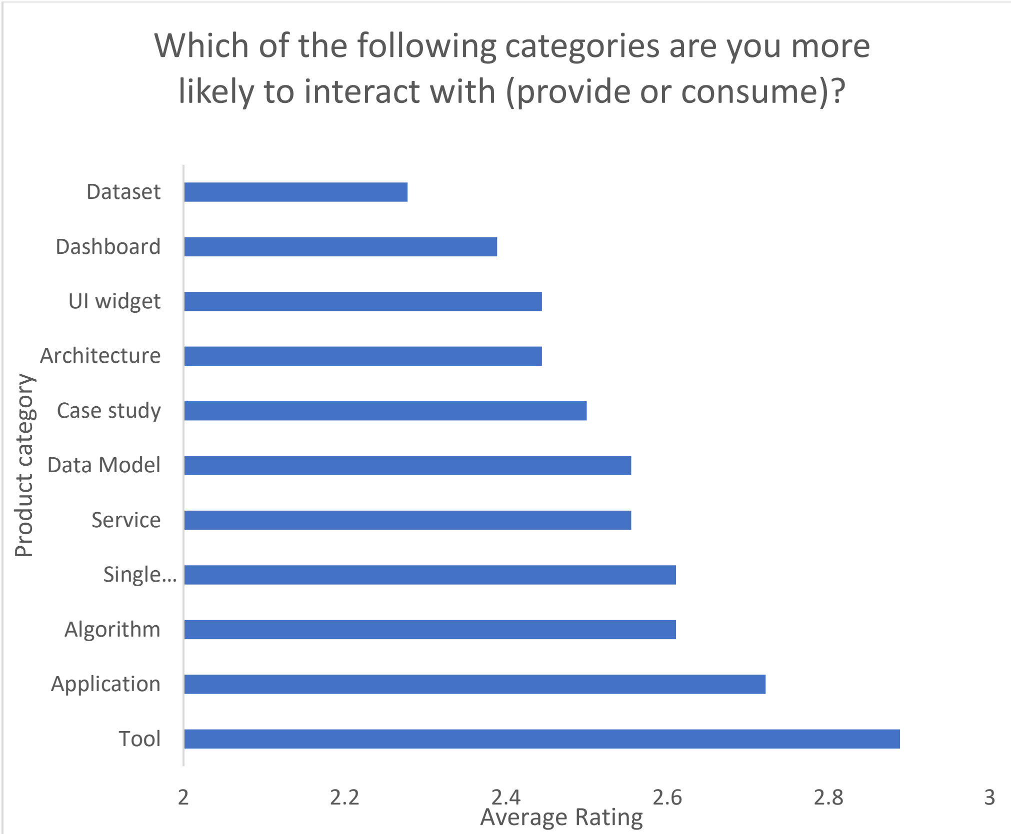

Figure 57: Average rating of the interviewed people, regarding the product categories that they might interact with (1: Not Likely to 4: Very Likely)

The users were also asked to determine how valuable the marketplace could prove for several stakeholders related to the SHOW project. This is a group of questions answered with the third answer set. A similar visualization as before, can be seen in Figure 58. The interviewed population believes that the marketplace can impact all stakeholder groups but mostly those directly engaged in transportations services, like transport operators and transport service providers.

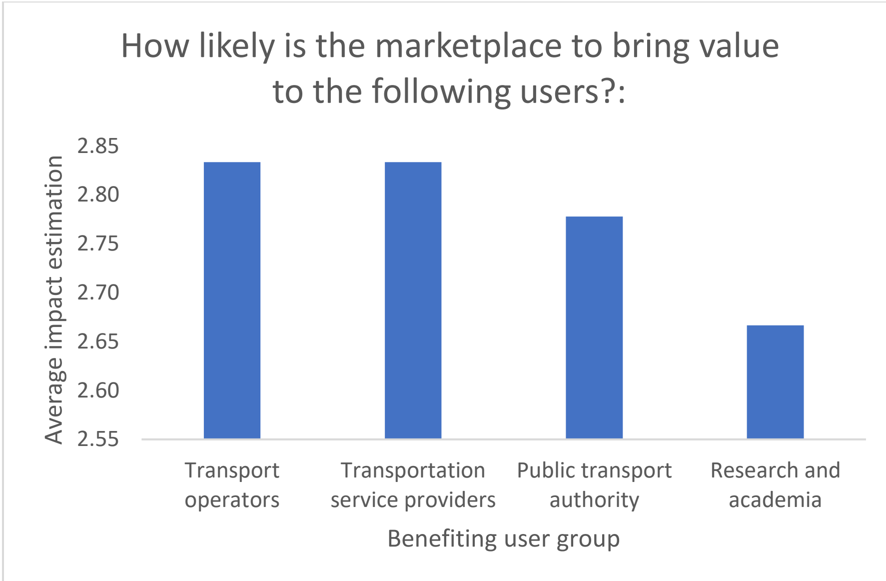

Figure 58: Average estimation of the interviewed people, for the impact that the marketplace could have on possible benefiting user groups (1: Not likely to 4: Very Likely)

Finally, the users were provided with a free-text form, for providing improvement feedback to the marketplace developers. Some suggestions that could be taken into consideration in future versions are listed below:

- “Work on design, use of colors, attention to the images quality”
- “Create the left column nicer (like a webpage)”
- “A matching service between offer and request”
- “It would be interesting to have real-world AV driving datasets”
- “maybe more up-to-date design of the marketplace. Popup info when pointer floats over some product (additional info, satisfactory rate of other users etc.)”
- “I would like to have something more attractive in terms of pictures”
- “It would be good to add the option of downloading/printing the info in a sort of document format’
- “Better explanation of the products”
- “Cooperation with other CCAM marketplaces in order for all the available solutions to be easily detected”

7 Google Analytics of the SHOW marketplace

This section will provide an overview of Google Analytics, a powerful tool used for tracking and analysing user engagement and behaviour on digital platforms. By collecting data on various metrics, such as user counts, event interactions, and geographic information, Google Analytics enables to gain valuable insights into their audience's activity. The following analysis will highlight key findings from the data collected, offering a clearer understanding of user engagement patterns and trends over time in the SHOW marketplace.

Figure 59 graph depicts the overall statistics of Google Analytics, namely, the event count and the user activity for the SHOW marketplace from February 1, 2023, to September 30, 2024. According to this graph the key metrics shown are:

- **Event Count**: 9,100 events during this period, representing the total number of interactions (such as clicks, page views, or other user activities).
- **New Users**: 418 users visited the SHOW marketplace for the first time during this timeframe.
- **Active Users**: 492 users engaged with the SHOW marketplace during this period.

The graph visualizes event spikes, with notable peaks around early February 2023, the official publication date of the SHOW marketplace and mid-June, the SHOW marketplace promotional campaign, where user activity increased significantly.

Figure 59: Overall statistics

Figure 60 shows the active user distribution for the SHOW marketplace across various countries from February 2023 to September 2024. The data highlights the geographical engagement of users and provides insights into where most activity is concentrated. Here's the breakdown:

- **Greece** has the highest number of active users (93), a quite reasonable finding, as the SHOW marketplace development team is located in Greece (CERTH).
- **United States** comes next with 61 active users and **China** follows closely with 53 active users showing notable engagement, from countries outside Europe.
- **Germany** (48 active users), **France** (30 active users), **Netherlands** (28 active users), and **Austria** (27 active users) represent strong European markets, further demonstrating that the platform has traction across several countries in Europe.

Figure 60: Active users per country

A similar analysis is depicted in Figure 61 related to user distribution across cities. This graph presents the distribution of active users for the SHOW marketplace across various cities. Thessaloniki leads with 79 active users, indicating that this city is the most engaged location, a quite reasonable finding as the CERTH development team is located in Thessaloniki. Amsterdam follows with 23 active users, showing strong engagement in the Netherlands. Helsinki ranks third with 19 active users, indicating notable participation from Finland. Paris, Vienna, Athens, and Barcelona show moderate engagement with 17, 14, 10, and 10 active users respectively.

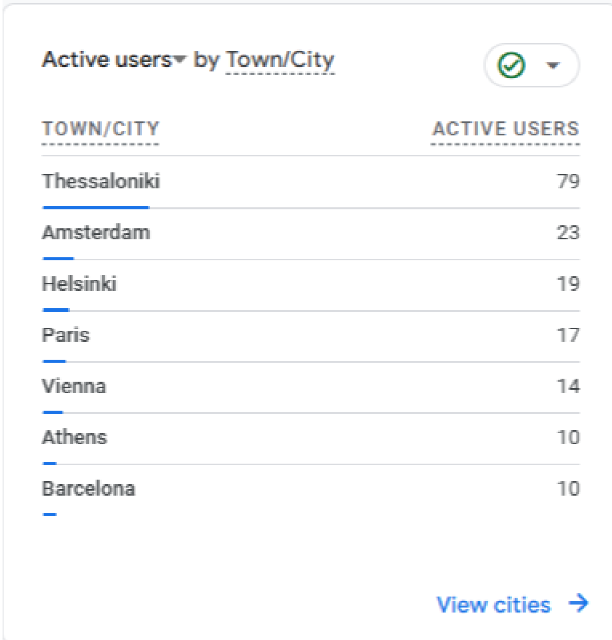

Figure 61: Active users per city

Finally, Figure 62 provides a detailed breakdown of user activity for the SHOW marketplace by country, tracking key metrics such as active users, new users, engaged sessions, engagement rate, average session time, and event counts across various regions.

Greece leads with 93 active users and 75 new users, contributing significantly to the platform with a high engagement rate of 60.84% and an average engagement time of 4 minutes and 33 seconds per session. The United States follows with 61 active users, though it has a lower engagement rate of 12.7%, indicating that while the SHOW marketplace reaches many users in the U.S., engagement could be improved. China, with 53 active users, shows the lowest engagement rate at 1.89%, suggesting challenges in retaining or engaging users from that region.

Many European Countries from bigger regarding their population such as Germany, France, Spain and Italy to smaller such as Belgium and Portugal exhibit moderate engagement rates of around 50%. European countries generally demonstrate relatively strong engagement, while regions like China Israel, and India show lower engagement metrics.

The table also includes data from 37 different countries, reflecting broad international interest in the SHOW marketplace. This geographical diversity highlights the platform's global reach, with users from regions like Europe, Asia, and North America. While Greece and the United States dominate in terms of user numbers, the presence of users from smaller regions like Bahrain and Cyprus suggests that the SHOW marketplace is attracting attention across multiple markets. This global engagement underscores the SHOW marketplace's potential for further expansion, along with opportunities to increase conversions through localized marketing strategies.

	Country	Active users	New users	Engaged sessions	Engagement rate	Engaged sessions per active user	Average engagement time per active user	Event count All events	Key events All events	User key event rate All events	Total revenue
	Total	492 100% of total	418 100% of total	457 100% of total	34.31% Avg 0%	0.93 Avg 0%	1m 55s Avg 0%	9,050 100% of total	0.00	0%	€0.00
1	Greece	93	75	160	60.84%	1.72	4m 33s	3,926	0.00	0%	€0.00
2	United States	61	61	8	12.7%	0.13	4s	235	0.00	0%	€0.00
3	China	53	1	1	1.89%	0.02	6s	76	0.00	0%	€0.00
4	Germany	48	44	72	48.98%	1.50	4m 08s	1,132	0.00	0%	€0.00
5	France	30	30	37	67.27%	1.23	50s	281	0.00	0%	€0.00
6	Netherlands	28	27	9	29.03%	0.32	10s	113	0.00	0%	€0.00
7	Austria	27	27	50	12.44%	1.85	2m 20s	1,300	0.00	0%	€0.00
8	Finland	26	26	13	15.29%	0.50	36s	286	0.00	0%	€0.00
9	Spain	20	20	24	51.06%	1.20	1m 17s	249	0.00	0%	€0.00
10	Italy	18	17	22	66.67%	1.22	3m 08s	447	0.00	0%	€0.00
11	Belgium	14	14	13	72.22%	0.93	1m 46s	209	0.00	0%	€0.00
12	Sweden	11	11	3	25%	0.27	28s	55	0.00	0%	€0.00
13	Switzerland	8	8	6	50%	0.75	40s	94	0.00	0%	€0.00
14	Czechia	7	7	4	44.44%	0.57	17s	40	0.00	0%	€0.00
15	Ireland	7	7	2	28.57%	0.29	8s	29	0.00	0%	€0.00
16	Portugal	5	5	3	60%	0.60	1m 26s	75	0.00	0%	€0.00
17	Russia	5	4	0	0%	0.00	0s	14	0.00	0%	€0.00
18	Denmark	4	4	4	100%	1.00	2m 17s	133	0.00	0%	€0.00
19	Norway	4	4	3	42.86%	0.75	1m 22s	35	0.00	0%	€0.00
20	South Korea	4	3	3	50%	0.75	42s	34	0.00	0%	€0.00
21	Poland	3	3	2	50%	0.67	3m 57s	21	0.00	0%	€0.00
22	United Kingdom	3	3	2	66.67%	0.67	20s	23	0.00	0%	€0.00
23	Singapore	2	2	2	50%	1.00	14m 52s	17	0.00	0%	€0.00
24	Türkiye	2	2	2	100%	1.00	1m 59s	20	0.00	0%	€0.00
25	Bahrain	1	1	1	100%	1.00	44s	9	0.00	0%	€0.00
26	Brazil	1	1	1	100%	1.00	31s	7	0.00	0%	€0.00
27	Bulgaria	1	1	1	100%	1.00	3m 41s	21	0.00	0%	€0.00
28	Cyprus	1	1	1	25%	1.00	34s	12	0.00	0%	€0.00
29	Hungary	1	1	1	100%	1.00	45s	6	0.00	0%	€0.00
30	India	1	1	0	0%	0.00	8s	4	0.00	0%	€0.00
31	Israel	1	1	1	2.86%	1.00	24s	84	0.00	0%	€0.00
32	Japan	1	1	1	33.33%	1.00	18s	9	0.00	0%	€0.00
33	Latvia	1	1	1	100%	1.00	34s	5	0.00	0%	€0.00
34	Philippines	1	1	0	0%	0.00	0s	3	0.00	0%	€0.00
35	Saudi Arabia	1	1	1	50%	1.00	7m 25s	37	0.00	0%	€0.00
36	Tunisia	1	1	1	100%	1.00	1m 34s	5	0.00	0%	€0.00
37	Vietnam	1	1	1	100%	1.00	7s	4	0.00	0%	€0.00

Figure 62: Analysis per event per country

8 Promotion of the SHOW marketplace

Promotional activities for the SHOW marketplace were carried out, including posts on social media and presentations at other European research projects. These efforts were made to increase visibility and engagement with the marketplace, emphasizing its relevance and value within the research and innovation community.

8.1 The SHOW marketplace in social media

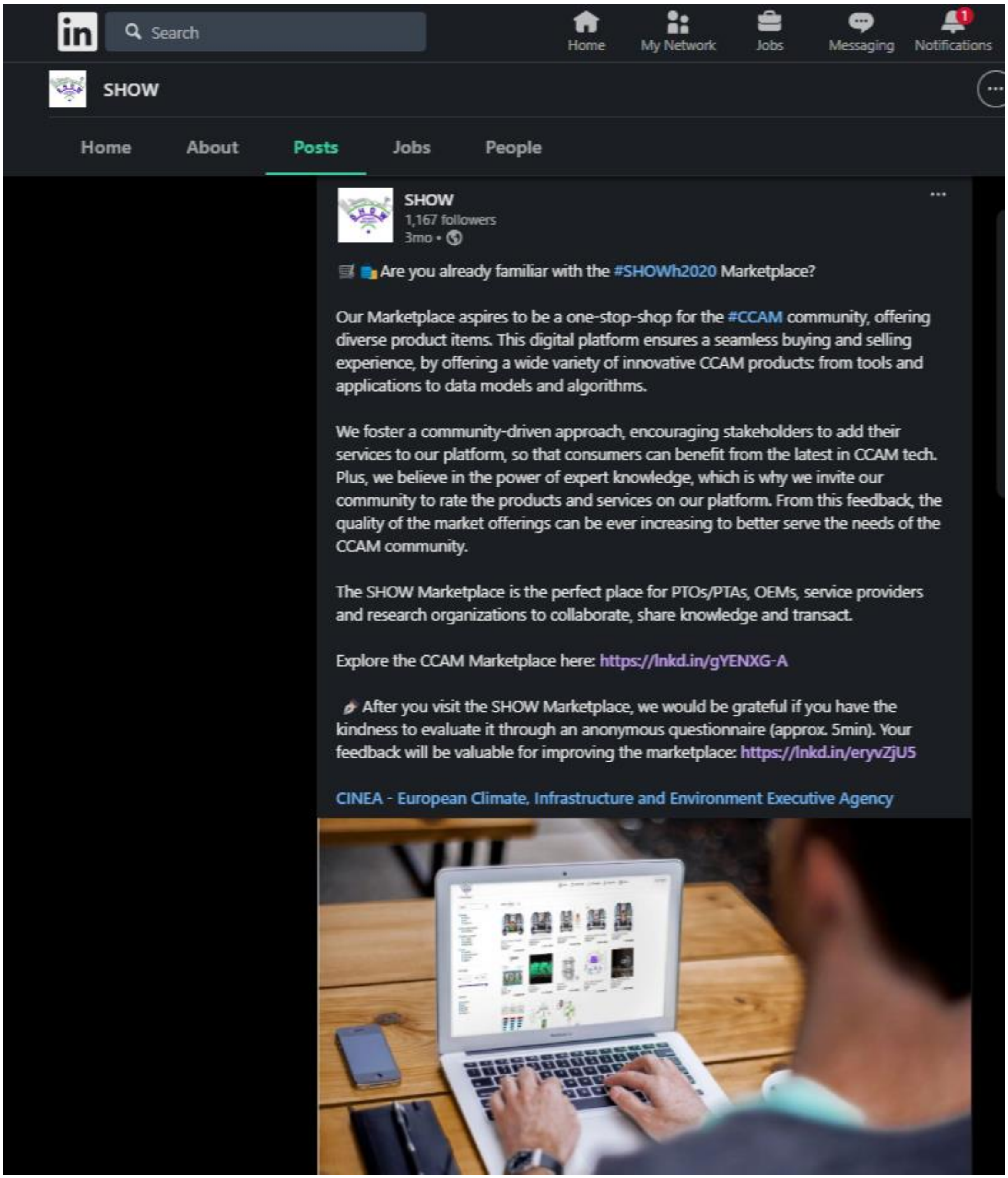

Figure 63: LinkedIn post about SHOW marketplace

8.2 The SHOW marketplace in Horizon Europe Projects

Promotional presentations about the SHOW marketplace were made at the Horizon Europe projects ULTIMO and REALLOCATE[13]. These efforts focused on showcasing the marketplace's features, fostering collaboration, and enhancing its visibility within the research and innovation community.

8.2.1 Presentation at ULTIMO

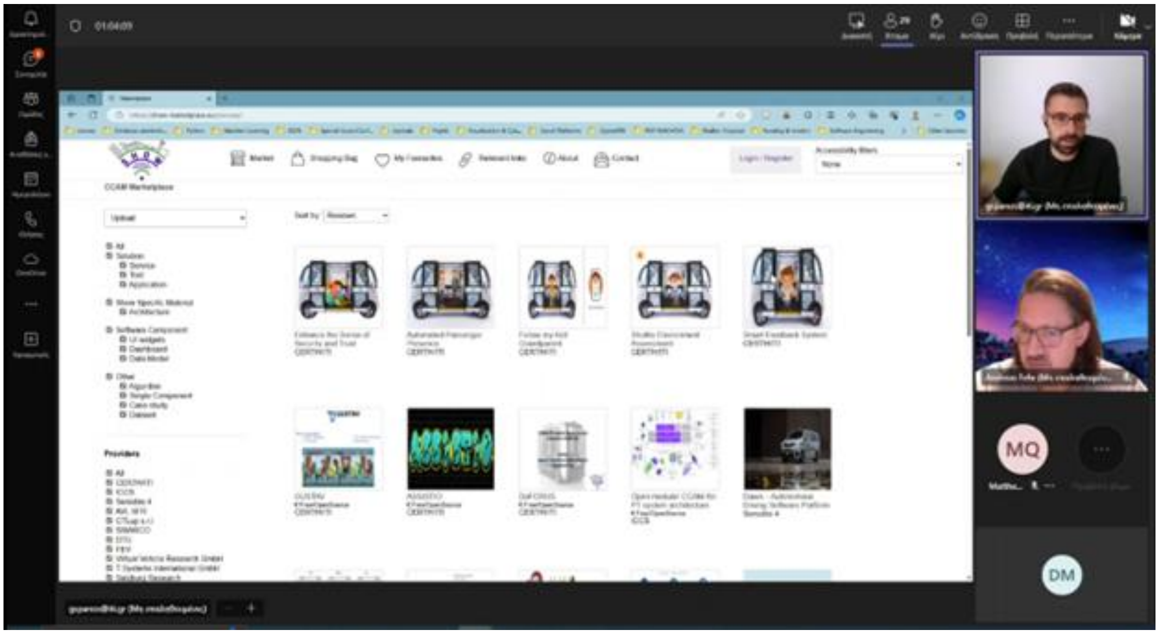

Figure 64: Homepage presentation at the ULTIMO project

[13] https://reallocatemobility.eu/

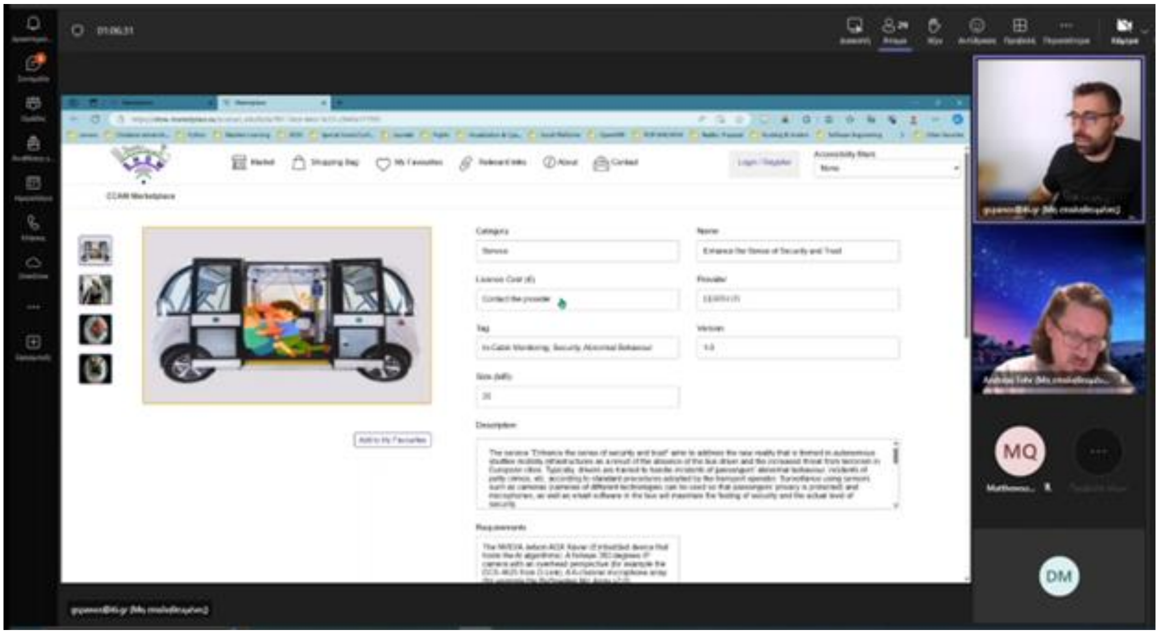

Figure 65: Product details presentation at the ULTIMO project

8.2.2 Presentation at REALLOCATE

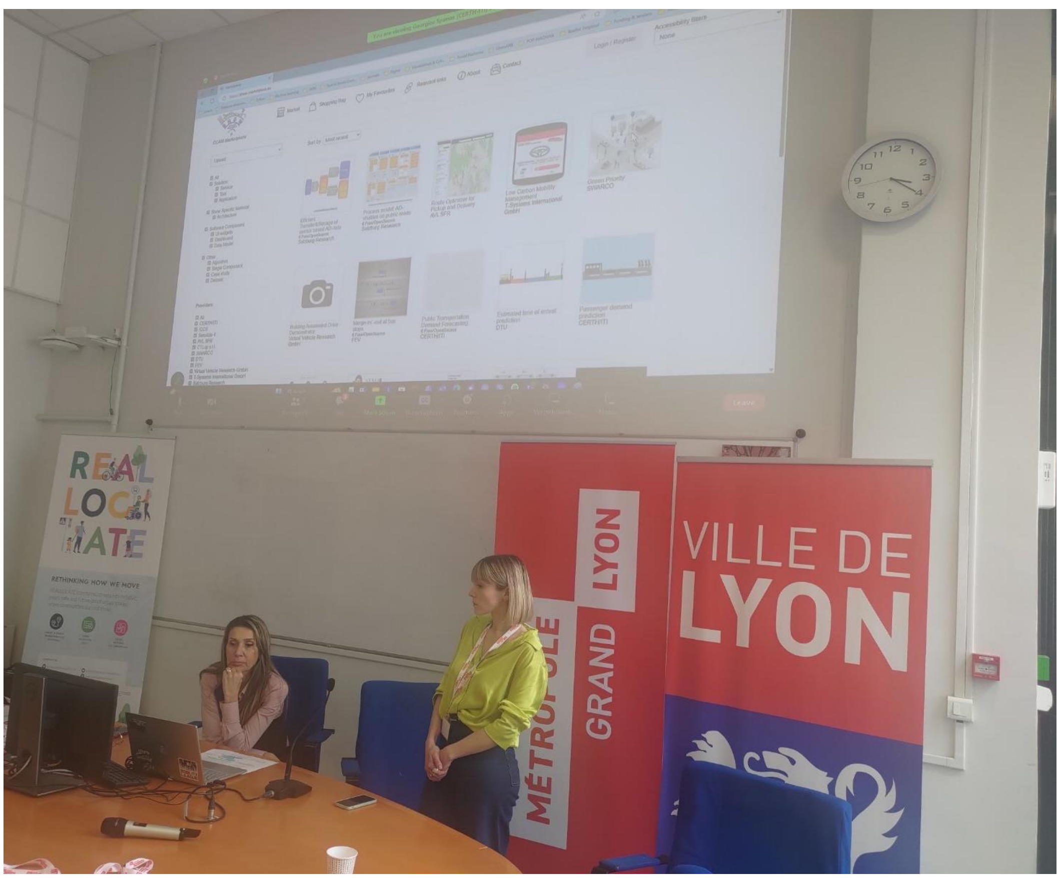

Figure 66: Homepage presentation at the REALLOCATE project

9 Conclusions

In the present deliverable, which is the final deliverable related to the SHOW marketplace, the work performed during the final period (M31-M57) in WP6: Services Marketplace, containing the following activities A6.1: SHOW Marketplace, A6.2: Metadata-based Value Added Services, A6.3: SHOW Operational services, A6.4: Energy Management services and A6.5 Dynamic Personalized Services is described extensively.

The SHOW marketplace aimed to be the first one stop shop for the CCAM community, offering various advantages to different stakeholders and stimulating the corresponding community both the research one and the industrial. Indeed, the various activities carried out this final period have assisted to that goal. More specifically, during the last period, the complete business plan of the SHOW marketplace, being of utmost importance for the further exploitation was developed and presented in detail in the current Deliverable D6.3. Moreover, the development of new services, presented in Section 3 along with the integration of new product items (either developed within WP6 or not) have enhanced the SHOW marketplace adoption, increasing the previous number of 13 product items by 15. Furthermore, the analysis of these 28 products existing in the SHOW marketplace revealed that 12 different service providers contributed to the SHOW marketplace content and there are seven different product categories.

The evaluation of the SHOW marketplace was performed in two different ways, the first one was the questionnaires shared in various stakeholders of the field and the second is the analysis of the Google analytics. Regarding the evaluation by the questionnaires, the results showed that the SHOW marketplace features are rated with high grades by the evaluators, although further improvements can be performed in the future. Regarding, the analysis of the Google analytics, it is obvious that the promotional campaigns helped in the SHOW marketplace traffic and that the success of the SHOW project with respect to its huge global visibility is depicted by the fact that the visitors of the marketplace come from 37 different countries.

Finally, special focus will be given to integrating the SHOW marketplace with FAME's established European framework for testing and evaluation, particularly the CCAM Test Data Space (TDS) and Common Evaluation Methodology (CEM). By leveraging FAME's extensive stakeholder network, harmonized methodologies, and robust data-sharing capabilities, we can ensure greater visibility, improve data interoperability, and facilitate knowledge exchange across all CCAM stakeholders. This alignment will not only increase the adoption of the SHOW marketplace but also contribute to a more coherent and collaborative European CCAM ecosystem, accelerating large-scale testing, demonstration, and the future scale-up of complete CCAM solutions.

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Appendix

*Fields marked with * are mandatory.*

Scope of the questionnaire

The scope of this questionnaire is to gather valuable feedback and insights from users and stakeholders who have interacted with the SHOW Marketplace. It aims to evaluate the marketplace from both technical and business perspectives. The questionnaire specifically seeks to assess the user experience with the marketplace's technical aspects (registration, uploading, filtering, etc.), and their willingness to engage with the platform. Additionally, it aims to understand the marketplace's relevance and potential value to different user categories and the CCAM community, and to identify potential improvements or additional features.

Your participation in this survey is voluntary and anonymous and will take approximately 10 minutes. You have the right to withdraw from it at any time, with absolutely no consequences or requirement of justification.

Your participation in this survey is voluntary and anonymous and will take approximately 10 minutes. You have the right to withdraw from it at any time, with absolutely no consequences or requirement of justification.

If you have any questions or concerns regarding this study, you can contact us in the following email addresses:

- gspanos@iti.gr

Consent Statement

- I have read and understood the purpose and conditions of the survey and wish to participate in it.
- I have been informed in a clear, simple and understandable way about the collection and processing of my personal data and I consent to it.

☐ I accept your terms.

Personal & Profiling Questions

1. *Industry/sector:
    a. Regulator
    b. Research
    c. Academia
    d. Operator
    e. Other
2. *How long have you been operating in the CCAM market?
    a. 0-5 years
    b. 5-10 years
    c. 10-15 years
    d. 15+ years

3. *Frequency of using online marketplaces for business purposes
    a. Daily
    b. Weekly
    c. Monthly
    d. Rarely

Technical Evaluation

1. *The layout and organization of the marketplace's interface were easy to navigate.
    a. Strongly Disagree
    b. Disagree
    c. Neutral
    d. Agree
    e. Strongly Agree
2. *The registration process was straightforward and easy to follow.
    a. Strongly Disagree
    b. Disagree
    c. Neutral
    d. Agree
    e. Strongly Agree
3. *How would you rate your experience with uploading a product? Please provide a rate from 1: Very dissatisfied to 5: Very Satisfied.

	Very dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied
*Clarity of guidelines	○	○	○	○	○
*Ease to navigate the upload interface	○	○	○	○	○
*Customization option for your listing	○	○	○	○	○
*Ability to add your content (images, videos, etc)	○	○	○	○	○
*Availability of relevant categories and tags	○	○	○	○	○

4. *How satisfied are you with the loading time of each feature of the marketplace?
    a. Very dissatisfied
    b. Dissatisfied
    c. Neutral
    d. Satisfied
    e. Very satisfied
5. *Do you feel confident sharing your personal information for registering to the platform?
    a. Not confident
    b. Slightly confident
    c. Moderately confident
    d. Confident
    e. Very confident
6. *Do you believe that all the security measures are in place to guarantee the sound and safe sharing of your product?
    a. Strongly Disagree
    b. Disagree
    c. Neutral

d. Agree
e. Strongly Agree

7. *What devices did you use to interact with the marketplace?
☐Mobile
☐Tablet
☐Desktop PC
☐Laptop PC

Business Evaluation

1. *Are you confident in sharing your work through the SHOW marketplace?
   a. Yes
   b. No
2. *Have you joined third-party marketplaces or communities to share your outputs?
   a. Yes
   b. No
   c. Do not want to reveal
3. *Is it relevant for the stakeholders' use?
   a. Not compatible
   b. Somewhat compatible
   c. Compatible
   d. Highly compatible
4. *How likely is the marketplace to bring value to the following users?

	Not likely	Somewhat Likely	Likely	Very likely
*Research and academia	○	○	○	○
*Transport operators	○	○	○	○
*Transportation service providers	○	○	○	○
*Public transport authority	○	○	○	○

5. *Which of the following categories are you more likely to interact with via the market-place (provide or consume)?

	Not likely	Somewhat likely	Likely	Very likely
*Service	○	○	○	○
*Tool	○	○	○	○
*Application	○	○	○	○
*Architecture	○	○	○	○
*UI widget	○	○	○	○
*Dashboard	○	○	○	○
*Data Model	○	○	○	○
*Algorithm	○	○	○	○
*Single Component	○	○	○	○
*Case study	○	○	○	○
*Dataset	○	○	○	○

6. *Are you willing to pay a fee to the platform?
   a. Yes

    b. No
7. *Were you able to find the specific products/services you were looking for?
    a. Yes
    b. No
8. *What other capabilities would you like to be added to the marketplace? Describe in a short sentence.

* What other capabilities would you like to be added to the marketplace? Describe in a short sentence.
150 character(s) maximum

Contact

[Contact Form]