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Zero Emission flexible vehicle platform with modular powertrains serving the long-haul Freight Eco System

ZEFES

ZEFES - Deliverable report

D4.1 – Digital twin specification and architecture

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Publishable summary

Central to the ZEFES project is the establishment of a digital environment and framework that will enable and support the operation of managerial tools aimed at logistics and freight transport companies. As stated in Objective 3 and Sub-Objectives 3.1 and 3.2 of the project proposal, the digital tools will be designed to facilitate zero tailpipe emission vehicle integration in fleets, optimise logistical task assignments considering routes, infrastructure and refuelling/recharging opportunities, and develop predictive maintenance strategies including deployment of diagnostic & prognostic techniques.

These decision-making tools, as defined in DoA, comprise:

- **Buying decision**: a platform that helps to find suitable ZEV fleet for certain fleet operations
- **Mission planning**: a platform that optimises the routing for a certain mission by using an operator’s fleet specification
- **Right vehicle in right duty**: a platform that selects the most suitable vehicles from the fleet for certain operations and addresses the problem of different weight and safety restrictions for European Modular Systems (EMS) deployment
- **Dynamic correlation:** a tool to enhance virtual representation of real world features
- **Predictive Maintenance**: a platform can predict vehicle maintenance needs

Activities conducted during Work Package 4 to-date have covered:

- Understanding the critical needs from fleet operators and alignment of the specification of the ZEFES decision making tools against these specific needs
- Defining and documenting the digital platform and tools specifications and requirements

Output from this work is reported in this Deliverable document. Although some of the tools' workings will involve complex digital processes, no technical roadblocks are expected during their elaboration and use. The two areas requiring further discussions and agreements regard the confirmation of the tools’ requirements with the operators, and how much connectivity to the outside world and to the real-world assets the digital platform will be granted. Both will impact the features available from the platform and the tools, and will also affect the depth of the analysis work part of the final impact assessment work.

Work and consultations with partners are on-going to progress both issues.

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Abbreviations & Definitions

Abbreviation	Explanation
AEMPT	Advanced Energy Management Powertrain
API	Application Programming Interface
BEV	Battery Electric Vehicle
BI	Brand Independent
CCU	Connectivity and Control Unit
CPES	Cyber Physical Energy System
CPS	Cyber Physical System
CPSoS	CPS of Systems
CRG	Curved Regular Grid
DoA	Description of the Action
EMS	European Modular Systems
ESS	Energy Storage System
ETA	Estimated Time of Arrival
FCEV	Fuel Cell Electric Vehicle
FL	Feature Layer
FMS	Fleet Management System
GUI	Graphical User Interface
HRS	H2 Refuelling Station
Hybrid RDR	Hybrid Ripple-Down Rules
IP	Intellectual Property
KPI	Key Point Indicators
LCA	Life Cycle Assessment
LFP	Lithium Iron Phosphate
LoFi	Low Fidelity
LOS	Level Of Service
LSTM	Long Short Term Memory
LTO	Lithium Titanate
MCS	Megawatt Charging System
ML	Machine Learning
MoCs	Models of Computations
NMC	Nickel Manganese Cobalt
OEM	Original Equipment Manufacturer
PBS	Performance Based Standard
POI	Point Of Interest
POTs	Patterns Over Times
RM-ODP	Reference Model of Open Distributed Processing
ROI	Return of Investment
ROM	Reduced Order Model
SHBERA	Smart Energy System Reference Architecture

SME	Subject Matter Expert
SoC	State of Charge
SoH	State of Health
TCO	Total Cost of Ownership
TC	Technical Committee
V2G	Vehicle to Ground
V2X	Vehicle to X
VCU	Vehicle Control Unit
(Z)DP	(Zefes) Digital Platform
ZEV	Zero Emission Vehicle

1 Introduction

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The tools' impact and effectiveness will depend on the breadth of information that will be made available regarding the operation and status of the real-world assets and of the wider eco-system for long haul truck operation. Access to such information will enable the creation of digital twins of the real-world assets and environment; the Advanced Manufacturing Research Centre (AMRC) offers a definition of digital twins as 'live digital coupling of the state of a physical asset (…) to a virtual representation with a functional output'[1]. They also describe typical roles fulfilled by digital twins, as shown on Figure 1, highlighting the duality between real physical assets and the digital representation of these assets in a virtual environment, and the connectivity between the real and virtual systems.

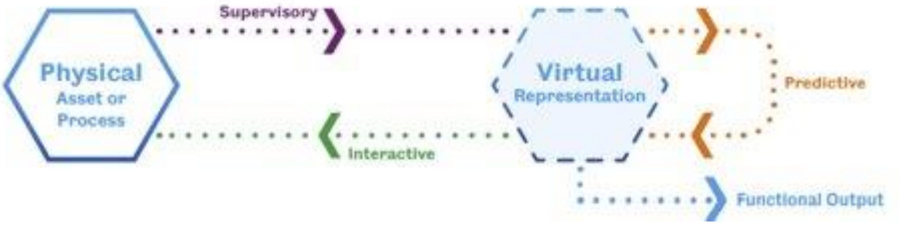

Figure 1 – Definition and roles of a Digital Twin

On ZEFES, the real-world assets will consist of the Zero Emission Vehicles deployed on the Use Cases, their individual components, the electric charging and H_2 refuelling stations, together with eco-system items such as road network, traffic, and weather. **Error! Reference source not found.** depicts the flow between the ZEFES real world assets, the virtual environment including the digital twins, and the resulting vehicle managerial and decision-making tools which will be delivered to the end users, i.e. is the logistics and freight transport companies.

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[1] Untangling the requirements of a Digital Twin – October 2020 – Prof. Rabb Scott, Uni. of Sheffield/AMRC

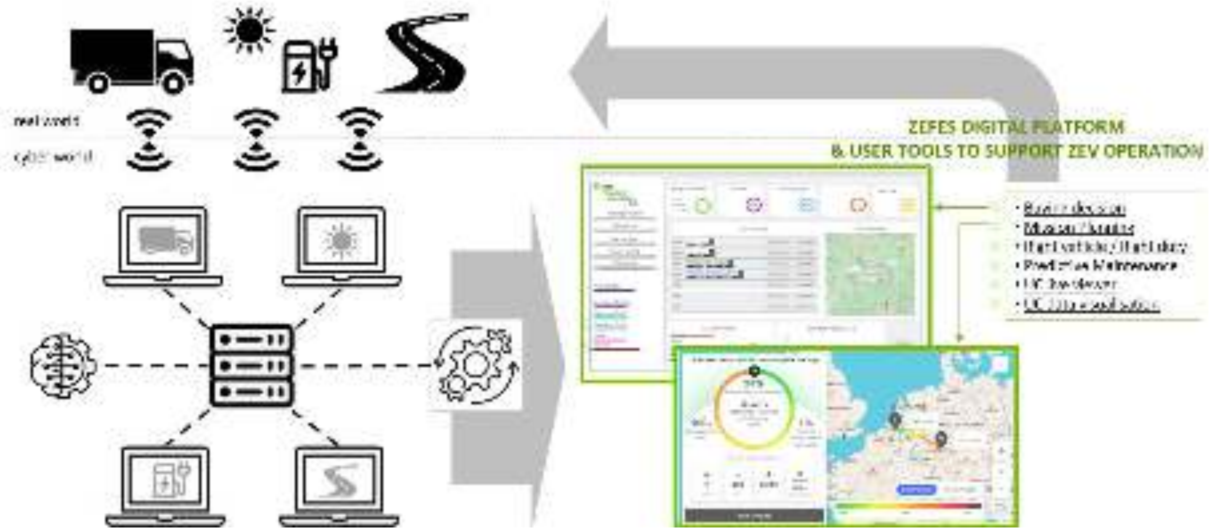

Figure 2 – Real world assets, digital platform and digital twins, and ZE vehicle and fleet managerial tools

Work Package 4 is responsible for the delivery of the entirety of the virtual layer shown on **Error! Reference source not found.**, which will be referred to as the Digital Platform (DP). To document the needs from the platform, the partners adopted a requirements-based approach, whereby the definition of the end tools and associated functionalities are driven by the expressed needs from the logistics and fleet operators. This encompasses:

- Gather end-user requirements and formulate key problem statements
- Derive and specify general tools features
- Elaborate general platform functional architecture
- Capture detailed tools and platform requirements
    - Document existing models, services, datasets etc., and those to be developed
- Develop tools and platform
- Test and validate

This report documents the work done covering the first 3 points, and reports the work in progress related to point 4. A brief summary of each section, and how they relate to each other, is provided thereafter.

Section 2 summarises the information gathered from early discussions with the logistics and fleet operators appointed as partners on ZEFES, to get an understanding of the fleet operators' needs and priorities in the purchase and deployment of ZEVs into their fleet. This information is used to help define the functionalities required from the tools.

Section 3 provides a state of the art review of tools and individual service functions produced during previous funded projects, highlighting areas of commonality and possible re-use, and areas needing further development. The review also covers aspects of the digital infrastructure implementation, that is the computing hardware environment, the modalities of data and information storage, data management, deployment of service functions, communication protocols between service functions, and security aspects.

Section 4 introduces the digital platform concept, focusing on the description of the platform lay-out and of its elementary blocks (the service functions), which are to be used, combined, and orchestrated into specific workflows to generate the data and information delivered in the decision making tools.

Section 5 provides a detailed specification for each tool, in terms of what information and factors need to be considered, and what pieces of information need to be generated and reported to the fleet operators in order to facilitate decision making. This specification work feeds from the discussions held and summarised in Section 2. It is expected that further input will be received and integrated into the tools' specifications as discussions with stakeholders continue.

Section 6 covers the detailed documentation of requirements for each of the decision-making tools. This consists in detailing how the individual elementary blocks described in Section **Error! Reference source not found.** will be used and orchestrated to deliver the functionalities described in Section 5. This work will continue beyond the issue of this report and is therefore supported by separate, live, requirements documents.

Section 7 provides a breakdown of the digital platform requirements in terms of the platform architecture, general computation processes, data storage and management, and access control.

2 Operators and Fleet Management Needs

In advance of gathering full stakeholder needs and requirements from Task 1.3, a short survey was initiated as part of Work Package 4 in order to gain an initial understanding of the fleet operators' needs and priorities in the purchase and deployment of ZEVs into their fleet. Understanding these needs is a key part in the definition and specification of tools aimed at supporting operators in their decision-making process.

The questionnaire was distributed to fleet operators involved as partners on the ZEFES project: DPD, COL, GRU, GBW, PG, PRI. This section summarises the questions and feedback received during that initial consultation.

2.1 Operators Questionnaire and feedback

The questionnaire was designed to capture the diverse range of requirements and priorities that operators may have, tailored to their specific operational needs. By soliciting input from a wide range of operators, we aimed to gather valuable insights into the varying needs and expectations within the fleet industry. The following are the questions sent to the operators:

- General consideration when buying new fleet vehicles
- Vehicle characteristics and attributes that are considered when buying new fleet vehicles
- Constraints that affect the selection of new fleet vehicles
- Thoughts and considerations when buying Zero Emission Vehicles (BEV & FCEV)

The feedback was received from all the operators who are Partners on ZEFES. Even though the overlap of the feedback is minimal, together they cover a wide range of necessary topics and issues.

2.1.1 Feedback – General Considerations

Listing all the topics mentioned in the feedback is beyond the scope of this document. However, majority of the topics with high overlap and priority were considered:

- Total Cost of Ownership (TCO): Total cost of ownership of a fleet of vehicles is the most important factor to make a fleet buying decision. TCO includes a multitude of variables which can impact the variance
- Return of Investment (ROI): ROI helps assess the profitability and effectiveness of the fleet operations
- Trip Distance: The average trip distance of an operator will give rise to different business needs
- OEM Service Network
- R&D partnerships with OEMS
- OEM Warranty
- OEM Service Time
- Energy Consumption
- Technical Compliance

2.1.2 Key Vehicle Characteristics for ZEV's

The following are the vehicle specific considerations when buying new fleet vehicles. The requirements such as range and payload capability vary based on the operational needs.

Performance and Capability:

- Range
- Battery size
- Fast charging speed
- Refueling speed (specific to Fuel Cell Electric Vehicles - FCEVs)
- Tank capacity (FCEV)
- Payload capability
- Driveline performance
- Power (battery and fuel cell)

Safety and Connectivity:

- Safety features
- Vehicle connectivity
- Telematics capabilities
- Remote diagnosis
- Data analytics

Logistics and Support:

- Trailer volume
- Access to assistance
- Access to spare parts
- Areas with limited access

2.1.3 Constraints specific to ZEVs

When integrating Zero Emission Vehicles (ZEVs) into a fleet, the important factors that need to be considered are:

Integration in planning tool: Ensuring effective integration into existing fleet management and planning tools.

Reliability of Technology: Evaluating the reliability and performance of ZEV technology helps to maximize the utilization rate.

Availability of public funds: Accessing public subsidies or incentives to mitigate the high initial cost of ZEVs.

For FCEVs, additional constraints include safety, refilling options, payload limitations, maintenance requirements, and reliability. For BEVs, constraints include charging time, charging infrastructure availability, and payload limitations. By addressing these constraints, fleet operators can make informed decisions and strategies for successful ZEV integration.

2.1.4 Operators feedback - Summary

Based on the feedback from the operators it is evident that they are open to incorporating ZEVs into their fleet. However, the key considerations remain the same provided that the technology is reliable. It outlines the following categories:

Business needs: Considering the Total Cost of Ownership (TCO) and Return on Investment (ROI) is crucial for making successful business decisions. This analysis helps assess the financial implications and potential benefits of adopting ZEVs.

Vehicle Specifications: Evaluating ideal vehicle characteristics that satisfy payload and range requirements while minimizing energy consumption is essential. This ensures the chosen ZEVs are well-suited for the fleet's operational needs.

OEM network: Recognizing that service network, service time, and warranty provisions vary among Original Equipment Manufacturers (OEMs) is important. Optimizing the fleet's utilization rate relies on reliable OEM support and minimizing downtime.
Carbon footprint: Addressing the industry's common goal of reducing the overall carbon footprint is a key driver for operators to switch to ZEVs. This aligns with environmental sustainability objectives.

These considerations were integrated into the specification work for the decision-making tools, as reported in Section 5. Further feedback is expected from the survey conducted in Task 1.3, and from further stakeholder engagement. This will be reported after the release of this document, however any considerations relevant to Work Package 4 will be considered for the design of the digital platform and associated tools. These will be documented in the live tools requirements capture document described in Section 6.

3 State of the Art Review

Along with understanding fleet operators' requirements, the other outward-facing activity during the inception phase of Work Package 4 involved the review of past funded projects to gather experience and knowledge pertinent to ZEFES. This included the review of the projects' deliverable reports and of any tools produced. This review work is reported in the following sub-sections, and covers aspects of the digital platform relevant to both end-user functionalities and digital implementation.

3.1 Zero Emission Vehicle KPI Tools and Methodology

The following projects were identified for review: LONGRUN, CEVOLVER, AEROFLEX, TRANSFORMERS and OPTEMUS. A detailed account of this work is provided in Appendix Section 13.

3.1.1 LONGRUN

LONGRUN focused on the development of efficient and sustainable long-distance powertrains for heavy duty trucks and coaches. A simulation platform was also developed to support the design and the development of the powertrains. Two tools from LONGRUN's WP1 are relevant to the ZEFES project.

- **LONGRUN Life Cycle Assessment (LCA) tool[2]:** To focus on overall Carbon footprint and energy consumption. This involves evaluating fuels, focusing on the production (Well-to-Tank) and the tailpipe CO2 emissions (Tank-to-Wheel). From ZEFES perspective, the LCA tool can be used to assess the CO2 footprint on the WTT emissions especially on renewable energy production.
- **LONGRUN Simulation platform:** [3]To calculate energy consumption and CO2 emissions of the vehicle using conventional, electric and hybrid powertrain. The powertrain technologies that are not covered by VECTO (European Commission's Vehicle Energy Consumption calculation TOol) version will be covered in this tool. **Relevance for the buying decision tool in ZEFES:** Simulation model of a standard diesel truck for estimating the CO2 savings compared to an equivalent BEV/FCEV and Eco-routing can be implemented for selecting the appropriate route considering the constraints of road topology, real/historic traffic data, weather conditions along the route.

3.1.2 OPTEMUS

Optimised energy management and use (OPTEMUS) represents an opportunity for overcoming one of the biggest barriers towards large scale adoption of electric and plug-in hybrid cars, range limitation due to limited storage capacity of electric batteries.

One of the technologies developed during the project was **eco-routing** [4]navigation which is a system that find most energy efficient route in road network to travel from an origin to destination. The system uses an algorithm that considers various factors such as traffic, road slope, speed limits, and vehicle characteristics to calculate the optimal sequence of segments that minimizes the energy consumption of the vehicle. Another technology developed in the project was the **eco-driving**, which is a system that evaluates the driving style of the driver and provides feedback and guidance to improve it. The eco-driving assistance suggests actions to the driver to approach the optimal behaviour. **Learnings**

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[2] LONGRUN LCA calculation tool - LONGRUN (h2020-longrun.eu)

[3] LONGRUN SIMULATION PLATFORM - LONGRUN (h2020-longrun.eu)

[4] Optemus - Optemus | Optimised and systematic energy management in electric vehicles

from these two tools can be used in ZEFES for routing and establishing optimal driving behaviour. Along with these technologies the project also worked on Smart seat, compact refrigeration unit and regenerative shock absorber. However, these technologies are not directly relevant to ZEFES.

3.1.3 CEVOLVER

The CEVOLVER[5] project built on the OPTEMUS project to address some of the challenges of BEV design. It used affordable batteries that were suitable for urban use and long daytrips. It also optimized the thermal management of the cabin and powertrain components to increase efficiency. Moreover, it developed improved functions for range prediction, eco-driving and eco-routing driver assistance based on vehicle connectivity.

The project used a tablet, a CCU, an OEM cloud/ a Brand Independent (BI) cloud to connect the vehicle with the outside world and provide data content from different sources. The tablet was the interface for the driver's input and information display. The CCU was an electronic unit that connected the vehicle with the OEM cloud. The OEM cloud hosted proprietary services and acted as a gateway to CEVOLVER services. The brand independent cloud provided neutral access to third party data providers and computing resources. The possible paths of connection were:

- Tablet <> CCU <> OEM cloud <> BI cloud
- Tablet <> OEM cloud <> BI cloud, if no CCU was implemented.
- Tablet <> BI cloud, if OEM had no cloud infrastructure.

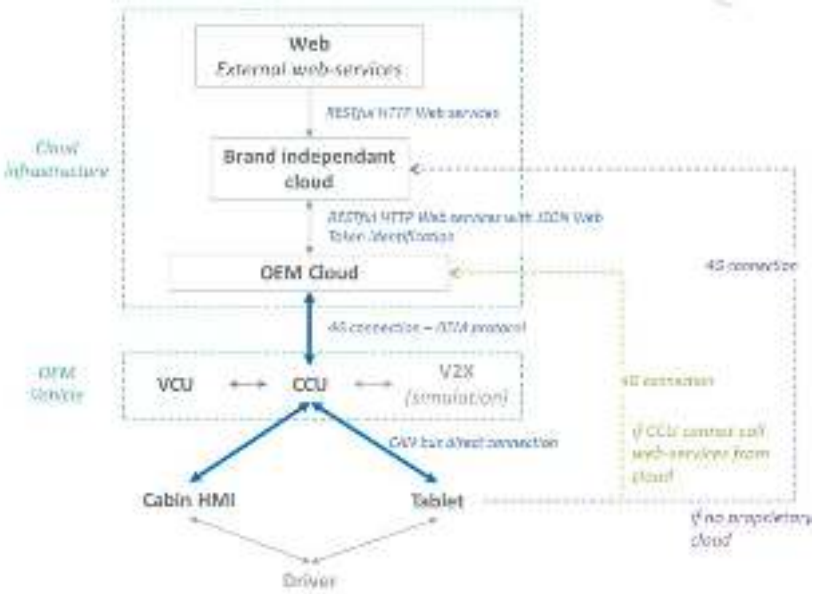

Figure 3 – CEVOLVER system connectivity

The project also logged road network information, weather information and data transfer from VCU of vehicle on battery SoH, SoC at different frequencies.

The methodology of CEVOLVER could be applied to the ZEFES project to choose the best route, lower emissions footprint (CO2) and maximize powertrain efficiency. The project used an API to communicate live details of traffic, weather and charging and select an eco-route accordingly.

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[5] Results - CEVOLVER

3.1.4 TRANSFORMERS

TRANSFORMERS focused on the reduction of energy consumption of road freight transport by developing and demonstrating innovative truck and trailer combinations. The project innovations include improved and mission adaptable loading efficiency measures, mission adaptable aerodynamics, and distributed trailer mounted electric driveline. This project was continued with the AEROFLEX project[6]. There are no direct learnings or technologies from these two projects which can be used for ZEFES digital platform.

3.2 Vehicle and System Modelling

Vehicle models developed on most recent EU projects (namely *ORCA (H2020, GA no: 724087), LONGRUN (H2020, GA no: 874972), ASSURED (H2020, GA no: 769850), CEVOLVER (H2020, GA no: 824295)*), have consisted of low fidelity (Lo-Fi) multi-physics map and analytical equation-based model of the forward-facing powertrain of the battery electric car/bus/truck were designed and implemented in addition to the various energy, thermal, and charging management strategies in the form of the ECO-features, i.e., ECO-charging, ECO-comfort, ECO-driving and ECO-routing. The LoFi/analytical models were parametrized and calibrated using literature data found by the model developers and/or with component data that were provided by the OEMs.

The powertrain models were developed in MATLAB/Simulink®, ran with fixed solver setting with step-size set between 0.01 and 0.1s. The following is the list of the library of powertrain components available from previous projects:

Power electronics subsystems
- High-powered bidirectional DC/DC converter
- Low-powered unidirectional DC/DC converter
- Inverter

Mechanical subsystems
- Gear and transmission
- Vehicle chassis, wheels
- Friction brakes

Electromechanical subsystems
- Electric Motor

Electrochemical subsystems
- Battery: LFP, LTO, and NMC

Thermal subsystems
- HVAC (for cabin & battery cooling/heating)
- Thermal model: Powertrain, Cabin and ESS

Control subsystems
- Driver (generate the speed profile from navigation information (given for example by eco-routing) or user defines the target speed profile)
- Energy, thermal, and charging management system
- Triple ECO-features: ECO-charging, ECO-comfort, ECO-driving

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[6] TRANSFORMERS - Uniresearch

Statistics

- Total cost of ownership (TCO) (€/km) and energy consumption (kWh/km)
- Life cycle Analysis

Further information on the individual projects and the models developed is reported in Appendix Section 14.

In all platforms, only black-box models were exchanged among partners to safeguard the models in terms of Intellectual Property (IP). Consequently, model users were unable to access critical information regarding the models. To address this limitation and enable model users to customize the models, only parameterization were made available, the simulation framework introduces common parameters that were tunable by model users. This allows greater flexibility and customization options for the users while still protecting the underlying IP of the models. The overall system integration work flow is described in the below figure.

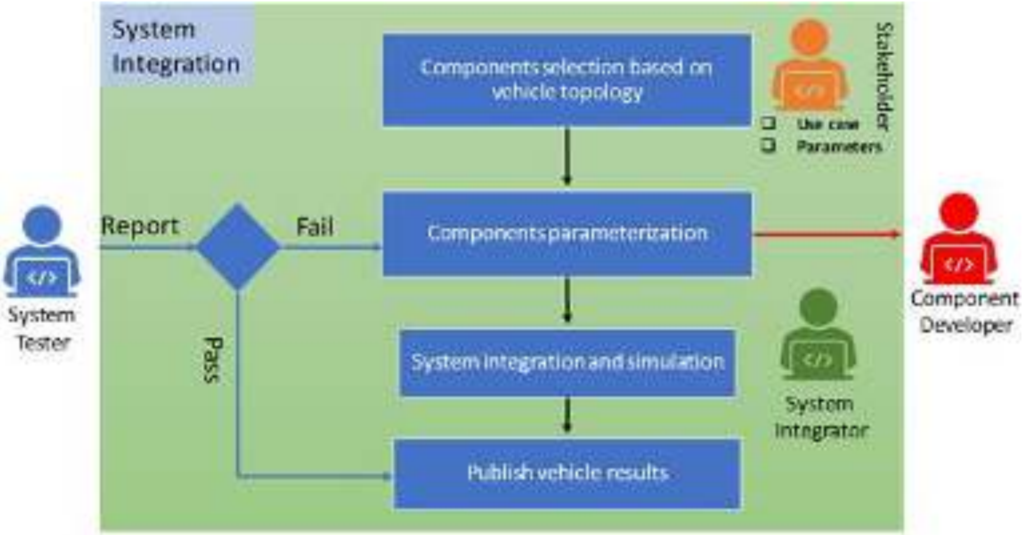

Figure 4 – Exemplary system integration workflow between project partners followed in the previous EU project (Courtesy of CEVOLVER and HiFi-Elements)

3.3 Vehicle to Infrastructure Interaction Modelling

Modelling the vehicle-infrastructure interaction involves independent models for vehicle combinations and the road surface that can interact together via tyre models. Any vehicle combination needs to be accessed for both low-speed manoeuvrability and high-speed stability to obtain an overall safety assessment related to compatibility of the vehicle with specific routing. When low speed manoeuvrability is considered, typically simplified kinematic models are used. A kinematic model is a simplified representation of the motion of a vehicle. It focuses solely on describing the movement, position, velocity, and acceleration of the vehicle combination, using mathematical equations and geometric relationships. Tyre slip phenomenon can also be modelled into kinematic equations of motion; however, they involve added complexity, lack of modularity, fail to capture the suspension dynamics, and crucially, do not interact with infrastructure models.

Past European projects such as FALCON[7], AEROFLEX and 5G-Blueprint[8] have used so called multi-body modelling methodologies to overcome the limitations of kinematic models. The multi-body formalism of the vehicle dynamics of any combination using a tool such as MATLAB's Simscape[9], automatically generates equations of motion for vehicle components which significantly influence the vehicle dynamic behaviour. Following sub-section describes the methodologies and models used for multi-body-based vehicle-infrastructure modelling and simulation.

Modelling methodology

Figure 5 shows the general workflow of any vehicle-infrastructure simulation. Apart from the high-fidelity multi-body models previously mentioned, the Curved Regular Grid (CRG) road model standard is used to model road sections to perform any manoeuvre of interest. CRG offers the ability to model road sections with parameters such as roughness, width, curvature, banking, and also custom surface profiles. The TNO Delft-Tyre[10] modelling package for MATLAB provides the resulting vertical, lateral and longitudinal forces of the tyres, by employing the Magic Formula tyre model[11]. Furthermore, a path following controller is used to make the vehicle follow a specific trajectory for instance, driving a roundabout or highway exit, or to perform a standard manoeuvre such as a lane change.

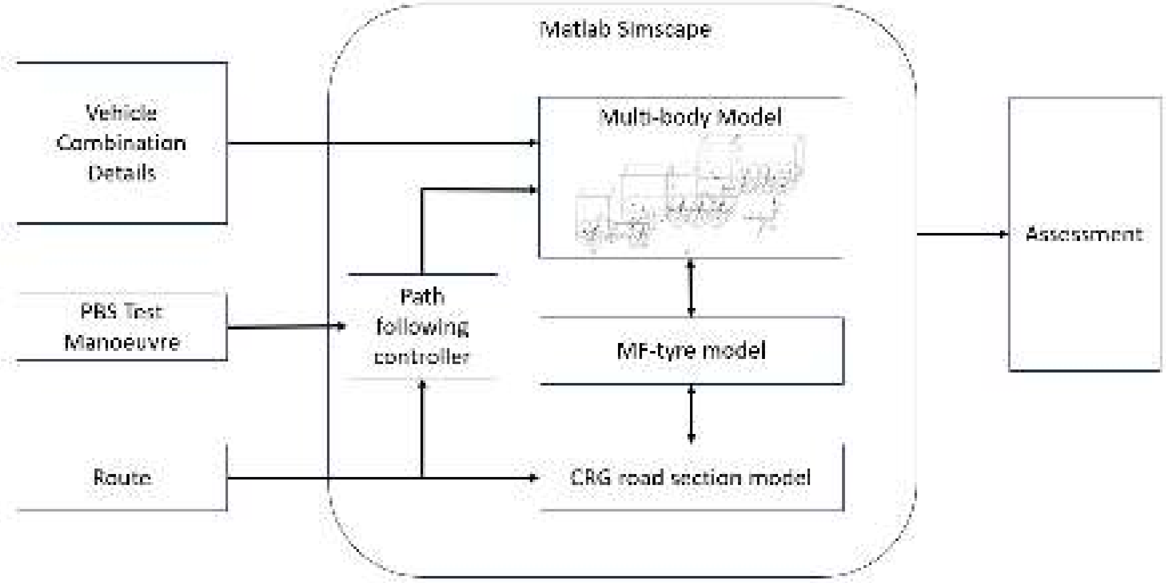

Figure 5 – General workflow of vehicle-infrastructure simulation

In order to simulate any of the various possible vehicle combinations, a library of vehicle components called the Commercial Vehicle Library is used, consisting of pre-modelled and fully parametric vehicle

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[7] Definition and Validation of a Smart Infrastructure Access Policy Utilising Performance-Based Standards, Conference of European Directors of Roads. 2019. Available: https://cedr.eu/news-data/1482/FALCON-project-publishes-CEDR-Contractor-Report

[8] https://www.5gblueprint.eu/about/main-objectives/

[9] https://www.mathworks.com/products/simscape-multibody.html

[10] https://research.tue.nl/en/publications/vehicle-dynamics-analysis-using-simmechanics-and-tno-delft-tyre

[11] Tire and Vehicle Dynamics - 3rd Edition (elsevier.com)

assemblies (e.g., truck, trailers, semitrailers, etc.) and additional vehicle components (brake system, driveline, etc.). This library of models in Simscape is validated using actual test data[12].

This workflow can be adapted to the required scenario, such as:

- In FALCON: The multi-body models of vehicle combinations along with basic road models are simulated with Performance Based Standard (PBS) tests. PBS test manoeuvres such as startability, tail swing, low-speed swept path, rearward amplification, etc., are simulated and the data (key performance indicators) from the simulations are evaluated by comparing with thresholds based on type of combination. Hence, PBS tests offer a broad indication of low and high-speed performance metrics.

- In AEROFLEX: Along with the PBS tests as in FALCON, evaluation of high-speed performance in real-world conditions of actual highway exit trajectories in a given route is done by modelling the infrastructure with the CRG standard. Actual GPS coordinates (obtained from Google Maps) of such road sections are used to model these sections in 3D, allowing for modelling the road surface along with the actual banked curve of the exit. A similar strategy is also used to model the real-world low-speed manoeuvrability scenarios that are considered critical such as roundabouts and sharp turns. The desired route is checked for critical sections like these, and the actual trajectories are modelled and simulated. Swept paths of the vehicle envelope are compared with the available road boundaries during assessment.

- In 5G-Blueprint: The CRG modelling method is used to model a distribution center with a sloped dock. Using measurements of the terrain, the CRG model is constructed to reflect the changes in elevation. The purpose in this case is to evaluate the performance of path following controllers in the target environment, using a multi-body tractor-semitrailer model.

Relevance to ZEFES: the methodology used in previous work is quite applicable to ZEFES, where the low and high-speed performance of various vehicle combinations need to be assessed for any given route. The use of high-fidelity multi-body vehicle, tyre and CRG road models is relevant and needed for ZEFES.

Main gaps with ZEFES: previous work lacks compatibility with ZEFES in 3 aspects, real-time availability and relevant infrastructure data, and optimized roundabout trajectories:

- Real-time performance: Previous work was based on offline simulations for the assessment of vehicle-infrastructure interaction. The tools developed worked with ad-hoc situations for specific routes. These models were developed for research purposes where interoperability with other services in real-time were not considered. Interoperability with other services is needed in ZEFES for the application of the digital twin.
- Infrastructure data: Another major gap is the availability of accurate maps that have clear information about road boundaries. This information is critical when assessing the low-speed manoeuvring of vehicle combinations in roundabouts and sharp turns, with swept path analysis. Roundabout design varies across regions, and hence, it is necessary to accurately distinguish between road and curbs/boundaries in order to guarantee that a vehicle combination (especially longer vehicles) can pass a roundabout safely.

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[12] Analysis of high capacity vehicles for Europe: application of performance based standards and improving manoeuvrability — Eindhoven University of Technology research portal (tue.nl)

- Optimized roundabout trajectories: Articulated vehicles need to follow a different, more extreme trajectory to negotiate roundabouts compared to rigid vehicles[13]. This trajectory was pre-determined for each roundabout exit based on driver behaviour in AEROFLEX, but the trajectory was not optimized for type of vehicle and roundabout. In order to more accurately assess the capabilities of various vehicle combinations in any roundabout, the trajectories need to be optimized to use as much of the available road width as possible. This is also where accurate road boundary data is necessary.

3.4 Digital Twin and Cyber Physical System (CPS) applications

3.4.1 Change2Twin

Abstract summary of project. Change2Twin[14] was an EU-funded project (Horizon 2020 DT-ICT-03-2020-951956[15]), part of the ICT Innovation for Manufacturing SMEs (I4MS) initiative, to help manufacturing SMEs and mid-caps in their digitization efforts to deploy digital twins. From Autumn 2020 to Spring 2021 Change2Twin executed four pilot experiments with companies from diverse manufacturing branches.

Relevance: although the project was targeted at manufacturing SMEs, it does provide at least two relevant deliverables to ZEFES:

Deliverable D1.1[16], version 1.0, contains an extensive and in-depth overview of technologies and methodologies that enable Digital Twinning.
Deliverable D1.2[17], version 1.0, contains an extensive and in-depth overview of standards that are relevant for Digital Twins.

Especially relevant for ZEFES in **Deliverable D1.1** from Change2Twin is the methodology which offers a stepwise[18] approach to Digital Twins. It starts with the why, to determine your purpose, and goes across the full lifecycle of the Digital Twin, where the SME business case determines the needed abilities and scope of the Digital Twins. As the methodology helps SMEs getting aware of position, timeline, needs, and goals, it can also help the different stakeholders, suppliers of components and (digital) services help in determining what they expect from their Digital Twins.

In the **Deliverable D1.2**, the project mentions ISO/TC 22/SC 31[19], a SubCommittee (SC) on data communication for vehicle applications. This SC 31 is part of ISO/TC 22 Road vehicles. This Technical Committee (TC) focuses on standardization "*of all aspects for all types of road vehicles and their interfaces approved for operation on public roads for the whole life cycle*". This includes aspects like

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[13] https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29TE.1943-5436.0000601
[14] https://www.change2twin.eu/about/
[15] https://cordis.europa.eu/project/id/951956
[16] https://www.change2twin.eu/wp-content/uploads/2021/11/D1.3-Digital-Twin-Enabling-Technology-Catalogue.pdf
[17] https://www.change2twin.eu/wp-content/uploads/2021/11/D1.2-First-report-on-standards-relevant-for-digital-twins.pdf
[18] https://downloads.esi.nl/leaflets/TNO_Digital_Twin_Primer_SMEplus.pdf
[19] https://www.iso.org/committee/5383568.html

hardware and software, driving automation, communication and connected driving and test equipment/tools. SC 22 (smaller scope) thus includes data buses and protocols (including dedicated sensor communication, V2X communication (including V2G), diagnostics, test protocols, interfaces, and gateways (including those for nomadic devices) and data formats. Note there is a ZEFES relevant subcommittee ISO/TC 22/SC 32 as well, which is concerned with "*electrical and electronic components and general system aspects* “, which includes topics like wiring harness (e.g., cables, connectors, interconnections), dedicated connectors (e.g., trailer connectors, OBD-connector), cybersecurity and software updates.

Another relevant IEC and ISO Joint (J) TC (JTC) mentioned in Deliverable D2.1 is ISO/IEC JTC 1, which has the broad scope of Information technology[20]. For the Digital Twins within ZEFES the SC 41 is relevant as it pertains to the “*Internet of things and digital twin*”. ISO/IEC JTC 1/SC 41 is being supported administratively by IEC[21].

Main gaps with ZEFES goals: this project was targeted at creating Digital Twins for the manufacturing industry. While much can be learned from the methodology and the overview of standards, it is not enough to create a Digital Twin for Zero Emission Vehicles in general.

3.4.2 Cerbero

Abstract summary of the project: the Cross-layer modEl-based fRamework for multi-oBjective dEsign of Reconfigurable systems in unceRtain hybRid envirOnments (CERBERO) was an EU funded project (H2020-ICT-2016-1-732105 - CERBERO[22]) that aimed at developing a design environment for CPS based of two pillars: a cross-layer model based approach to describe, optimize, and analyse the system and all its different views concurrently. From 2017 to 2020 it researched design of several Cyber Physical Systems (CPS), for example a Smart Travelling CPS of Systems (CPSoS) for Electric Vehicles (EV).

Relevance for ZEFES: in **Deliverable D3.5**[23] Models of Computation (2018) an overview is provided of then state-of-the-art Models of Computations (MoCs) used for the design of Cyber-Physical Systems (CPS). It does so by describing:

- the properties of semantics (analyzability, decidability, reconfigurability, expressiveness, determinism, etc.),
- the kind of algorithm it supports (data-driven, control-driven, etc.),
- the level of abstraction it captures (system-of-systems, system, component, etc.)
- the type of implementation it translates into (hardware, software, distributed, etc.)

Examples of Models of Computation described are: Synchronous Dataflow, Parameterized and Interfaced Synchronous, Petri Networks, Register Transfer Level, Transition System, Discrete Event System, and Situated Cognitive Engineering. In **Deliverable D3.6**[24] the CERBERO project discusses a

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[20] https://www.iso.org/committee/45020.html
[21] https://www.iec.ch/dyn/www/f?p=103:7:0::::FSP_ORG_ID:20486
[22] https://cordis.europa.eu/project/id/732105
[23] https://www.cerbero-h2020.eu/wp-content/uploads/2018/12/D3.5.pdf
[24] https://www.cerbero-h2020.eu/wp-content/uploads/2018/12/D3.6.pdf

"*Cross-layer Modelling Methodology for CPS*", which is relevant to ZEFES as it also includes types of models that interact in different ways. It also considers the concept of model-based engineering. In **Deliverable 5.1**[25] "CERBERO Holistic Methodology and Integration Interfaces" are presented which is also relevant to ZEFES as it covers the topic of integration of models through interfaces. It does so from a theoretical as well as practical (implementation) point of view.

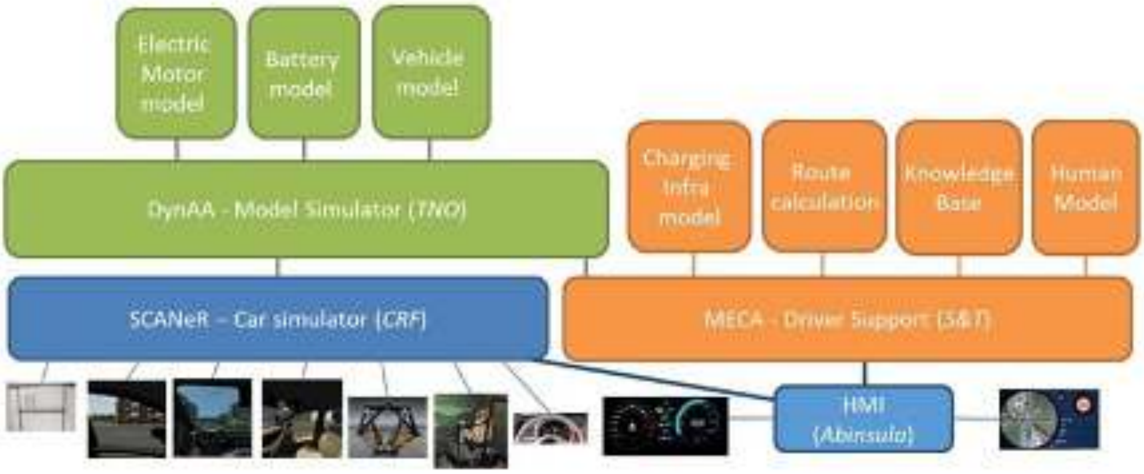

Figure 6 – Schematic overview of the M36 ST demonstrator components and their interfaces (source: D6.4: Smart Travelling Demonstrator, figure 3.1, page 10)

From the perspective of model integration for EVs, the project's Smart Travelling Demonstrator [26] is especially relevant. Basically, it is a system (of subsystems) where several simulation models have been integrated. This included a model of a battery and an electric motor. In Figure 6, a diagram from **Deliverable D6.4**: Smart Travelling Demonstrator[27] is shown of the relationships between the models involved and the simulation tooling DynAA and MECA.
Note that the DynAA and MECA tools are part of the CERBERO Framework Components as described in **Deliverable D5.2**[28]. ZEFES relevant aspects are the ability to carry out simulations in parallel instances and the system in the loop simulation feature. As of 2023 the DynAA tool is still being used and further developed in other projects.

Main gaps with ZEFES goals: while there is overlap between CERBERO and ZEFES with respect to the integration of models, ZEFES is also targeted at creating a Digital Twin at different levels of abstraction in the physical world. There is the level of ZEV components, like a tire or battery, there is the level of the ZEV itself and there is the level of a fleet of ZEVs. To that, the ability to dynamically compose workflows using components of different companies is also needed in ZEFES, which is not explicitely there in CERBERO. ZEFES can and should make use of lessons learned by this project though.

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[25] https://www.cerbero-h2020.eu/wp-content/uploads/2020/06/D5.1.pdf
[26] https://www.cerbero-h2020.eu/smart-travelling-for-electric-vehicle/
[27] https://www.cerbero-h2020.eu/wp-content/uploads/2020/06/D6.4.pdf
[28] https://www.cerbero-h2020.eu/wp-content/uploads/2020/06/D5.2.pdf

3.4.3 InterConnect

Abstract of the project: according to CORDIS the InterConnect[29] project has started in 2019 and will run until March 2024. The idea is to create a resilient and practical ecosystem for appliances and services related to energy management. It focusses on creating interoperability between devices and services to create an open level playing field.

Relevance for ZEFES: while InterConnect is not directly about Digital Twinning, it is relevant in terms of a Cyber Physical Energy System (CPES). The term CPES is not used InterConnect, but in practice InterConnect is about a complex system of systems that are interconnected by the European electrical grid. In **Deliverable D2.1**[30] a first version of the Secure Interoperable IoT Smart Home/Building and Smart Energy System Reference Architecture (SHBERA) can be found. Using different points of view, like high-level organisation view with an emphasis on energy system aspects, a high-level technical oriented view focussing on Internet of Things elements, a lower-level technically oriented point of view that looks at Interoperability aspects and finally a view in terms of semantic ontologies. InterConnect uses the concept of multiple viewpoints from the Reference Model of Open Distributed Processing (RM-ODP)[31] to deal with the need for stakeholders from different domains to focus on the relationships between system components (they need to see to understand it from their domain), while keeping the viewpoints connected at the architectural level. This deliverable also describes the relationship with other conceptual/architectural related (reference) frameworks like AIOTI, ONEM2M, FIWARE, W3C WOT, IDS, HBAM and the SGAM (see D2.1 for a summary).

In **Deliverable D2.3**[32] "*Interoperable and secure standards and ontologies*" it is described how InterConnect tried to relate (semantical) concepts in several existing ontologies (and/or standards), as a way to integrate concepts related to a system of systems (of components) at different layers of abstraction. ZEFES can use this deliverable if it needs to determine which semantic ontologies are relevant to document the information model for interoperability of ZEFES components.

Main gaps with ZEFES goals: the main objective of InterConnect seems to be interoperability for components involved and/or related in energy management systems. While this sometimes includes EVs, InterConnect does not focus on creating digital twins of these components. To this, it is hardly concerned with computation and the concept of co-simulation. Also, the project tries to implement a so called 'Semantic Interoperability Layer' where sets of so called 'triples' or 3-tuples[33] are exchanged between components. While – at a theoretical level - this might seem to support a flexible way of exchanging information (and/or knowledge), the computational resource usage is high as the triples need to be interpreted 'on-the-fly'. Also, it takes a significant amount of training to understand this way of information exchange. ZEFES should not go this way if it wants to deliver a way of component integration that can be understood and used by a wide range of designers, modellers, and engineers.

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[29] https://cordis.europa.eu/project/id/857237

[30] https://interconnectproject.eu/wp-content/uploads/2022/03/D2.1-Secure-Interoperable-Smart-Home-Building-and-Smart-Energy-System-Reference-Architecture_FR_v2.pdf

[31] https://link.springer.com/content/pdf/10.1007/978-0-387-34882-7_1.pdf

[32] https://interconnectproject.eu/wp-content/uploads/2023/05/D2.3-Interoperable-and-secure-standards-and-ontologies_v1.0_final_clean.pdf

[33] https://www.w3.org/TR/PR-rdf-syntax/

3.4.4 BigData4Energy

Abstract of the project: according to CORDIS, the Big Data For Energy (BD4NRG[34]) project runs from October 2021 to June 2024. The overall objective was to "to confront big data management challenges for the energy sector, giving a competitive edge to the European stakeholders to improve decision making and at the same time to open new market opportunities".

Relevance for ZEFES: while BD4NRG is not directly about Digital Twinning, it is relevant in terms of a Cyber Physical Energy System (CPES) and management of complex data-driven systems. In **Deliverable D3.1**[35] a technical release of the tools for Data ingestion from the different source, on the data-driven pipelines management, on the checking the quality of data can be found. The different aspects of data gathering and transforming it into the useful information, needed to take the proper decisions are covered. Together they provide a powerful framework for data processing. In Digital Twinning world data, coming from different data sources, should be gathered and transformed as well in the same fashion. This deliverable also describes the relationship with other conceptual/architectural related (reference) frameworks like AIOTI, ONEM2M, FIWARE.

In **Deliverable D4.1**[36] "*Data Modelling & Open Modular AI-based edge-level Analytics Toolbox*" it is described how the analytical tools are being used in the Predictive maintenance of the electrical grids and in checking the coming data on its quality. The most relevant solution describes the federation between cloud and edge IoT devices through the use of the Federated Learning platform and technique.. ZEFES can use this deliverable if it needs to establish the proper framework for the predictions between the centralized Digital Twin platform and edge IoT devices in trucks.

Main gaps with ZEFES goals: the main objective of BigData4Energy seems to be the components involved and/or related in energy management systems which can deal with the big quantities of data and solve real time problems with the newly upcoming data. While this sometimes includes EVs, BigData4Energy does not focus on creating digital twins of these components. To this, it is hardly concerned with computation and the concept of co-simulation. Also, the project tries to implement specific scenario useful to the 12 pilots of the project, which lack the generic approach for the computations. Every scenario is implemented separately, thus, the security and isolation from both data owners and model owners perspective is not handled deeply enough. ZEFES should not go this way if it wants to deliver a way of component integration that can be understood and used by a wide range of designers, modellers, and engineers.

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[34] https://www.bd4nrg.eu/resources/results

[35] https://www.bd4nrg.eu/sites/default/files/2023-06/D3.1%20BD4NRG%20Governance%20%E2%80%93%201st%20Technology%20Release%201.0_0.pdf

[36] https://www.bd4nrg.eu/sites/default/files/2023-06/D4.1%20BD4NRG%20High%20Performance%20Data%20Processing%201.0.pdf

3.4.5 AEROFLEX

Abstract of the project: according to CORDIS, the Aerodynamic and Flexible Trucks for Next Generation of Long Distance Road Transport (AEROFLEX[37]) project ran from October 2017 to September 2021. The overall objective was to "*develop and demonstrate new technologies, concepts and architectures for complete vehicles with optimised aerodynamics, powertrains and safety systems as well as flexible and adaptable loading units with advanced interconnectedness contributing to the vision of a "physical internet".*

Relevance for ZEFES: in the public summary of **Deliverable D2.2**[38] "*Architecture and Design of the AEMPT*" (2019) a technical solution for implementing the Advanced Energy Management Powertrain (AEMPT) framework, which is clearly related to ZEVs that have relatively new electrical powertrains. The framework was developed for an efficient operation of distributed powertrains in long haul EMS vehicles. It contains truck related concepts like the Global Energy & Torque Management System (GETMS), a Local System Management (LSM), electric drive control unit (EMG ECU), Electronic Brake System (EBS), etc. and their interaction using the ISO11992 protocol. These concepts are important to Digital Twin designers. In AEROFLEX the logical GETMS component received the capabilities from electric drives in the trailer units (e.g., battery state of charge, available electric acceleration, and brake force).

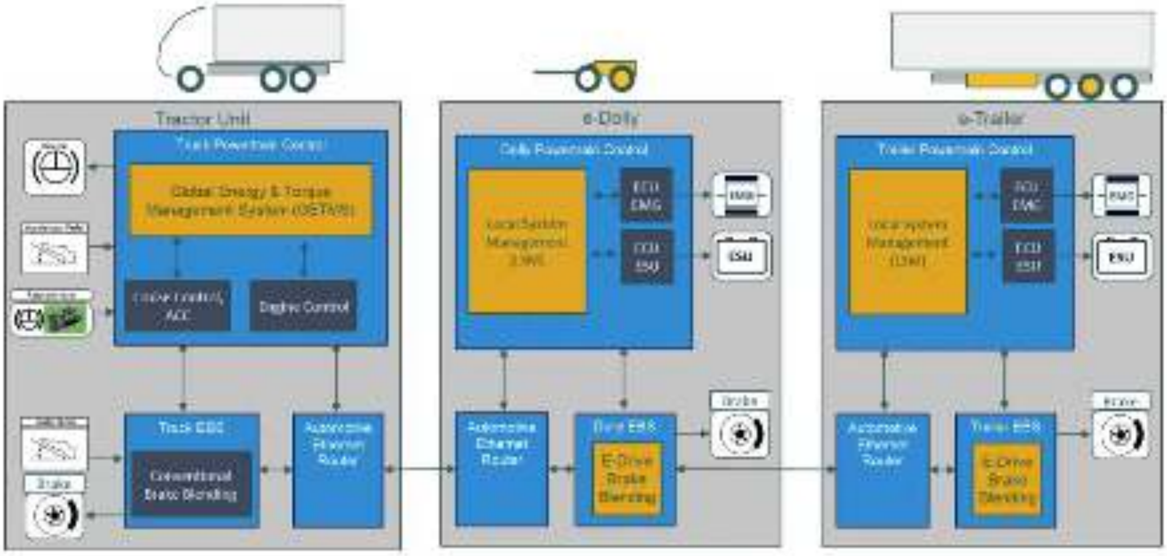

Figure 7 – Topology of the AEMPT System from the AEROFLEX Deliverable 2.3 (page 2)

For information- and communication technology engineers in ZEFES the topic of an Automotive Ethernet communication protocol is relevant as well, as it was designed to overcomes the ISO11992 CAN restrictions. It combined ISO11992 messages and additional data into one Automotive Ethernet protocol, that could deal with higher data rates needed for sensors like rear cameras. In **Deliverable 2.3**[39] "*Validation report AEMPT and ECU with AEMPT for truck, dolly, (semi)trailer*" a diagram can be

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[37] https://cordis.europa.eu/project/id/769658

[38] https://aeroflex-project.eu/wp-content/uploads/2020/08/AEROFLEX-D2.2-Architecture-and-Design-of-AEMPT-PUBSUM.pdf

[39] https://aeroflex-project.eu/wp-content/uploads/2021/03/AEROFLEX-D2.3-Validation-report-AEMPT-and-ECU-with-AEMPT-PubSum.pdf

found in figure 0-1, which is included in this report in Figure 7. Extra information regarding the Automotive Ethernet can be found in the final event slides[40], starting at slide 16.

Main gaps with ZEFES goals: while the overlap in the use of trucks in the projects are clear, AEROFLEX did not explicitly look at the digital twinning of trucks using an open level playing field of commercially available digital models at different levels of abstraction. However, the ZEFES project should take account of the lessons learned in the on-board (near) real-time exchange of data and/or information regarding the behaviour of the truck, both from a monitoring as control perspective.

The learnings from the review of prior tools and methodologies employed during past projects have been used to guide and support the elaboration and development of the ZEFES digital platform, and is captured in the work reported in Sections 5, 6 and 7.

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[40] https://aeroflex-project.eu/download/9-AEROFLEX-Block-1300-1400_final.pdf

4 Digital Platform Concept

As described on **Error! Reference source not found.** of Section 1, the digital platform term embodies the virtual layer which starts with the acquisition of real world data, and ends with the provision of decision-making information to the fleet operators via the managerial tools' user interfaces. In between, a collection of models, digital twins, databases, tools, algorithms etc. – all referred to as service functions or elementary blocks – are built, updated and orchestrated to generate the information destined to the end users. Figure 8 provides an expanded diagrammatic representation of the digital platform.

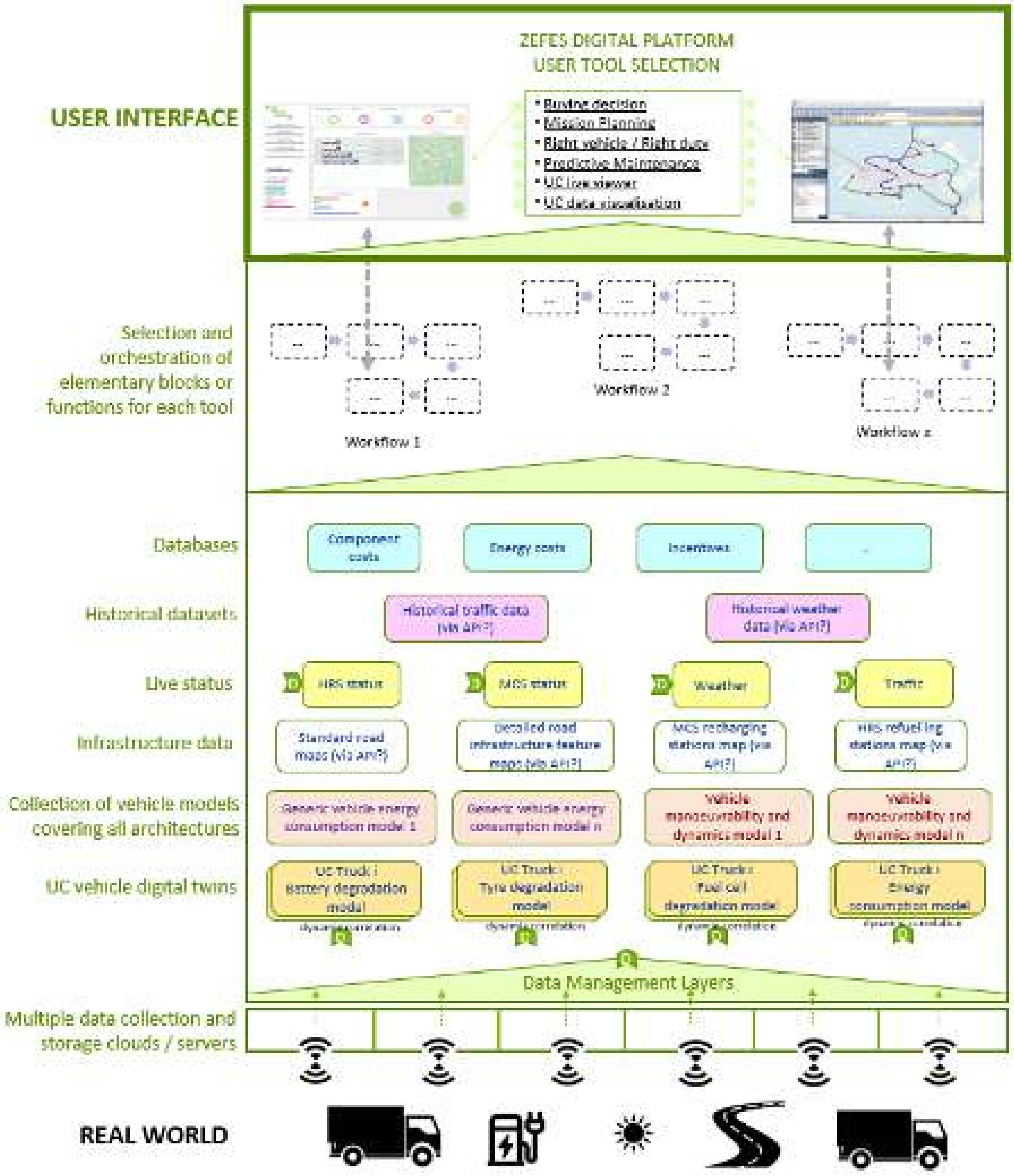


Figure 8 – Digital Tools Platform general lay-out

The following sub-sections describe the individual digital platform elementary blocks in greater details, and provide additional information on the Data Management Layers, in terms of accessing and handling real world data from the trucks and the environment, and provide a more architectural and process-focused description of the platform (Section 4.2.4).

4.1 Vehicle and System Models

Based on the experience from previous EU projects, it is found that forward-facing simulation platforms are a valuable approach in estimating the requirement specifications of various subsystems in an Electric Vehicle configuration. This estimation is based on the vehicle dynamics and the powertrain output, represented by the required drive cycle or generated cycle. The desired vehicle speed profile, along with the corresponding vehicle dynamics, contributes to the performance evaluation of each component subsystem within the configuration. Mostly the virtual frameworks were mandatory in early phases to select optimal sizing of components for the demonstrator vehicles by supporting the engineering decisions. This methodology is that adopted to support Work Package 2 activities, which are concerned with the design optimization and right sizing of zero-emission vehicles powertrains through simulation.

In the context of Work Package 4, the requirements from the vehicle models are different in that their purpose is to support the making of operational and logistical decisions, as opposed to support vehicle system sizing and selection activities. Their integration into wider and iterative workflows requires that simulation times be extremely short, much less than a second, whilst retaining the accuracy of the reference vehicle simulation models. Scope for continuous, automated model tuning to refine prediction accuracy should also be considered.

To that effect, the vehicle simulation models used within the digital platform to predict vehicle energy consumption will consist of Reduced Order Models (ROM). A ROM is a simplified, high-fidelity model, without the computationally complex components or subsystems, yet maintaining equivalent accuracy to that of the full model. The main motivation of the ROM is faster run-time, allowing simulation of thousands of scenarios in relatively short time.
Activities on the work package will include the exploration of methods that can be used to create reduced order models. In general, there are two categories of ROM:

1) Simplification of model: Reducing or simplification of complex parts of the simulation model into simple mathematical expression or through linearization. Changing the model parameters or running the model at bigger time-steps can help to reduce the simulation time. Another method is to compile the model into C code which can reduce the run-time significantly. The only downside of this method is the need to have full access to the original simulation models, in a fully open form
2) Data-driven methods: This method only relies on input and output of a system. Typically a Machine Learning (ML) model is used to learn the behaviour of a system. Regression models such as Gaussian Process Model, or tree-based model such as gradient boosting can be trained against complex models and can interpolate new operating point very successfully. Time-series models such as Long Short Term Memory (LSTM) neural networks are good at learning complex time variant data

Owed to the restricted access nature of the vehicle models generated during WP2, the process adopted for Work Package 4 will be the Data-Driven-Method, and will be applied to the models generated during the course of Work Package 2. It will involve the use of open-source python packages to prepare and train machine learning models against the physics and equation-based models of Work Package 2. The diagram below shows the general process to build an ML reduced-order-model.

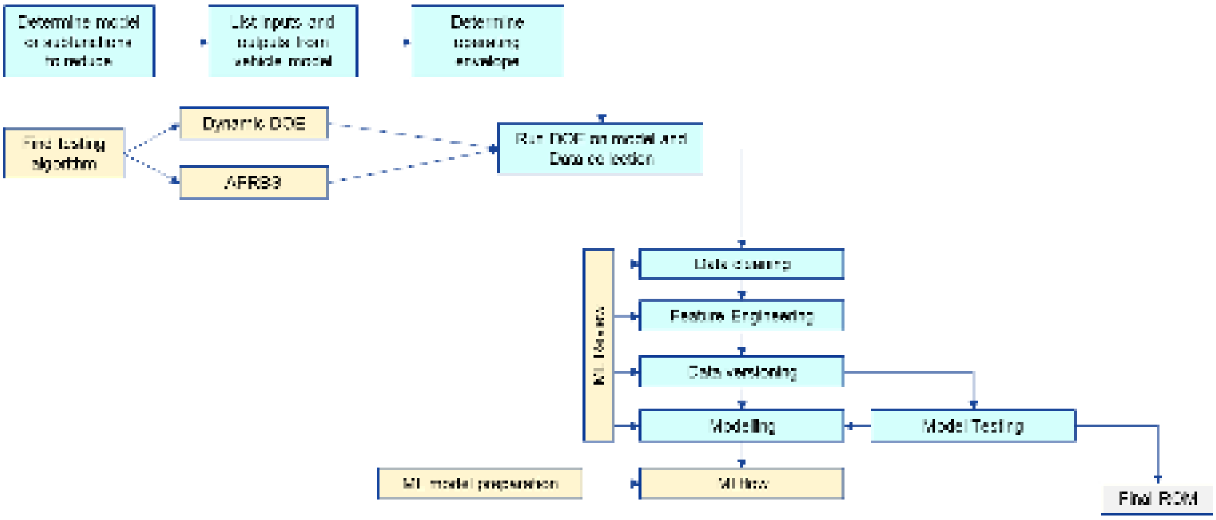


Figure 9 – Process for creating an ML Reduced Order Model

A further requirement in terms of models comes from the need to support ageing, diagnostics and predictive maintenance tasks for the Use Case vehicles. These will specifically focus on the vehicles' battery systems, the fuel cell and balance of plant systems, and the tyres. Since the information and insight refresh frequency required for these activities will be relatively low (e.g. of the order of days), the model run time is less critical and therefore the use of system models which retain a level of physicality can be maintained. This will allow the representation of system's behaviours at the start of the Use Case trials, and therefore before any data have been collected. Over time, and as more and more data is collected from the vehicles, similar Machine Learning methodologies to those described above will be employed to ensure that models are continuously retrained and their accuracy enhanced. These models will then be exploited to run what if-scenarios and understand the need and/or timing of maintenance, and assess the impact of revised operation through updated control on the systems' ageing profile, and maximise life expectancy.

Physical models used for that purpose will be derived from those deployed in Work Package 2, with POW supplying fuel cell ageing models, FHG supplying battery models, and Michelin supplying tyre models.

4.2 Infrastructure Data Sets

4.2.1 Map data and feature layers (based on PTV technology)

Reliable spatial data is the power behind strategic and operative processes and systems. It forms the basis of reliable information, which is essential for accurate decision-making using a spatial reference.

Feature Layer (FL) architecture was developed in order to offer a wide variety of information to external providers in corresponding data layers for routing and rendering. The focus, on the one hand, is on being capable of processing huge amounts of data in the routing and rendering engines and, on the other hand, on allowing a wide variety of theme combinations. In the process, the prioritisation of layers, clarity of themes, ease of use through configuration and attention to time-dependent attributes played a major role. By using a unified architecture, it is now possible to meet the different requirements with regard to routing relevant information contained in the transport logistics.

4.2.1.1 Static Feature Layers

Preferred Routes

This Feature Layer contains a prioritized road networks or rather routes for certain vehicle types like trucks with special loads or heavy vehicles. Many countries identify routes where dedicated vehicles or vehicles with particular loads are allowed or prohibited to drive. In addition, there are many recommendations by authorities and/or typical organizations about routes in special situations. Also security or environmental aspects might lead to the set out of special route networks. This information does have influence in routing and costs.

Figure 10 – Preferred routes layer

Restriction Zones

This layer provides restricted transit areas for example truck transit zones. This Feature Layer contains restricted transit areas i.e. areas which have special restrictions. These restricted areas may be used by certain vehicle types, but only as start or destination otherwise they must not be passed through. This captures:

- Forbid whole areas to vehicles having a total permitted weight above a certain threshold
- Delivery vehicles are allowed to navigate in areas that are free for delivery, but ONLY at start and destination ("At Waypoints")
- Area restrictions may be given for a certain set of vehicle types, identified through a transport System property

As part of the EU regulations on limits for air pollutants, various regions and cities with high particulate air pollution installed so-called clean air and action plans, which includes environmental zones or drive-through zones prohibiting the transit of specific types of vehicles for example trucks larger than 7.5 t.

Figure 11 – Restriction zones layer

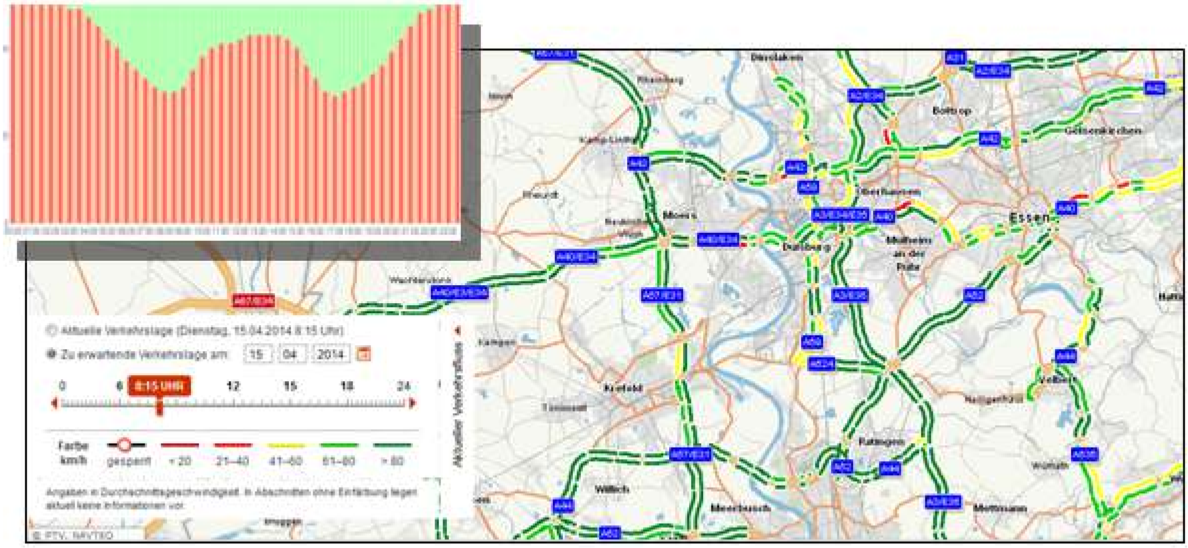
If waypoints are located outside of the restricted zone, the zone will be circumnavigated (left picture). If a waypoint is within the restricted zone, it will be entered (right picture).

Speed Patterns

This layer provides statistical and time-dependent absolute speeds for a given set of road segments, that can be used by the routing engine instead of the NC/SC speed of the vehicle profile. The freeFlowSpeed property is used to store the free flow speeds. Modelled Patterns Over Times (POTs) can be applied to the free flow speeds, via the Generator API, to provide time-dependent absolute speeds.

Transfer of past traffic patterns per road segment show the expected Level Of Service (LOS) in the future. This forecast helps to recognize and avoid traffic jams or at least include the anticipated time loss into the Estimated Time of Arrival (ETA).

As soon as real-time Dynamic Traffic Information is available as a Feature Layer, it can be combined with the historic Traffic Patterns. The combination of forecasted and actual traffic information result in a more precise view of the near future for example road works in combination with a traffic jam as the result of an accident.



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● Zu erwartende Verkehrslage am 15 04 2014

Angaben in Durchschnittsgeschwindigkeit. In Abschnitten ohne Einfärbung liegen aktuell keine Informationen vor.

Figure 12 – Speed pattern layer

Truck Speed Patterns

This layer is derived from the Speed Patterns but it is used for trucks instead of cars. So additional data like height data, truck speed limits or passing restrictions are considered in the route calculation.

Time Zones

This layer provides time zone information at a given location. This information is necessary to consider time dependent restrictions correctly in the route planning. For example temporary road closures and road works. Different time zones can be considered in routing and estimated time of arrival ETA calculation. Time zones can be precisely displayed, especially in connection with historical traffic information and traffic patterns.

Truck Attributes

This layer provides truck attributes (truck-specific driving restrictions). These attributes concern the dimension, the weight or the type of the vehicle. For example, this could be important for the clearance height of tunnels or the weight restriction of bridges. New with the Feature Layer technology are the time dependent restrictions. These restrictions are only valid during a certain period of time. The truck attributes are considered in the routing or in distance matrix calculation. Therefore you gain more accuracy and a better planning basis.

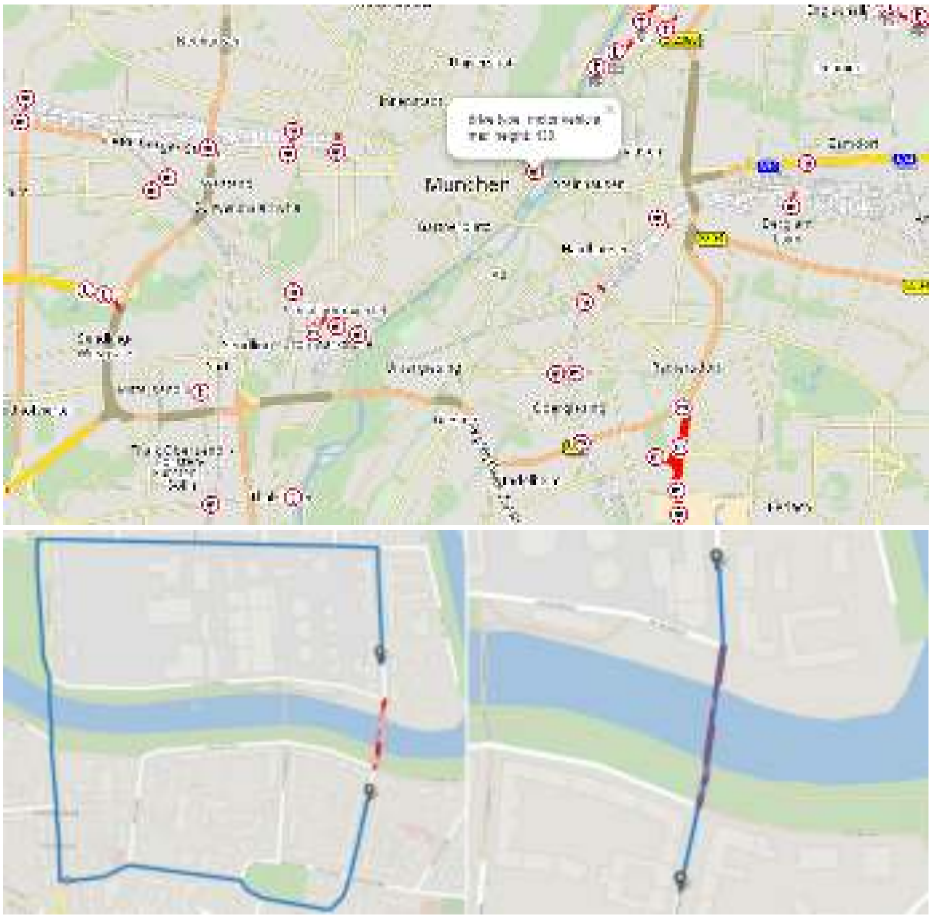


Figure 13 – Truck attributes layer

If the vehicle exceeds the limited weight, the road section will be avoided (left picture), otherwise it will be passed (right picture).

Points Of Interest

Points of Interest (POIs) are locations like restaurants or gas stations. Points of Interest can be displayed on top of the base map, together with some descriptive text information.

Figure 14 – Points of interest layer

4.2.1.2 Dynamic Feature Layer

Dynamic Feature Layer contains additional dynamic content.

Traffic State - real time or forecasted speeds on the network (currently only for internal use)

Traffic Incidents - real time or forecasted traffic events. This layer provides actual traffic information to consider incidents like traffic jams in the route planning. Up-to-date traffic information is provided as dynamic Feature Layer and can be downloaded from the Layer Delivery Server with the PTV Content Update Service plugin.

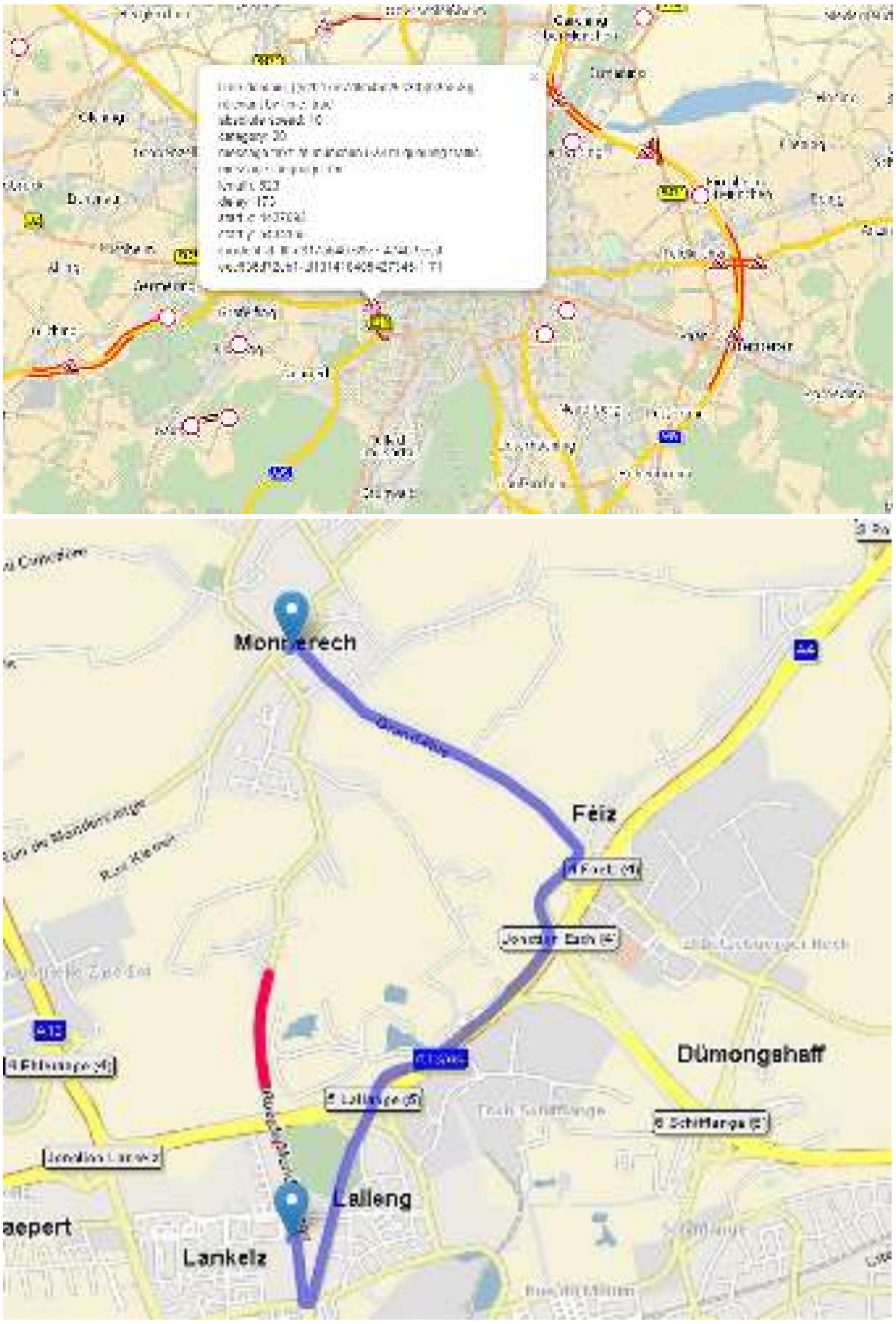


Figure 15 – Traffic incident layer

4.2.2 Infrastructure Data for Vehicle-Infrastructure Interaction Analysis

The infrastructure data of relevance are the locations of roundabouts, sharp turns and highway entry/exits in any mission route. In order to obtain these critical sections in a route, actual information of the infrastructure is obtained from map data providers, such as PTV and Google. Data in the form of GPS coordinates (latitude, longitude, and altitude) are used to locate and annotate the data with roundabouts, sharp turns and highway entry/exits (Google's data set contains these annotations but lacks logistics specific routing that PTV's data provides). These identified sections are then constructed in the Curved Regular Grid (CRG) format based on the actual trajectories of the sections as shown in figure 6. The resulting infrastructure data set is a set of CRG files (one for each identified critical section) that are available for simulation tools to use to analyze vehicle performance in each section.

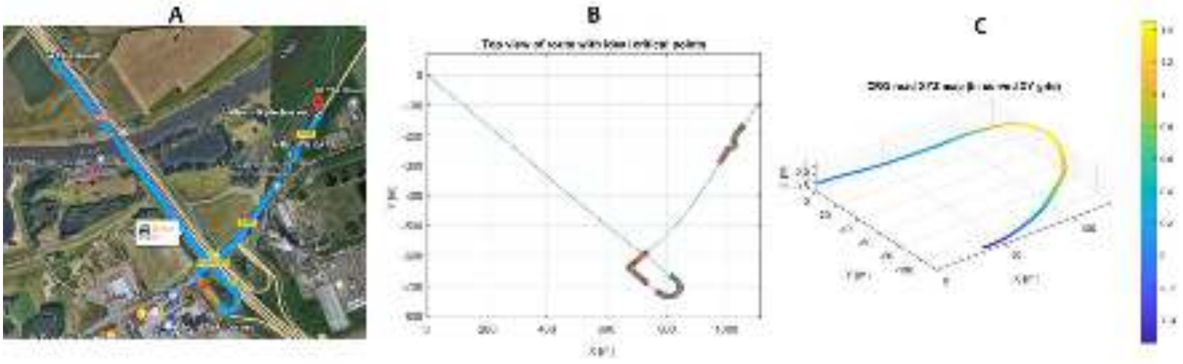


Figure 16 – Generation of Curved Regular Grid (CRG) road models. A: example route with critical sections, B: identified critical sections from GPS data, C: CRG model of the identified highway exit

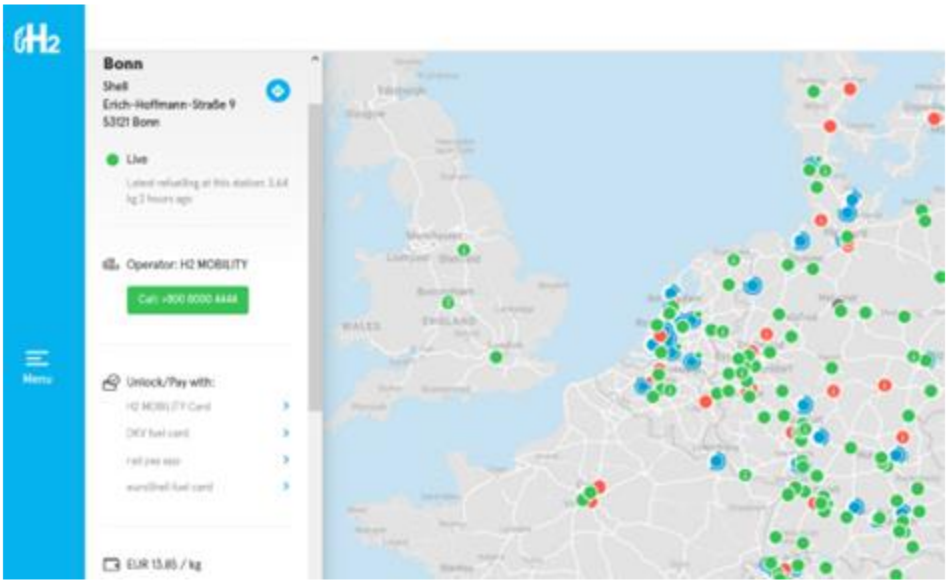
Apart from trajectories of each section, road boundaries are needed for swept path analysis, but this data is not directly available from map APIs, hence satellite images of the critical sections (especially roundabouts and sharp turns) are processed to obtain clear definitions of the road lanes and boundaries. The resulting road boundary data in the form of polygons (cartesian coordinates in the frame of each road section) are then used during swept path analysis.

4.2.3 Hydrogen Refueling Station Status Information

To optimize the refuelling time of the truck, the filling can be planned with Live data of the Hydrogen Refuelling stations status. The data of interest are HRS gas temperature and H2 availability [kg] for a planned fill.

The status of the vehicle tank, i.e., tank SoC and tank temperature can further optimize the filling event by matching the HRS conditions.

The App H2Live data provides the status of stations in service.



Bonn
Shell
Erich-Hoffmann-Straße 9
53121 Bonn

Live

Operator: H2 MOBILITY

Unlock/Pay with:

EUR 13.85 / kg

Figure 17 – H2Live data

4.2.4 Megawatt Charging System Infrastructure Information

For the purpose of developing digital twins, data sets are gathered from product specification sheets, communication protocol and charger software implementation documents, and performance reporting at the point of energy delivery. Specifically, data will be gathered at the equipment layer (what is physically installed at a site), at the protocol layer (what data is being exchanged and how), at the software layer (what functionality is embedded in the charger), and the performance layer (what is happening during a charging session). The model can be augmented by introducing data informing on warranty, maintenance, and the useful life of the charger.

Data set parameters (not exhaustive):

- Charging equipment: Charger specification sheet and installation manual
    - Examples: Input power, output power, enclosure rating, dimensions, efficiency (energy delivered vs lost)
- Communication protocol: Industry implementation documents (OCPP 1.6J, OCPP 2.0.x, ISO 15118-2, ISO 15118-20, OCPI X.X [when relevant])
- Charger software layer: charger software release notes (for most up-to-date software version)
- Performance:
    - Uptime, downtime, limited state
    - Energy delivered (in kWh) – power, voltage, amperage
    - Reliability; plug-in success, session success, or a variety of potential issues/faults [informed by error codes] * *data requests may be limited*
    - Monetization; revenue generated from energy delivered
    - Safety – informed by sensor alerts (ex: tilt sensor) [informed by error codes; may have hardware safety response (power disconnect)]
    - Utilization: power share strategy, # of sessions, average session time/energy delivered, etc.
- Charger Care:
    - Warranty in years
    - Preventative maintenance schedule
    - Expected charger life

4.3 Digital Twin Platform Architecture

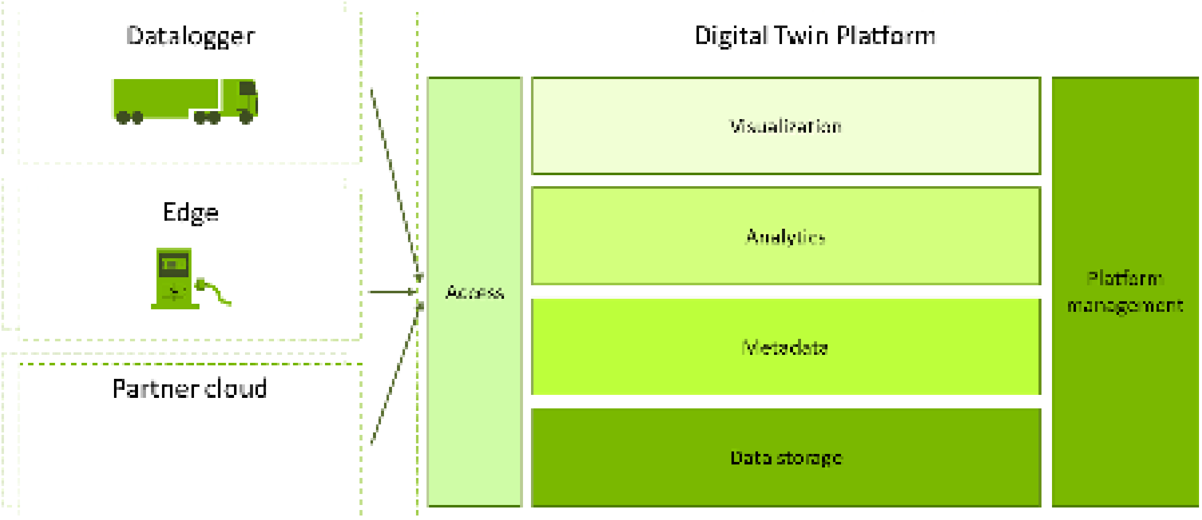


Figure 18 – High level view of Digital Platform architecture

The Digital Twin Platform will host the data and the analytical processes of the ZEFES project. Such a platform is necessary to allow for low barrier to entry collaboration between partners by ensuring that data is centrally available, but only shared when intended. Data from e.g. dataloggers on trucks, charging infrastructures or partners is stored on the platform, and described using metadata. (Digital Twin) Models provided by partners are also stored on the platform and described in a metadata database. ZEFES models in principle run on the Digital Twin Platform, although for certain steps they can connect to partner clouds. The models are composed using workflows in the analytics layer. Finally visualizations are created based on the results of the analyses. Every layer is subject to access control – for access from outside, but also to ensure users and workloads cannot read data or use models that they are not authorized for. The requirements for the Digital Twin Platform architecture are described in Section 7.

5 Specification of the ZEFES Digital Tools

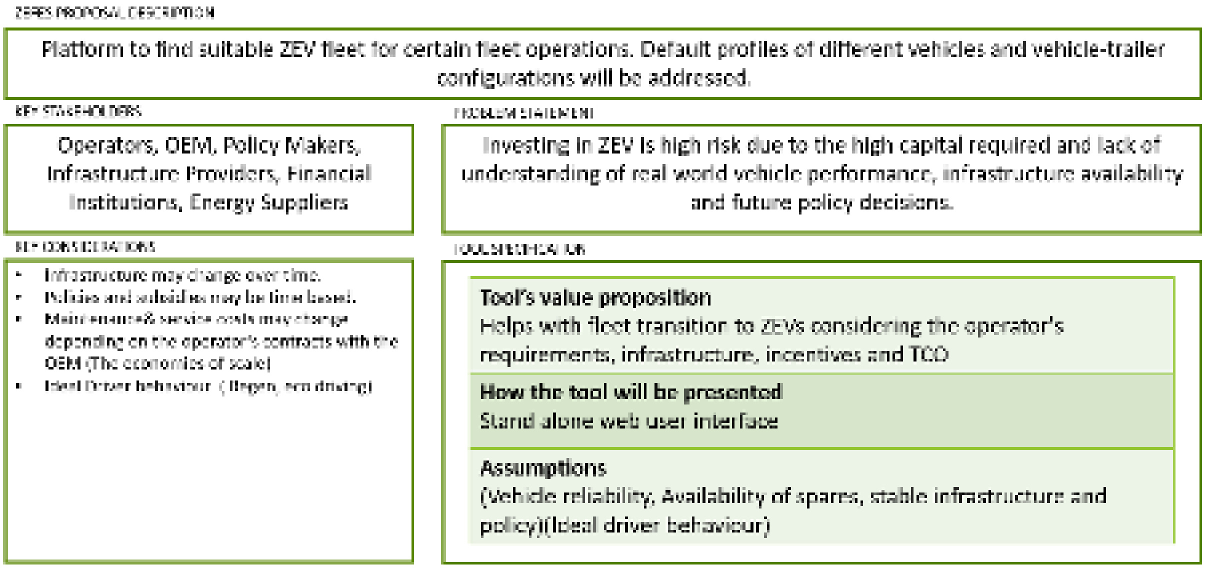
The ZEFES DoA put forward five decision making tools, aimed at supporting fleet operators with the deployment and operation of zero-emission vehicles in their fleet. These are:

- Buying decision
- Mission planning
- Right vehicle in right duty
- Dynamic correlation
- Predictive Maintenance

Each tool's purpose and general specification, as informed from initial discussions with fleet operators (reported in Section 2), are described in the following sub-sections. Presented are the information and data intended to be generated by each tool, together with the inputs, assumptions and constraints considered for the generation of those outputs.

It should be noted that this approach is mainly relevant for the first 3 tools. Dynamic Correlation and Predictive Maintenance, which deal with data science and analytics, have until now been handled by Work Package 4 partners directly. Proposals are made as to what insight information can be generated, and these will be shared and discussed with stakeholders as development of the tools progresses. The Predictive Maintenance section in particular introduces the principles of data science and machine learning; the details and breadth of their implementation on ZEFES will eventually depend on what real-world asset data is allowed to feed into the digital platform. These discussions are on-going.

5.1 Tool 1 - Buying Decision Tool



ZEFES PROPOSAL DESCRIPTION

Platform to find suitable ZEV fleet for certain fleet operations. Default profiles of different vehicles and vehicle-trailer configurations will be addressed.

KEY STAKEHOLDERS

Operators, OEM, Policy Makers, Infrastructure Providers, Financial Institutions, Energy Suppliers

PROBLEM STATEMENT

Investing in ZEV is high risk due to the high capital required and lack of understanding of real world vehicle performance, infrastructure availability and future policy decisions.

KEY CONSIDERATIONS

- Infrastructure may change over time.
- Policies and subsidies may be time based.
- Maintenance& service costs may change depending on the operator's contracts with the OEM (The economics of scale)
- Ideal Driver behaviour (Regen, eco driving)

TOOL SPECIFICATION

Tool's value proposition
Helps with fleet transition to ZEVs considering the operator's requirements, infrastructure, incentives and TCO

How the tool will be presented
Stand alone web user interface

Assumptions
(Vehicle reliability, Availability of spares, stable infrastructure and policy)(Ideal driver behaviour)

Figure 19 – Buying Decision Tool overview.

5.1.1 Problem Statement

In sustainable commercial transportation, fleet operators are presented with novel challenges when selecting the Zero Emission vehicle fleets that match their specific operational needs. The need to retain operational efficiency and commercial profitability remain non-negotiable, and therefore their ability to choose ZEV solutions that are suitable for their operation, and in particular the level of certainty and confidence with which those decisions are made, is of paramount importance.

Fleet managers face challenges in estimating realistic total costs of ownership, gauging the environmental impact of the fleet, optimizing the configuration of the ZEV tractors and trailers. Moreover, the integration of charging infrastructure for the BEVs and refilling stations for the FCEVs presents complexities to mitigate underutilization.

5.1.2 Description

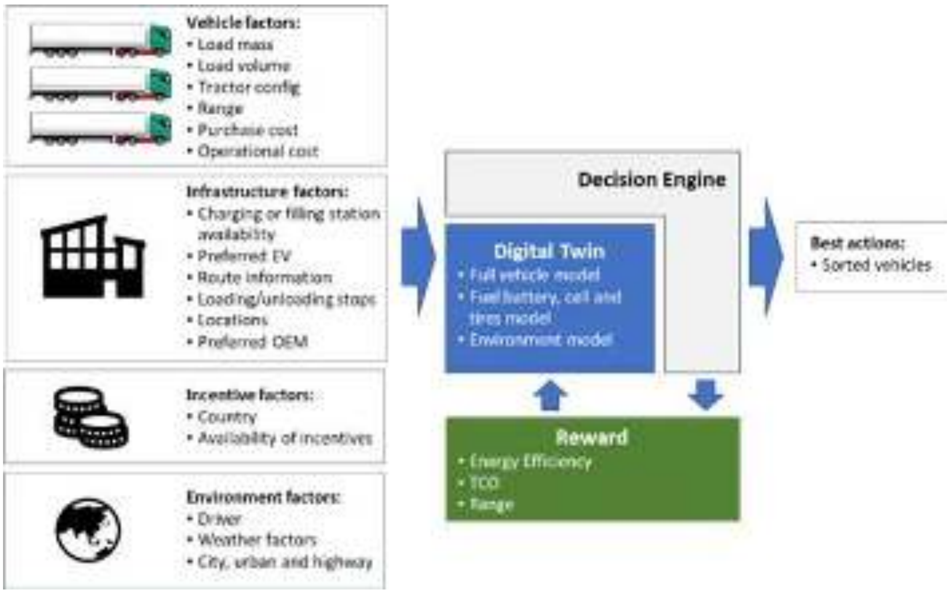


Figure 20 – Buying Decision Tool workflow concept.

The buying decision tool aims to improve the process of selecting, configuring, and optimizing ZEV fleets, thereby contributing to a more streamlined and effective approach to implementing sustainable transportation.

In order to understand the operator's need, a questionnaire was sent to the ZEFES fleet operators. These conversations provided valuable insights into the limitations of their current process and the expectations they have for a future tool. From these discussions, reported in Section 2, significant features that the ZEFES tool should encompass have been identified.

One key feature is to calculate the total cost of ownership of the vehicle and of a fleet of zero emission vehicles. The tool will consider different operating conditions of the vehicle such as the payload, volume, weather and traffic. It is recognized the depot charging system is also an important factor, therefore the ZEFES platform aims to provide insights into the viability of a depot Megawatt Charging System . The visual Range and Reach polygon enable precise range estimations under diverse operating conditions, while the breakdown of CO2 savings highlights the environmental benefits of Zero Emission Vehicles. Within the ZEFES project there will be ZEV trucks and trailers with different specification. However, one truck and trailer combination might not be suitable for a range of duties. Therefore, feature to be able to configure tractor and trailers is identified as one of the essential features.

Figure 21 – Buying Decision Tool key features.

5.1.3 Key Stakeholders

In the scope of the project, the following are the key stakeholders for the tool:

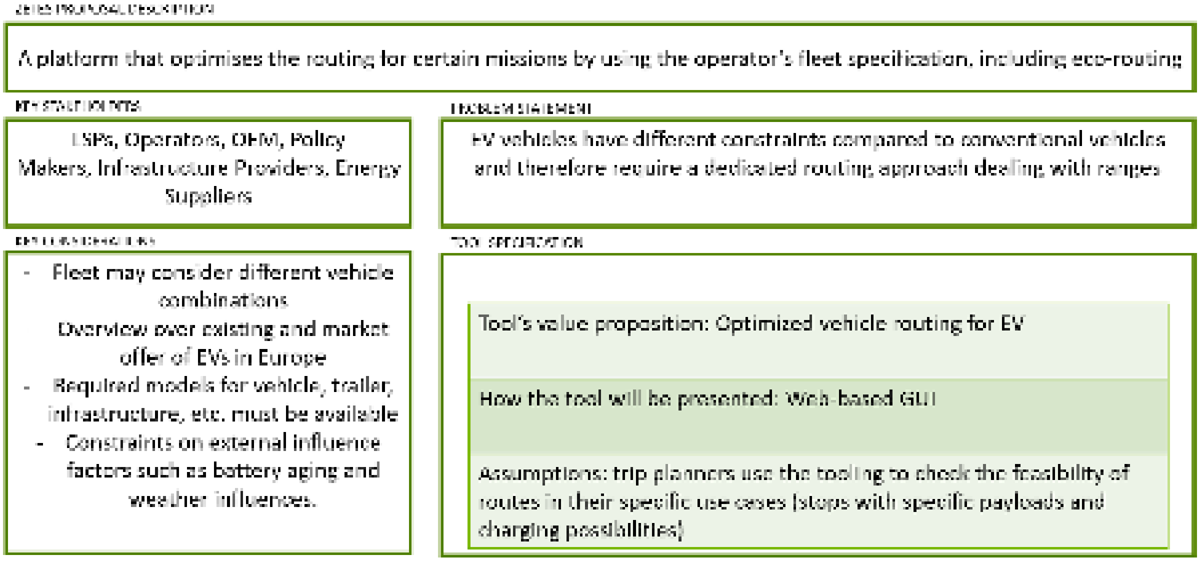
- Logistics companies
- Forwarders
- Fleet owners
- OEMs

5.1.4 Key features

The following are the integral features of the buying decision tool to facilitate informed decision making and optimized operations.

- **TCO calculation:** Estimates the Total cost of ownership of the vehicle throughout its operational lifespan.
- **Range and Reach polygon:** Visualize the projected range under specific operating conditions, allowing for better planning and optimization.
- **Potential CO2 savings breakdown:** Estimates the CO2 savings achievable by a ZEV in comparison to an equivalent diesel truck.
- **MCS analysis/ suggestions:** Offers in-depth insights into the costs associated with the Depot megawatt charging system for the selected fleet of BEV trucks, along with potential recommendations for improvement.
- **Fleet configurator:** This feature allows operators to configure the ZEV tractors and trailers according to their specific operational needs.

5.2 Tool 2 - Mission planning



ZEFES PROPOSAL DESCRIPTION

A platform that optimises the routing for certain missions by using the operator's fleet specification, including eco-routing

KEY STAKEHOLDERS

LSPs, Operators, OEM, Policy Makers, Infrastructure Providers, Energy Suppliers

PROBLEM STATEMENT

EV vehicles have different constraints compared to conventional vehicles and therefore require a dedicated routing approach dealing with ranges

KEY CONSIDERATIONS

- Fleet may consider different vehicle combinations
  Overview over existing and market offer of EVs in Europe
- Required models for vehicle, trailer, infrastructure, etc. must be available
- Constraints on external influence factors such as battery aging and weather influences.

TOOL SPECIFICATION

Tool's value proposition: Optimized vehicle routing for EV

How the tool will be presented: Web-based GUI

Assumptions: trip planners use the tooling to check the feasibility of routes in their specific use cases (stops with specific payloads and charging possibilities)

Figure 22 – Mission Planning tool description

5.2.1 Problem statement

Climate change poses significant challenges for the transportation sector. European governments are compelling fleet owners to achieve substantial reductions in their CO2 emissions through legislation and taxation measures. At the local level, low or zero-emission zones are increasingly being established, accessible only by electric vehicles. As a result, more and more companies are starting to electrify their transportation fleets.

The adoption of electric vehicles poses new challenges for transportation planners and fleet managers. Which electric vehicles should I invest in? What charging infrastructure do I need? How will limited range affect my transportation operations and profitability? What is the impact of weather conditions and driving behaviour on energy consumption? The EV Truck Route Planner supports to answer these questions.

5.2.2 Description

The mission planning service (work title: BEV Truck Route Planner) by PTV is designed specifically for logistics companies that are interested in electric fleets. It provides a comprehensive catalogue of electric vehicles in Europe and a powerful tool to calculate & plan routes for electric trucks & vans. The BEV Truck Route Planner helps logistics companies to discover electric commercial vehicles, and to plan realistic scenarios for them, to see, if they are suited for their transportation tasks. The migration of fleets to electric vehicles helps companies to reduce fuel costs, increase productivity, reduce their carbon footprint, and contribute to a more sustainable future. The BEV Truck Route Planner provides a comprehensive catalogue of commercial electric vehicles in Europe, including information on their range, charging possibilities and other key specifications. This catalogue is regularly updated and enhanced, to ensure that logistics companies have access to the latest information on electric vehicles. The tool is customizable to fit the needs regarding vehicles or individual functionality.

The route is based on PTV's state-of-the-art routing algorithms and know-how. It calculates the optimal route, considering all relevant vehicle-specific restrictions as well as current and historical traffic conditions. For realistic vehicle consumption on the route, we calculate payloads at each stop and consider influences such as driving behaviour, elevation, temperature and wind effects, vehicle age and battery usage.

Figure 23 – Mission Planning tool

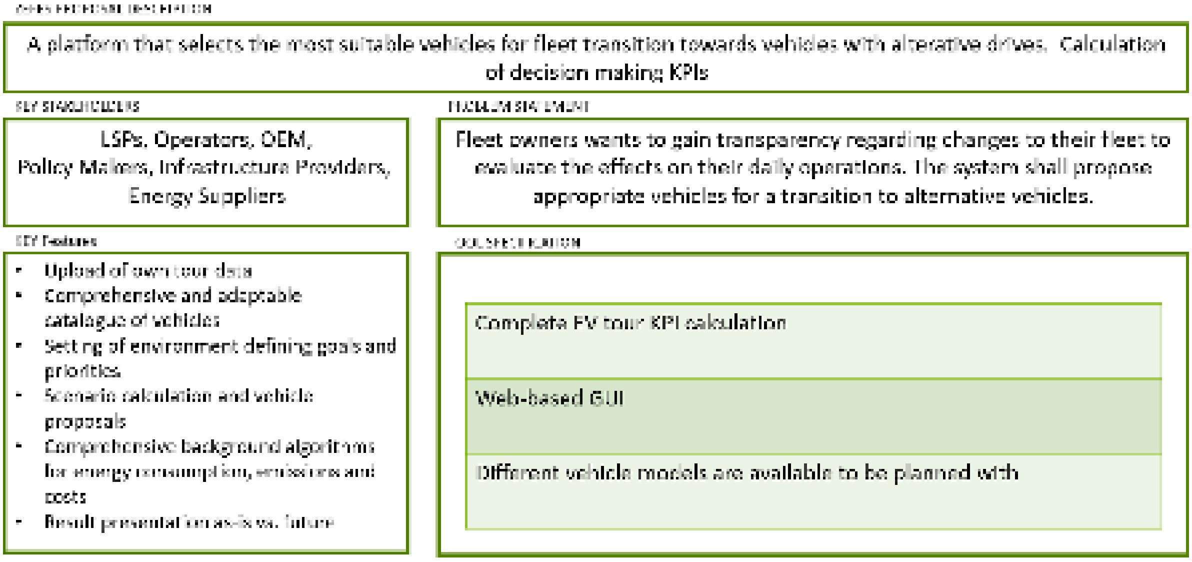
5.2.3 Key Stakeholders

- Logistics companies
- Forwarders
- Fleet owners
- OEMs

5.2.4 Key features

- Plans routes for a specific e-vehicle (can also be H2, FCEV)
- Comprehensive catalogue of Truck & Van EVs in Europe
- Realistic consumption calculation
- Cutting-edge EV truck routing and planning algorithms.
- Consideration of relevant vehicle-specific restrictions
- Consideration of driving behavior, elevations, temperature, and wind influences

5.3 Tool 3 - Right vehicle in right duty



ZEFES PROPOSAL DESCRIPTION

A platform that selects the most suitable vehicles for fleet transition towards vehicles with alterative drives. Calculation of decision making KPIs

KEY STAKEHOLDERS

LSPs, Operators, OEM,
Policy Makers, Infrastructure Providers,
Energy Suppliers

PROBLEM STATEMENT

Fleet owners wants to gain transparency regarding changes to their fleet to evaluate the effects on their daily operations. The system shall propose appropriate vehicles for a transition to alternative vehicles.

KEY Features

- Upload of own tour data
- Comprehensive and adaptable catalogue of vehicles
- Setting of environment defining goals and priorities
- Scenario calculation and vehicle proposals
- Comprehensive background algorithms for energy consumption, emissions and costs
- Result presentation as-is vs. future

TOOL SPECIFICATION

Complete EV tour KPI calculation

Web-based GUI

Different vehicle models are available to be planned with

Figure 24 – Right Vehicle Right Duty description

Figure 25 – Right Vehicle Right Duty concept

5.3.1 Problem statement

Companies face the challenge of complexity and not sufficiently known KPIs while transferring existing fleets towards alternative commercial vehicles regarding availably, feasibility, emissions, and costs.
The desired service is dedicated to supporting knowledge-based investment decisions for alternative fuel vehicles in fleets, in the dimension's scenario viability, commercial KPIs, environmental impact, route planning.

5.3.2 Description:

The envisaged tool 3 Right vehicle in right duty (working title: EV- Fleet Analyst) enables decision makers to apply, test and tune scenarios on their existing tour structures in a completely tailored approach.
The solution provides a comprehensive vehicle database that can be individually adapted to the fleet owners' desires.
The solution comprises a full stack trip planning solution which allows to calculate user specific scenarios, e.g., winter/summer, costs scenarios, charging setups, vehicle mixes.
Appropriate vehicles for a transition towards alternative fuels are suggested.
Result presentation covers as-is vs future as well as comparisons at discrete tour level (different vehicles). KPIS for the comparison are feasibility, consumptions, emission, monetary costs.

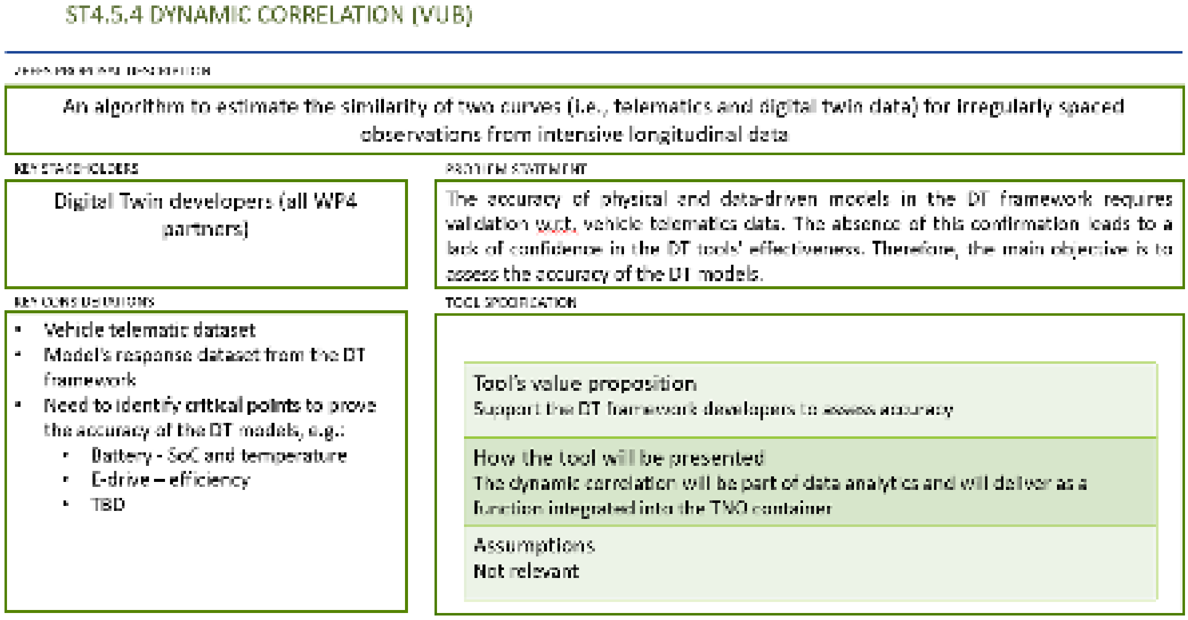
5.3.3 Key Stakeholders

- Logistics companies
- Forwarders
- Fleet owners
- OEMs

5.3.4 Key features

- Upload of own tour data
- Comprehensive and adaptable catalogue of vehicles
- Setting of environment defining goals and priorities
- Scenario calculation and vehicle proposals
- Comprehensive background algorithms for energy consumption, emissions and costs
- Result presentation as-is vs. future

5.4 Dynamic Correlation Tool



ST4.5.4 DYNAMIC CORRELATION (VUB)

ZEFES PROBLEM DESCRIPTION

An algorithm to estimate the similarity of two curves (i.e., telematics and digital twin data) for irregularly spaced observations from intensive longitudinal data

KEY STAKEHOLDERS

Digital Twin developers (all WP4 partners)

PROBLEM STATEMENT

The accuracy of physical and data-driven models in the DT framework requires validation w.r.t. vehicle telematics data. The absence of this confirmation leads to a lack of confidence in the DT tools' effectiveness. Therefore, the main objective is to assess the accuracy of the DT models.

KEY CONSIDERATIONS

- Vehicle telematic dataset
- Model's response dataset from the DT framework
- Need to identify **critical points** to prove the accuracy of the DT models, e.g.:
    - Battery - SoC and temperature
    - E-drive – efficiency
    - TBD

TOOL SPECIFICATION

Tool's value proposition
Support the DT framework developers to assess accuracy

How the tool will be presented
The dynamic correlation will be part of data analytics and will deliver as a function integrated into the TNO container

Assumptions
Not relevant

Figure 26 – Dynamic Correlation description

5.4.1 Problem statement

Accurate digital twin preparation involves creating a virtual representation of a physical asset, system, or process to simulate and analyze its behavior and performance in real-time or historical contexts. Trustworthiness and accuracy are critical issues in this process, as they directly impact the usefulness of the digital twin prediction and/or estimation. Hence, it is mandatory to check the correlation between digital twin framework data and vehicle telematics data to confirm trustworthiness of the prediction.

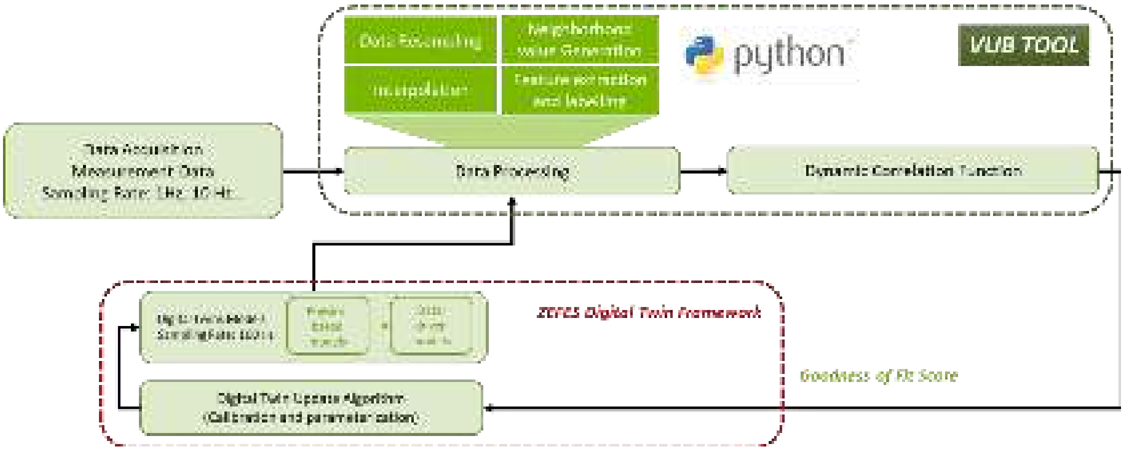


Figure 27 – Stepwise workflow of the dynamic correlation tool

5.4.2 Description

Dynamic correlation refers to the process of continuously comparing and updating the digital twin with real-world data from the vehicle telematics. By dynamically correlating the digital twin with the actual system, the WP4's digital twin developers can identify and rectify discrepancies, ensuring that the virtual representation accurately reflects the real-world behavior. The dynamic correlation tool of VUB will be an integrated part of the data analytics of the entire ZEFES digital twin framework. The tool will be developed in Python and will be containerized by TNO, so that it can be easily utilized different developer entity (e.g., plug-and-run), the overall architecture of the is shown in Figure 27. Here's how dynamic correlation can support to improve trustworthiness is summarized: (a) ***Real-Time Validation:*** with dynamic correlation, real-time telematics data from vehicle is continuously fed into the digital twin at different sampling frequency (ranges from 1 Hz to kHz). This enables instant validation of the twin's predictions using physic and data-driven models (simulation step size) against real-world observations. Any inaccuracies or deviations can be promptly identified and corrected through twin's updating algorithm, improving the trustworthiness of the digital twin; (b) **Data Quality Control:** by comparing the digital twin's output with the telematics data, digital twin developers can identify issues related to data quality or biases. This process helps in identifying and filtering out noisy or erroneous data.

In summary, dynamic correlation tool will bridge the gap between the digital twin and the physical system data. The tool will enable continuous validation, adaptation, and improvement, resulting in a more accurate and trustworthy digital twin.

5.4.3 Key Stakeholders

- Digital twin model developers (all WP4 partners)

5.4.4 Key features

- Any model developer would be able to apply this tool for faster validation of their model response
- Fast run and validation
- Any sampling frequency of the sensor data can be provided as input to the tool no need to carry out pre-processing
- Missing sensor values will be replaced by neighborhood values
- Sensor data can be interpolate or extrapolate to be in the same scale of the digital twin

5.5 Tool 5 – Predictive Maintenance Tool

5.5.1 Problem statement

Successful logistics operations are based on the maximum utilization of the fleet vehicles. Operators are prepared for the scheduled maintenance and downtime of the vehicles. However, unforeseen downtime of the vehicles due to part or system failure can disrupt the operations and negatively impact the financial performance of the operation.

With the emerging vehicle technologies such a Battery electric and Fuel cell vehicles there is a need for Predictive maintenance tool. From our discussions with the operators, reliability of the vehicle has been identified as one the hurdles to switch to ZEV fleets. Predictive maintenance tool can assist with the fault prediction of the ZEV specific components such as battery pack, fuel cell, e-dolly, e-trailers. Tire health is also an essential component to predict the maintenance period of the vehicle. Potentially, tires will be part of this tool's capabilities as well.

5.5.2 Description

Predictive maintenance is a data-driven technique to identify potential failures or anomalies of a system. The process involves collecting and analysing historical vehicle data and creating a model of the failure so that it can be predicted ahead of time.

Figure 28 – Predictive Maintenance SOH prediction

Maintenance Strategies:

1. **Condition- Based Maintenance:** The condition-based is the simplest maintenance and it monitors the sensors and looking out for anomalies in real-time. These can be implemented on the vehicle itself.
2. **Predictive analytics:** It is concerned with predicting future failures before they really happen. It can use machine learning technique to identify failure trends or patterns within the vehicle data. This approach is applicable both at the vehicle and fleet levels.
3. **Prescriptive analytics:** Going beyond predictive methods, prescriptive analytics employs sophisticated algorithms to make decisions based on outcomes from condition-based and predictive analyses. It involves analyzing potential failures and recommending preventive actions. This method requires substantial training data to learn various failure scenarios. Fast-running digital twins simulate numerous scenarios, allowing continuous learning without complete system retraining.

Integration and Platforms:

These maintenance analytics techniques can be integrated into a comprehensive platform, considering factors like historical data availability, service records, and parts inventory. A fundamental example is the health monitoring system, which tracks component degradation, such as State-of-Health (SoH) for batteries.

The figure below shows how the four machine learning models can be integrated into a smart predictive maintenance. An advanced predictive maintenance can be made up using all the techniques in one large maintenance platform as shown in the figure below.

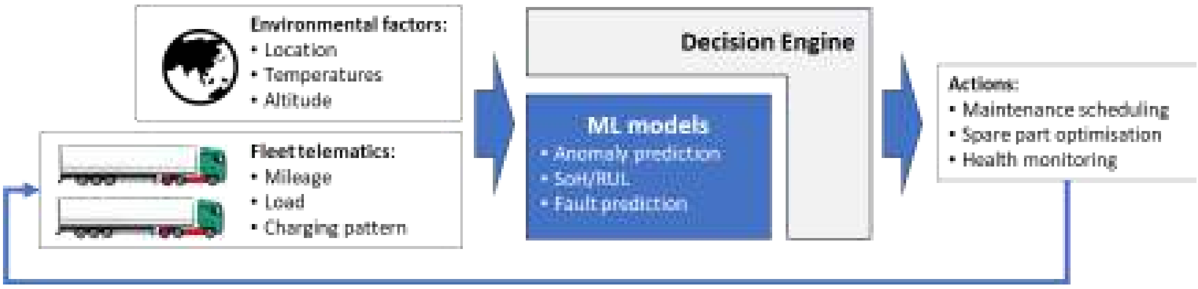


Figure 29 – Overview of predictive maintenance

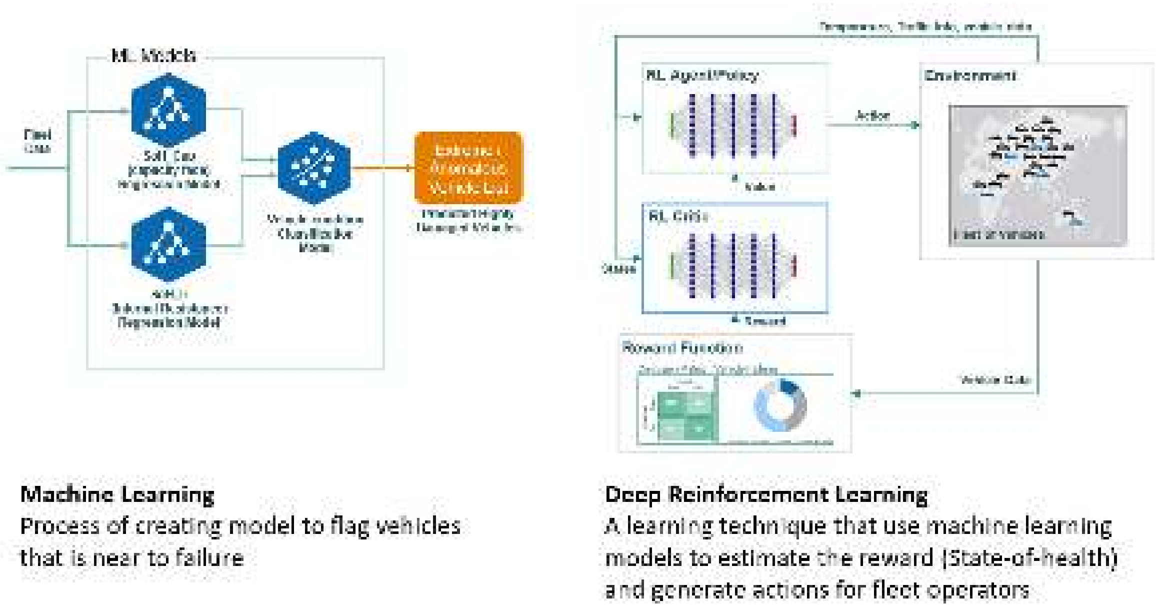
Machine Learning Models:

- **Degradation Prediction and Fault Classification:** Gradient boosting models, versatile ensemble models for regression and classification, are often used. They can incorporate complex data, such as labels and discrete variables, with continuous vehicle measurements. Gradient boosting models effectively capture intricate patterns within data.
- **Anomaly Detection:** Anomaly detection necessitates clustering models in an unsupervised learning process. Clustering helps identify patterns that may lead to anomalies, particularly beneficial for fleet management**.**
- **Decision Engines:** Decision engines automate decision-making processes to prevent forecasted issues. These could be ensemble models or deep neural network agents trained through deep reinforcement learning. The latter involves wrapping an AI system around degradation models to learn scenarios and reward effective actions.

Data Science Techniques:

- **Machine Learning:** Machine learning involves creating prediction models for values such as SoH, component degradation, temperature, or congestion patterns.
- **Reinforcement Learning:** Reinforcement learning, which falls under the umbrella of machine learning, tackles complex problems by generating optimal actions to prevent future failures via a reward-based system. This approach involves trial and error and is beneficial for scenario testing and fleet operator actions.
- **Deep Reinforcement Learning:** Deep reinforcement learning involves integrating deep neural networks into reinforcement learning techniques. This approach uses deep neural networks as agents wrapped around machine learning models (such as degradation models) to learn different scenarios and reward itself for taking good actions. Deep reinforcement learning is particularly useful for handling complex systems or problems.

  The capabilities of deep reinforcement learning can be extended with advanced ensemble models like Hybrid Ripple-Down Rules (Hybrid-RDR). This model combines a classification model with a decision tree-based knowledge acquisition engine. The knowledge acquisition engine can be trained with the assistance of a Subject Matter Expert (SME). This hybrid method requires less training and can be built incrementally as more data is collected.



Machine Learning
Process of creating model to flag vehicles that is near to failure

Deep Reinforcement Learning
A learning technique that use machine learning models to estimate the reward (State-of-health) and generate actions for fleet operators

Figure 30 – Differences between Machine Learning and Deep Reinforcement Learning and how the complement each other

Continuous Learning for Reliable Predictive Maintenance:
Machine Learning models are usually trained with a set of initial or historical data. These make the models unusable for new unseen areas. For instance, a model trained using data from hotter countries, then used to predict in cooler countries, will be unable to ‘adapt’ to this new data and will require retraining of its parameters. If millions of rows of historical of data were available, this would not be an issue. The problem usually arises when the initial training data set is small, as small training datasets can introduce bias in the model.

The inherent bias in the model eventually leads to its unreliability when tasked with predicting outcomes beyond its usual scope. This phenomenon is known as 'Distribution Shift.' A disparity between the training data and real-world data can result in inaccuracies within the machine learning model. To counteract this challenge, it becomes imperative to consistently update the models at set intervals, such as every month or year.

Models can be periodically updated or retrained. Typically, the alterations are minor, especially when the model has achieved stability. The continuous delivery and automation pipeline for machine learning models is of paramount importance to ensure that these models are kept updated and validated.

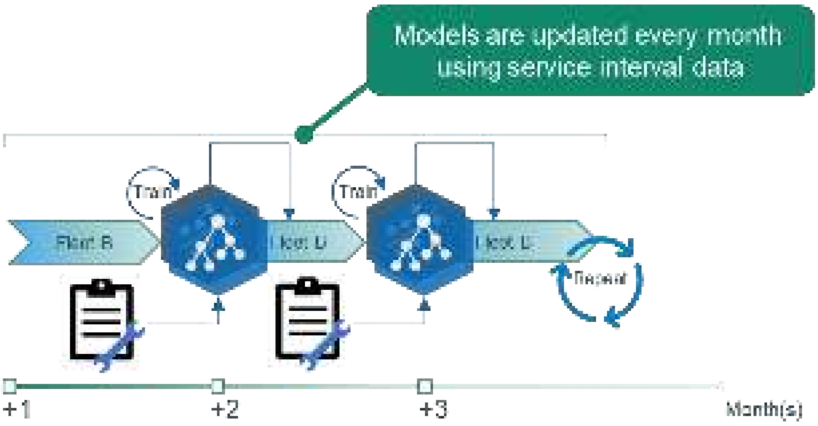


Figure 31 – Monthly model update

The advantages of continuous learning are the following:

- **Enhanced Model Prediction Accuracy:** Continuous learning contributes to the refinement of model predictions, resulting in more accurate forecasts.
- **Improved Assumptions Regarding Fleet Distribution:** As the models evolve through continuous learning, they garner a more precise understanding of the distribution of variables within the fleet.
- **Utilization of New Data for Distribution Shifts:** The integration of new data for addressing distribution shifts becomes feasible, particularly if an initial model build involves synthetic models or digital twins.

Retraining the models:

Training from Scratch: This approach is suitable for smaller models or datasets. However, as data volumes grow—such as in the case of a million rows of vehicle data—the modelling process can become excessively time-consuming.

Transfer Learning: Involving the reuse of parameters from an existing model, transfer learning accelerates the creation of a new model without necessitating a complete restart of the modelling process.

Continual Learning: This approach involves using the same model to adjust to new situations. For instance, if a new issue arises, the existing model can incorporate this new information without needing a complete model replacement. While transfer learning and continual learning have some similarities, they use different methods. Importantly, continual learning needs less training data compared to transfer learning.

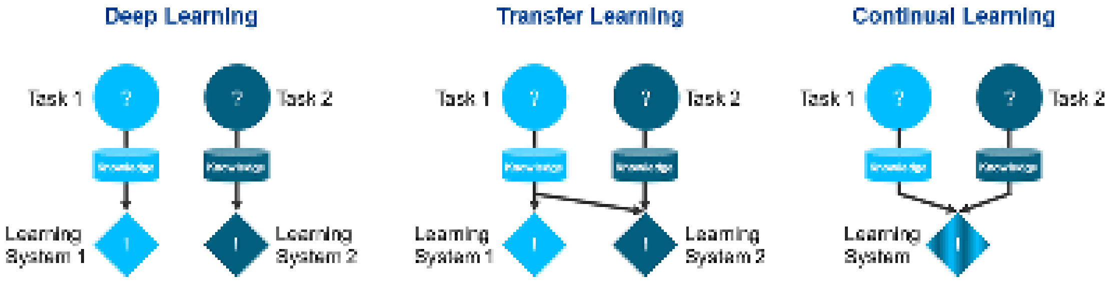


Figure 32 – Types of model retraining 1

5.5.3 Key stakeholders

- Fleet owners
- OEMs
- Tier 1 suppliers

5.5.4 Key features

Depending on the implementation, predictive maintenance tools offer a range of technical benefits for a fleet of vehicles.

- Reduced unplanned downtime
- Prevention of catastrophic failure
- Effective resource allocation/utilization of the fleet
- Extended component lifespan
- Data-Driven maintenance planning
- Integration with telematics
- Regulatory compliance

5.6 Other Tools/Functions

5.6.1 Interface to WP8

Work Package 8 focuses on the use-case evaluation and impact assessment of the project. In order to assess the performance of the ZEFES vehicles and innovations in real-world conditions, data will be used. The data needed by WP8 contains of the following:

- Operational data of the (pulling) vehicle including
    - Engine
    - Powertrain
    - Battery
    - HVAC system
- Operational data of the (e-)trailer
- Operational data of the charging and fueling infrastructure
- Environmental data such as weather conditions, traffic conditions
- Logistic mission planning data including outputs of the planning tools
- Data from the FMS of the shippers
- Static data (specifications) of all of the above

Part of this data need will be fulfilled through interfaces with the digital twin platform. The required interfaces depend on the assessment framework (that will be created in task 8.1 and described in deliverable 8.1). In this framework the assessment approach will be defined based on the KPI’s and expected results of the project innovations and use-cases.

Besides the operational data of the use-case demonstrations WP8 will also make use of reference vehicle data. This data concerns operational data of the vehicles (mostly diesel) currently running in the use-cases. The reference tests will take place before the demonstrator tests (in 2024).

5.6.2 Use Case Vehicle Realtime Display

Although not specifically mentioned as a necessary functionality in the Statement of Work document, the ability to visualise all Use Case vehicles' status and operation in a single graphical display during the test trials of Work Package 7 will be a useful addition to the digital platform offering. This will be undertaken during the platform development within Task 4.5.

6 Requirements of the ZEFES Digital Tools

Whilst Section 5 provides the digital platform tools specification, i.e. ***what*** the tools' general functionalities and outputs should be, this section sets out ***how*** the tools will be constructed, in terms of which of Section 4's elementary blocks datasets, models, services etc. will be used, and how these will be integrated into workflows to deliver the stated functionalities.

The elaboration of requirements is an on-going process and will continue to be documented during the tools' development phase, Task 4.5. To enable this, individual tool requirements are reported in separate documents which will continue their life cycle as requirements capture documents until the completion of Task 4.5.

The documents format follows standard requirements capture document format, and includes the following sections:

- Overall description
    - Product functions
    - User Classes and Characteristics
    - Operating Environment
    - Design and implementation Constraints
    - Assumptions and Dependencies
- External Interface Requirements
    - User Interface
    - Hardware Interfaces
    - Software Interfaces
    - Communication Interfaces
- System Features
    - Feature 1
    - …
    - Feature n
- Other Non-functional requirements
    - Performance Requirements
    - Safety Requirements
    - Security Requirements

Individual requirements capture documents are accessible from the following location:
Buying decision tool requirements document: link
Mission planning tool requirements document: link
Right vehicle in right duty tool requirements document: link
Dynamic correlation tool requirements document: link
Predictive maintenance tool requirements document: link
Other tools/functions requirements document: link

7 Requirements of the ZEFES Digital Platform

In this section, requirements for the ZEFES digital platform infrastructure are described, based on the needs to support the ZEFES tools as described in Section 6. Although this section presents content which is more aimed at developers than for end users, this work underpins the development of the digital platform functionalities and ensures the tools can be deployed and operated effectively, and also ensures that any data or service access restrictions are implemented appropriately.

7.1 Introduction

Before the main requirements to the ZEFES Digital Platform (ZDP) are listed, an introduction into several related ZDP concepts is provided.

7.1.1 Components for workflows

The ZEFES digital platform is a collection of ‘cyber’ components that together should support the creation of tools as described in chapter 6. A tool is created by defining a so-called *workflow*, which – within ZEFES – is an organization of components in a process that together transform (sensor) data / information to enriched information. Some cyber components are Digital Twins of ‘physical’ components in physical reality. All cyber and physical components together constitute a Cyber Physical System (CPS). The ZDP is the layer that separates the physical world from the cyber space.

7.1.2 Distribution across space, time and organizations

The collection of ZEFES CPS components is distributed geographically and across different service providers, which results in the distribution of responsibilities for the correct execution of all tasks / separate steps within a workflow as well. This causes the ZDP to deal with several challenges:

1. **Wireless interrupted communication across Europe:** the ZEVs are the source of data and are mobile, which means no direct physical connection in terms of cables. As wireless communication can be an issue in some areas, the ZDP needs to be able to deal with (sudden) loss of communication.
2. **Unresponsive components:** there are many causes for a component not to respond to a request for information. It might have become unreachable because of communications (see previous challenge), but it might also have ‘frozen’ and/or ‘halted’ or even disappeared due to the loss of hardware. The ZDP needs to be able to deal with components (part of workflow) that do not respond.
3. **Multi-vendor/service provider responsibilities:** there is no single vendor and/or service provider responsible for all components. The ZDP needs to be able to technically assign responsibility for the right party in the execution of workflows and report about this.

7.2 Main requirement 1: concerns need to be separated

To deal with the complexity of the distributed ZEFES CPS and to avoid issues with shared responsibility it is important to separate concerns. This enables agreements on who is responsible for what part / component of a workflow and also allows for a ‘conquer and divide’ approach that in turn also helps to avoid the creation of so called ‘silos’, where one vendor / service provider owns all components. These silos are the opposite of an open level playing field for commercial hardware, software and software providers. ZEFES implements separation of concerns by using two concepts. First the concept of layering and second the concept of generic platform management services.

7.2.1 Use layering

By distributing functionality across different layers, re-use of components is encouraged, and the providers of these components can focus on a specific functionality within a limited scope, instead of having to understand the whole ZEFES ecosystem in detail. If changes are made at a certain layer, the chance of other components having to change is reduced (compared to an unlayered design). This separation of concerns within the platform allows for flexibility with regards to the specific requirements of the tools as described in Section 6. The requirements for the tools themselves are still evolving, and the platform should be able to accommodate for these changes. The separation of concerns in the different layers allow for changes to be scoped to within the components or layers, rather than propagating changes throughout the whole architecture. Note that a well-designed interface (that shields component internals as much as possible) is key for this to succeed.

A layered version of the Digital Twin platform architecture is represented in Figure 33.

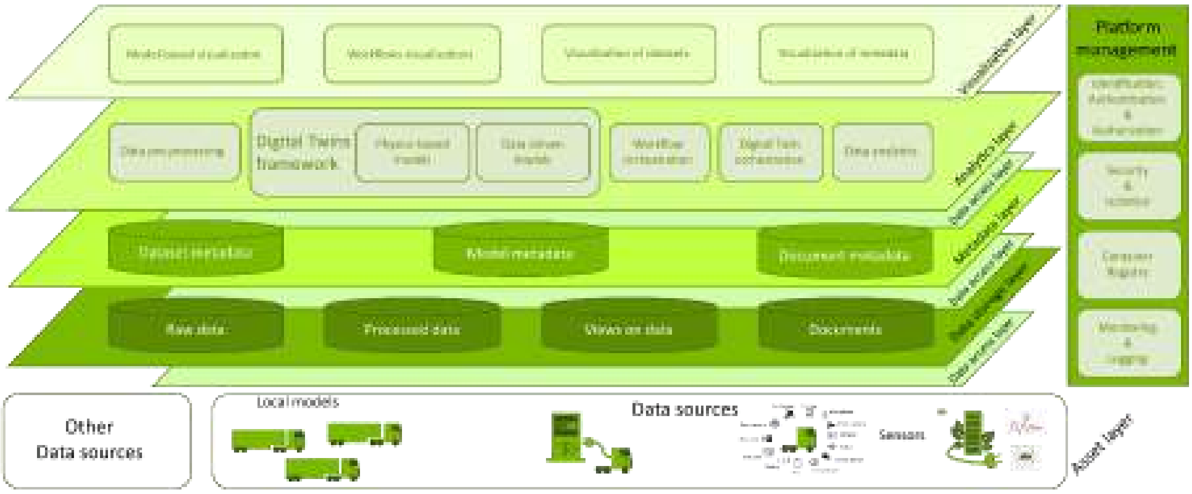


Figure 33 – Layered version of the ZEFES Digital Twin Platform architecture

In the remainder of this section the main layers (Asset, Data Storage, Metadata, Analytics, and Visualization) are described. The first three data related layers are accompanied by a data access layer, for controlling access to the data. See the second main requirement for more information on that aspect.

7.2.1.1 Asset (Data Sources)

The Asset layer consists of the data sources for the platform, including charging infrastructure, battery health, vehicle sensors. Often the data sources will be outside of the (cyber)scope of control for the platform, although considerations could be made to orchestrate data processing at the data sources themselves (edge processing), e.g. local models.

7.2.1.2 Data Storage

Data entering the system from the Asset layer is stored as **Raw data** in the Data Storage layer. This data is intended to be *immutable (not changeable after entering)*, so that it can function as a single point of truth. **Processed data** contains the results of (digital twin) models, applications and other processing steps that have been applied on the raw data. **Views** can be made that contain a subset of the raw or processed data, which can be shared with (models of) other organizations, ensuring they do not get access to restricted data (e.g. sensitive, too precise or too granular data). **Documents**, such as policies or manuals, can also be stored.

7.2.1.3 Metadata

The metadata layer is used as a catalog of the available data and models, such as what values are available and who the owner of the data is.

7.2.1.4 Analytics layer

The analytics layer contains the workloads that ingest, process and potentially create this data. **Data pre-processing** is part of the data ingestion process, where data flowing into the platform needs to be made useable, for example by decompressing or filtering incoming data. The **Digital Twins framework** supports *physics-based* and *data-driven models* with their execution and data access. **Digital Twin Orchestration** supports the communication between the different digital twins. **Workflow orchestration** is used to combine the different parts of the analytics layer for a specific goal, e.g. to support the tools described in Section 5. The orchestration of a workflow requires a runtime where the different models can be executed. There should be a workflow orchestrator, which is responsible for managing workflows on this runtime. The computational resources within this runtime should have a degree of scalability, where the total amount of computational resources available for a workflow can be scaled up or down depending on the workflow. This is important, as it is not yet known what the computational requirements of each tool in ZEFES will be. **Data analytics** are non-simulation workloads used to interpret the raw or processed data / results, in order to assess their quality or convert the data into useable information.

7.2.1.5 Visualization layer

The visualizations layer gives insight into the platform, such as visualizing the workflows, but also support the visualizations needed for the tools described in Section 5.

7.2.2 Provide generic management services

In order to let component suppliers focus on the data to information processing functionality, the ZDP offers platform management functionality. It can be seen as a cross-cutting layer, supporting the functionality at components at other layers.

7.2.2.1 Identification, Authentication & Authorization

Includes **Identification, Authentication & Authorization** services to control who has access to the specific services, computational models, and data on the ZDP. Also see main requirement 2.

7.2.2.2 Security & Isolation

These services provides **Security & Isolation** functionality to ensure the models and data do not accidentally leak across stakeholders or outside the platform.

7.2.2.3 Container Registry

The **Container Registry** services allows for storing various workloads such as Digital Twin models, analytics, and preprocessing workloads. This is a key facilitator in providing platform flexibility and scalability.

7.2.2.4 Monitoring and Logging

Monitoring & Logging services are used to detect and diagnose faults in the platform and in the (stakeholder) programs running in it.

7.2.2.5 Usage of external services

Some workflows require data or models from external services outside of the platform. The usage and access to these external services is often managed through so-called API keys. The entity managing the service can then handle usage and billing per API key.
Components within a workflow in the platform can make use of these external services. The account management of the platform should allow for the storage and management of API keys in a secure way, such that users can use their own API keys when running workflows. The billing with regards to the usage of the external services is then handled completely external to the platform.

7.3 Main requirement 2: Access to data and services needs to be controlled

Next to the separation of concerns another (related) requirement is the need to control access to data and services. This section describes where access control is needed in the ZDP. First an introduction to the flow of data on the ZDP will be provided. After that access control requirements will be discussed.

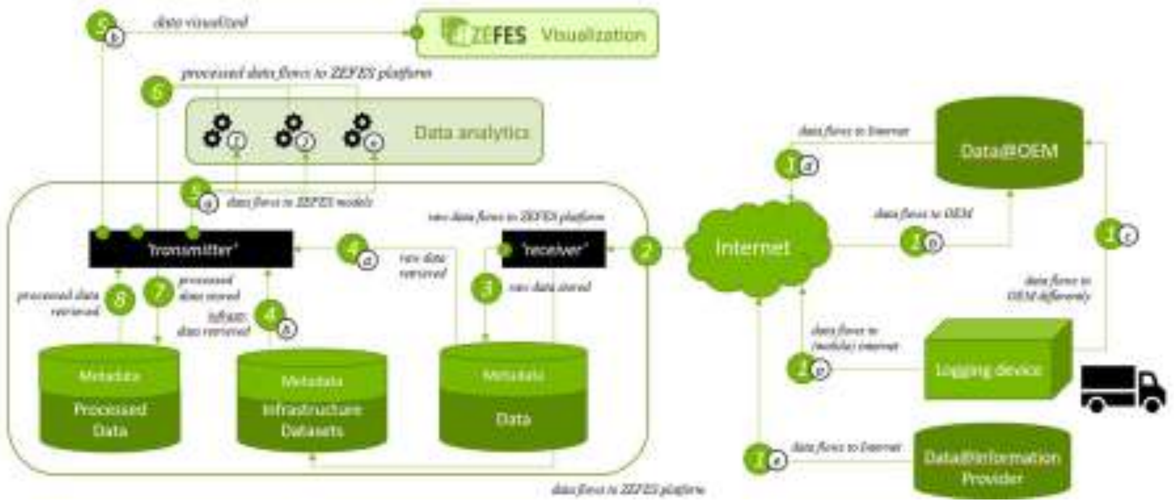


Figure 34 – Flow of data within the ZDP

7.3.1 Flow of data

Before access control to data can be located on the ZDP, it is necessary to first provide a high-level logical description of the flow of data in the ZDP. In Figure 34 a depiction is provided, which shares some symbols with the layered architecture in Figure 33. There are three main data categories: data (from the ZEVs), Infrastructure Datasets (e.g. road information) and Processed data. Each data category has metadata to it describing the available data. The layers have been removed for reasons of visual intelligibility. The following steps can be identified:

1. Data flow from assets like the ZEV or data/information providers to the ZDP. Data can flow from a logging device across mobile Internet (1a). It can flow directly to the ZDP, or it can flow to the ZEV OEM first (1b). Another link between ZEV and OEM is also possible (1c). The data flows from the OEM to the Internet. Data/information from digital providers also flow over the Internet (1e).

2. The data arrives at a logical component called the 'Receiver' that takes care of
3. storing the raw (sensor) data and/or at the infrastructure datasets. Note that the ZDP can also refer to ZDP external datasets. In this case the receiver gets a reference which is stored.

4. The raw (sensor) data (4a) and infrastructure data (4b) can be retrieved by a logical component called the 'transmitter'. This component is responsible for outputting data / information from the data layers of the ZDP.

5. After retrieval the data can be processed by Data analytic components (5a) or visualized (5b) at the higher layers.

6. Analyzed data flows to the ZDP Transmitter component which
7. stores the processed data which can then be
8. retrieved by the transmitter again for further analysis (5a) or visualization (5b)

The depiction in Figure 34 makes clear that the flow of data crosses boundaries of data ownership. For example: (sensor) data of ZEVs are probably not owned by the organization that owns parts of the ZDP. Also, OEMS might not want to share ZEV data with other OEMS. When located on the same ZDP there is the risk of unwanted sharing. The same goes for using analytic components and/or infrastructure datasets: companies might want to offer those as a commercial service and thus control of access is required.

7.3.2 Under lock and key

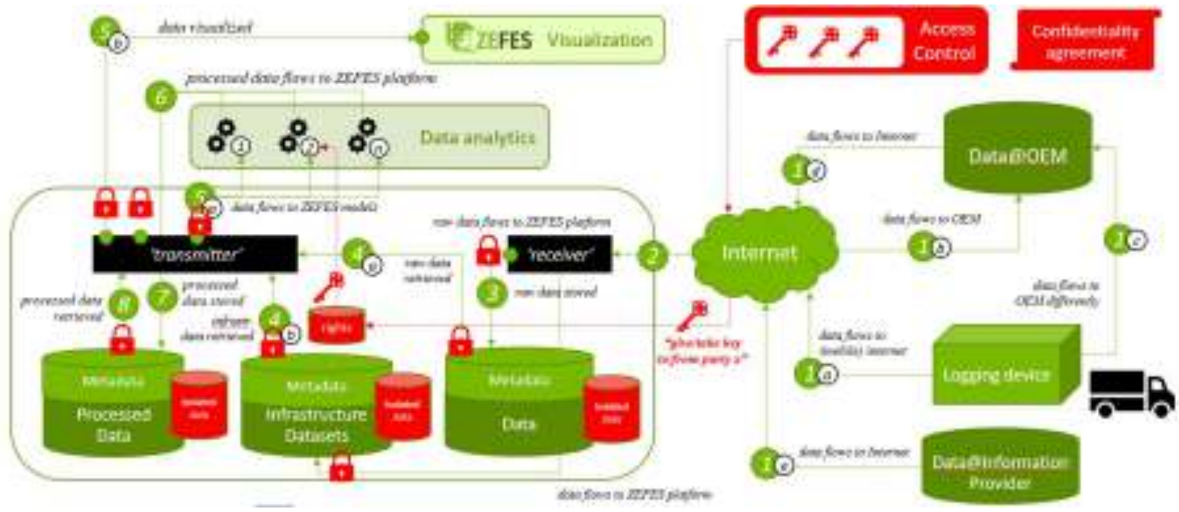


Figure 35 – Data flow on the ZDP under lock and key

With the high-level description of the flow of data on the ZDP in mind, it is now possible to locate where access control to data is needed. In Figure 35 locks and keys have been added to the depiction of the flow of data in Figure 34. Basically, at each point where data can be retrieved a lock is put, ensuring no one is able to retrieve (processed) data and/or infrastructure datasets. If necessary, data can be stored in isolated settings as well (also see the generic platform management Security & Isolation service). The keys for the locks can be handed out by the owners of the data, through an Access Control component (part of the Identification, Authentication & Authorization generic platform service). This component is reachable through the Internet and data owners (e.g., OEMS and/or truck owners) can authorize parties registered at the ZDP. Note that it is expected that confidentiality agreements will be signed between data owners and the parties that host (parts of) the ZDP. Note that this access control should be applied to data analytics as well: it should be able to restrict access to a specific service that offers data to information processing ('analytics') capabilities.

8 Results & Discussion

8.1 Results

Activities conducted during Work Package 4 to-date have covered:

- Understanding the critical needs from fleet operators and alignment of the specification of the ZEFES decision making tools against these specific needs
- Defining and documenting the digital platform and tools specifications and requirements

The latter is itself articulated around 5 key areas to ensure a successful delivery of the tools:

- The provision of individual service functions, such as models representing a physical asset (e.g. a model of the vehicle), existing services (e.g. mission planning tool), or computing functions or algorithms
- Implementation of a secure framework for the acquisition, storing and processing of the data
- The acquisition and management of physical asset data, such as live vehicle performance data or infrastructure status data
- Implementation of a connected environment allowing data exchanges between service functions, in line with the data protection requirements
- Orchestration of the service functions to generate the relevant functionality for each managerial tool

The delivery across all 5 areas is on-going and will be the focus of the work leading towards the completion of the tools, ready for testing by Month 20.

Although some of the tools' workings will involve complex digital processes, no technical roadblocks are expected during their elaboration and use. The two areas requiring further discussions and agreements regard the confirmation of the tools’ requirements with the operators, and how much connectivity to the outside world and to the real-world assets the digital platform will be granted. Both will impact the features available from the platform and the tools, and will also affect the depth of the analysis work part of the final impact assessment work.

Work and consultations with partners are on-going to progress both issues.

8.2 Contribution to project (linked) Objectives

Objective 3 of the ZEFES Project is to provide digital and fleet management tools specifically for HD ZEVs, fleet integration with remote operational optimisation of vehicle performance. This document acts as a specification and requirements document for each of the managerial tools, and provide a description of the digital platform supporting their implementation and operation.

8.3 Contribution to major project exploitable result

This report summarises the foundation work carried out for the specification and development of the digital platform and associated tools, which in turn will serve to facilitate zero tailpipe emission vehicle integration in fleets, to optimise logistical task assignments considering routes, infrastructure and refuelling/recharging opportunities, and to develop predictive maintenance strategies including deployment of diagnostic & prognostic techniques. The digital platform will also provide the analytical interface to support the impact assessment and life cycle analysis activities.

9 Conclusion and Recommendation

This document reports the work carried out to draw the specification and capture the requirements of each of the managerial tools, and provide a description of the digital platform supporting their implementation and operation, covering the platform's individual components and features, and the platform's general functional and process principles.

Although discussions took place with ZEFES operator partners to understand and capture their needs, further inputs are expected from Work Package 1 reports and through stakeholder meeting events. The feedback that will be gathered will be included into any necessary iteration of the work performed to date.

From a digital platform development perspective, activities over the coming months will cover the completion of the tools' requirements capture, the implementation, testing, and validation of the digital platform and tools. These will be delivered mostly through Tasks 4.3 and 4.5.

10 Risks and interconnections

10.1 Risks/problems encountered

Risk No.	What is the risk	Probability of risk occurrence[1]	Effect of risk[1]	Solutions to overcome the risk
WP4.1	Changing/evolving requirements from fleet managers and operators	1	2	Use Task 1.3 output and Stakeholders meeting to capture/freeze end user requirements. Platform inherently built with a modular approach to allow some reconfiguring of tools' workflows and outputs
WP4.2	Reduced access to vehicle logged data	1	2	Use synthetic/surrogate data to demonstrate tools functionalities when possible

1) Probability risk will occur: 1 = high, 2 = medium, 3 = Low

10.2 Interconnections with other deliverables

As depicted in Figure 3-1 of the DoA part B document, Work Package 4 interacts with most of the other project Work Packages. Outputs from those will all be captured within the workings of the digital platform, whether explicitly (e.g. number of digital twins as defined during Work Package 1) or implicitly (e.g. through maps capturing locations of charging stations as defined in Work Package 3). However, in relation to this deliverable, the more direct interconnections with a strong impact on the dealings of Work Package 4 can be summarised as follows:

Feed from:
D1.3: capture of stakeholder business needs (on-going, due M9)
D4.2: description of infrastructure datasets (on-going, due M10)

Feed into:
D4.3: definition and realisation of digital platform
D4.4: development of decision-making tools on digital platform

11 Deviations from Annex 1

In order to allow for the workflow as described in Section 8.2, it was necessary to bring forward the start of Task 4.3 with an early involvement of TNO to ensure a common understanding on needs of and the requirements from the digital platform infrastructure.

12 Acknowledgement

The author(s) would like to thank the partners in the project for their valuable comments on previous drafts and for performing the review.

Project partners:

#	Partner short name	Partner Full Name
1	VUB	VRIJE UNIVERSITEIT BRUSSEL
2	FRD	FORD OTOMOTIV SANAYI ANONIM SIRKETI
3	HYU	HYUNDAI MOTOR EUROPE TECHNICAL CENTER GMBH
4	KAE	KASSBOHRER FAHRZEUGWERKE GMBH
5	REN	RENAULT TRUCKS SAS
6	SCA	SCANIA CV AB
7	VET	VAN ECK TRAILERS BV
8	VOL	VOLVO TECHNOLOGY AB
9	ABB	ABB E-MOBILITY BV
9.1	ABP	ABB E-MOBILITY SPOLKA Z OGRANICZONAODPOWIEDZIALNOSCIA
10	AVL	AVL LIST GMBH
11	CM	SOCIEDAD ESPANOLA DE CARBUROS METALICOS SA
11.1	APG	AIR PRODUCTS GMBH
12	HEPL	HITACHI ENERGY POLAND SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA
13	MIC	MANUFACTURE FRANCAISE DES PNEUMATIQUES MICHELIN
14	POW	PLASTIC OMNIUM NEW ENERGIES WELS GMBH
15	RIC-CZ	RICARDO PRAGUE S.R.O.
15.1	RIC-DE	RICARDO GMBH
16	UNR	UNIRESEARCH BV
17	ZF	ZF CV SYSTEMS HANNOVER GMBH
18	ALI	ALLIANCE FOR LOGISTICS INNOVATION THROUGH COLLABORATION IN EUROPE
19	DPD	DPD (NEDERLAND) B.V.
20	COL	ETABLISSEMENTEN FRANZ COLRUYT NV
21	GRU	GRUBER LOGISTICS S.P.A.
22	GBW	GEBRUEDER WEISS GESELLSCHAFT M.B.H.
23	PG	PROCTER & GAMBLE SERVICES COMPANY NV
23.1	PGP	PROCTER AND GAMBLE POLSKA SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA
23.2	PGA	PROCTER & GAMBLE AMIENS
24	PRI	PRIMAFRIO CORPORACION, S.A.
25	PTV	PTV PLANUNG TRANSPORT VERKEHR GmbH
26	Fraunhofer	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV

27	HAN	STICHTING HOGESCHOOL VAN ARNHEM ENNIJMEGEN HAN
28	IDI	IDIADA AUTOMOTIVE TECHNOLOGY SA
29	TNO	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO
30	UIC	UNION INTERNATIONALE DES CHEMINS DE FER
31	CFL	CFL MULTIMODAL S.A.
32	GSS	Grupo Logistico Sese
33	HIT	Hitachi ABB Power Grids Ltd.
34	IRU	UNION INTERNATIONALE DES TRANSPORTS ROUTIERS (IRU)
35	RIC-UK	RICARDO CONSULTING ENGINEERS LIMITED

Disclaimer/ Acknowledgment

Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the granting authority can be held responsible for them.

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13 Appendix A – Review of tools generated during previous EU funded projects

13.1 LONGRUN

LONGRUN focused on the development of efficient and sustainable long-distance powertrains for heavy duty trucks and coaches. A simulation platform was also developed to support the design and the development of the powertrains.

In the WP1 of LONGRUN two tools were developed that are relevant to the ZEFES project: LONGRUN LCA tool – with focus on Carbon footprint and energy consumption and the LONGRUN simulation platform to calculate the energy consumption.

13.1.1 LONGRUN LCA calculation tool

Tool developed to perform a Life Cycle Assessment (LCA) evaluating fuels (1), focussing on the production (Well-to-Tank) and the tailpipe (Tank-to-Wheel) emissions. Recommendations are formulated on which fuel pathways are the most efficient in terms of total energy consumption and greenhouse gas reduction. The LCA will furthermore take into account Electricity (2), ICEs & Electric-Motors (3), Fuel Cells (4), Batteries (5), Storage of hydrogen (6), as well as the rest of the Vehicle (7). This LCA thus also compares the embedded CO2 emissions associated to the production and disposal of the most relevant components, including battery electric vehicles.

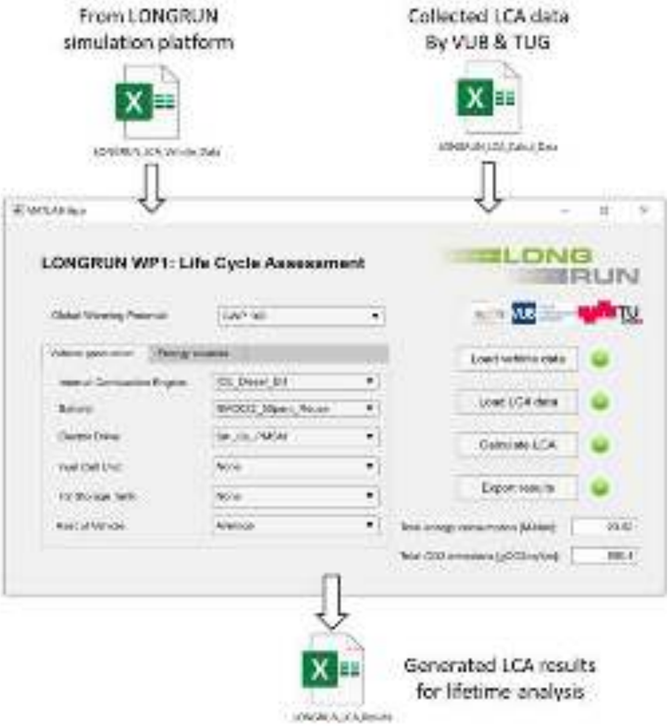

Figure 36 – LONGRUN LCA tool process

13.1.2 LONGRUN Simulation Platform

Tool developed to calculate energy consumption and CO2 emissions of the vehicle using conventional, electric and hybrid powertrain. The powertrain technologies that are not covered by VECTO version will be covered in this tool:

- Parallel Hybrid P2
- Parallel Hybrid P4
- Series Hybrid
- ICE based platform to validate against VECTO

13.1.3 Eco-routing

Cloud hosting connected services by IFPEN were integrated into the multiscale simulation LONGRUN platform to assess the benefits.

Intelligent routing strategies were developed using the detailed topology, real-time traffic, weather, and infrastructure. Energy and/or time optimal routes were proposed to the driver based on the parameters, therefore mission appropriate route can be selected.

Range Estimation:

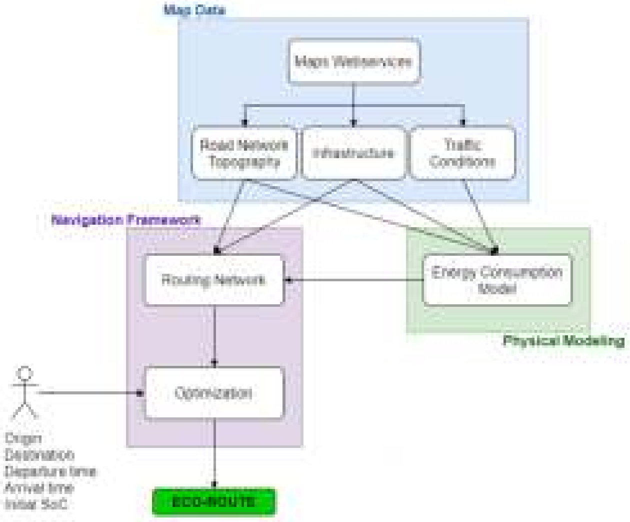

Figure 37 – LONGRUN Eco-routing methodology

13.2 CEVOLVER

CEVOLVER project relied on the OPTEMUS project.

13.2.1 Eco-routing and range estimation (2.1)

The eco-routing predicts an energy efficient route based on data from external web-services, which provide live information about traffic status. Several constraints can be taken into account such as travel time, battery state of charge (SoC) or point of interest (POI), among many others. A simplified vehicle model and speed profile are used in order to compute the energy consumption of every route segments contained in the area of interest, considering the actual traffic situation. The overall architecture of the eco-routing strategy consists of three main blocks: (1) the acquisition of road network and traffic data, (2) the vehicle consumption model, and (3) the energy-optimal navigation algorithm.

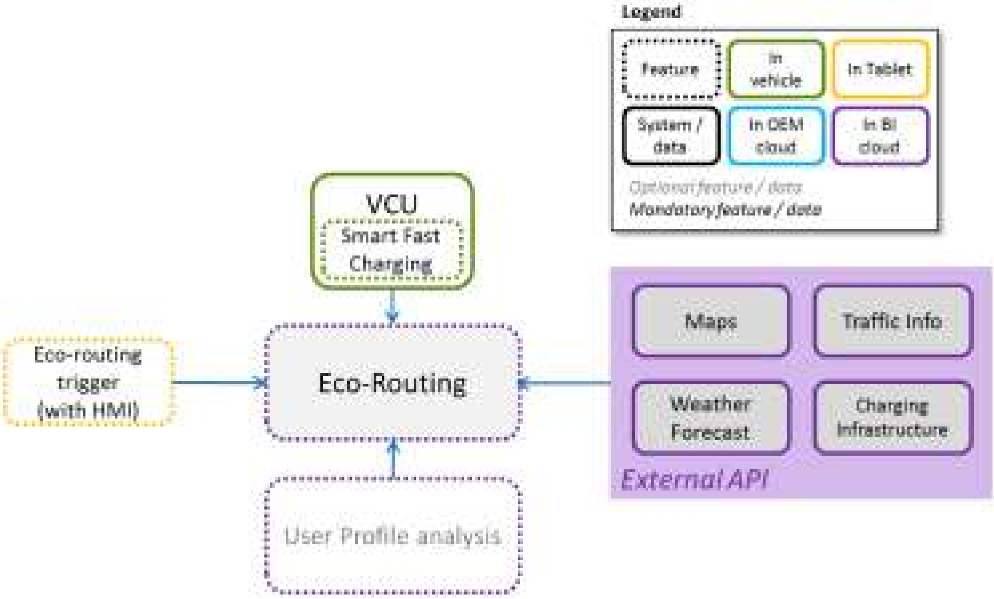

Figure 38 – CEVOLVER Eco-routing methodology

13.2.2 Eco-driving connectivity interface

In the project, the proposed eco-driving algorithm will compute an optimal speed profile according to energy consumption taking into account:

- The variability of speed limits along the route due to its topology (curvatures), or weather constraints (rain, snow, …), minimum legal speed limit
- The surrounding traffic that will constraint vehicle position on the route
- The e-powertrain constraints during derating operation, preventing extra vehicle loads
- The infrastructure constraints (traffic lights)
- The thermal management request (e.g. driving slower for optimal pre-conditioning of the battery for fast charging)

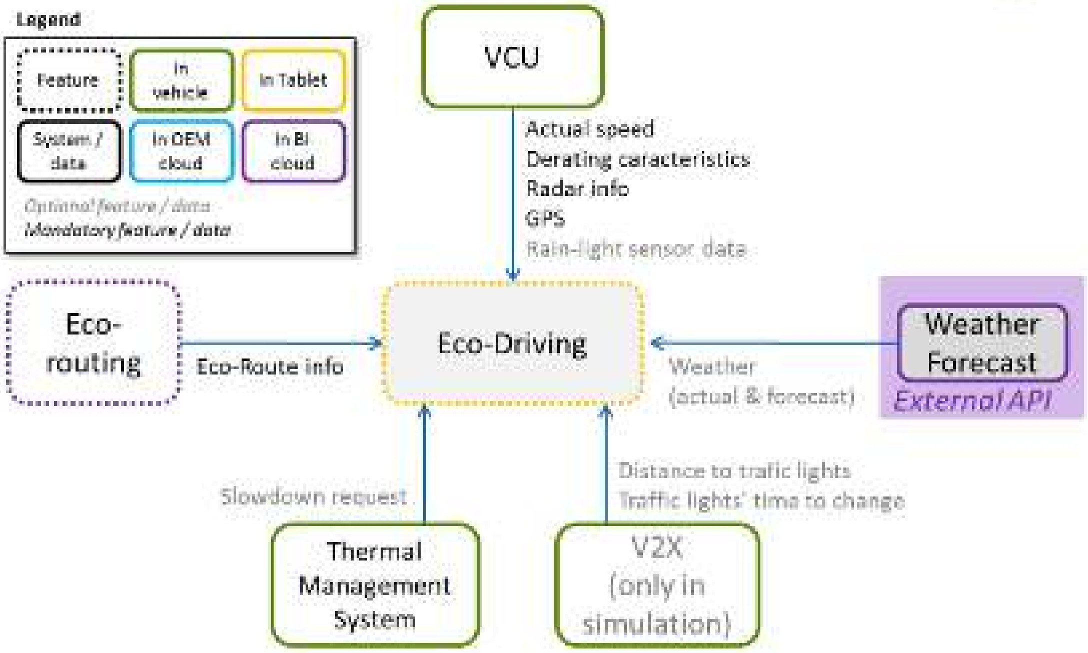

Figure 39 – CEVOLVER Eco-driving methodology

13.2.3 Connectivity

A tablet is used to handle the driver's input, to display information and to perform some of the CEVOLVER function such as the eco-driving and the eco-routing triggering. The CCU is an electronic Connectivity and Control Unit proposed to connect the vehicle with the outside world and provides data content from different data sources to other control units. The OEM cloud provides a direct connection to the vehicle's CCU, hosts proprietary services, and acts as a gateway to CEVOLVER services. The BI cloud provides neutral access to third party data providers and provides computing resources for heavy-duty computations.

Possible paths:

- Tablet <> CCU <> OEM cloud <> BI cloud
- Tablet <> OEM cloud <> BI cloud, if no CCU is implemented
- Tablet <> BI cloud, if OEM has no cloud infrastructure

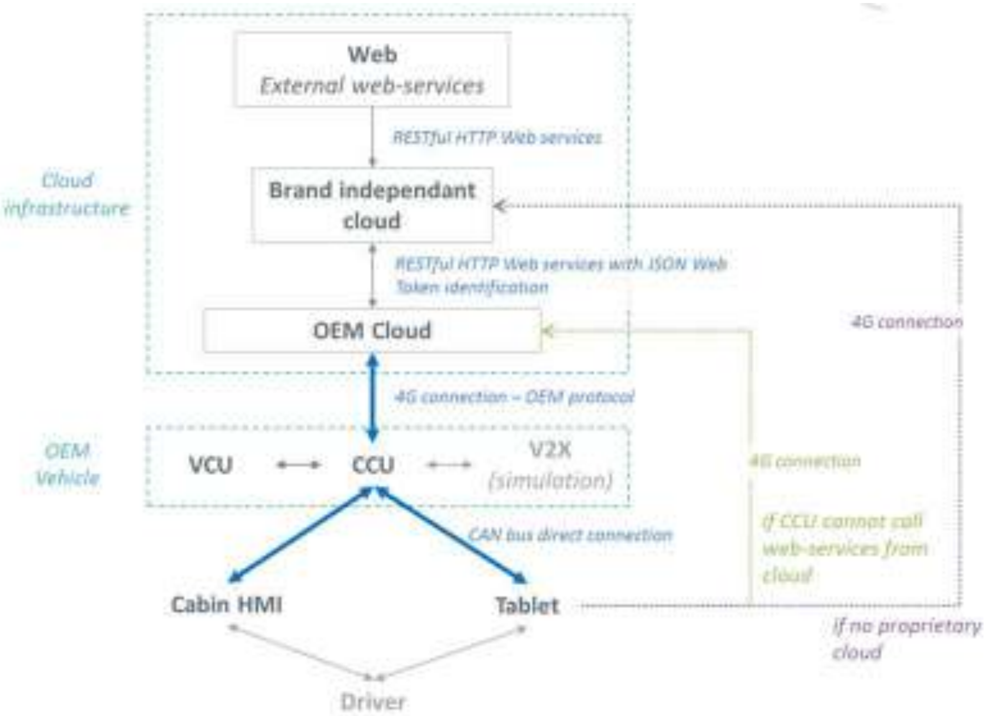

Figure 40 – CEVOLVER system connectivity

13.2.4 Road network information

- Road network information. Attributes obtained from HERE databases are:
  - linkID
  - Speed limit
  - Traffic flow average speed
  - Free flow speed
  - Link length
  - functional class (road type)
  - List of longitude/latitude/elevation
  - Termination of the link (traffic light, stop road signs, etc.)
  - Road roughness
- Weather information. Forecast weather description:
  - Temperature
  - Atmospheric pressure
  - Solar irradiance
- Traffic information
- Traffic events
- Charging point locations

13.2.5 VCU

Transfer rates between the OEM and the BI cloud:

- **Mass** estimation (vehicle + load) is evaluated at the beginning of the trip or after a long trip. It is sent when the eco-routing is triggered.
- **Current vehicle GPS/ timestamp/ speed** are acquired at 1 Hz and sent at the end of the trip or when the eco-routing is triggered.

- **Battery voltage/ current, and state of charge** are acquired respectively at 5 Hz and 0.1 Hz, and sent at the end of the trip (for data analysis) or when the eco-routing is triggered.
- **Battery state of health** is acquired once during the trip or at a regular distance interval accordingly to the SoH dynamic.
- **Vehicle class** used by the fleet statistics is sent when the eco-routing is triggered.
- **Cabin information** (current temperature air flow and humidity) is acquired and sent when the eco routing is triggered
- **Information about leading vehicle** (distance, speed) is used by the eco-driving feature if the car has a Lidar, Radar or front camera equipment. It is acquired at 1Hz.

13.3 AEROFLEX

The technical baseline for AEROFLEX includes other EC-funded research projects such as TRANSFORMERS, CONVENIENT, ECOCHAMPS and FALCON

One of the key targeted areas for the project is the European freight transport market for 2035: the drivers, the constraints, the trends, and the mode and vehicle choice criteria.

13.3.1 Assessment Framework

Assessment framework was developed to compare the AEROFLEX innovations on different vehicle configurations and different routes. And assess their fuel efficiency.

Requirements of the final technical assessment, the focus within in the technical assessment is on the fuel efficiency, how many litres required to drive the vehicle for one kilometre(l/km) or to move one tonne of payload for one kilometre (l/tkm)

Efficiency:

- The assessment framework should enable the calculation of fuel consumption in litres of fuel
- The assessment framework should enable the calculation of travel distance in kilometres
- The assessment framework should enable the calculation of travel time in hours

Typical European long-haul transport applications:

- The assessment matrix should consist of selected use-cases for typical long-haul road transport in Europe, representing at least major goods categories and applications.

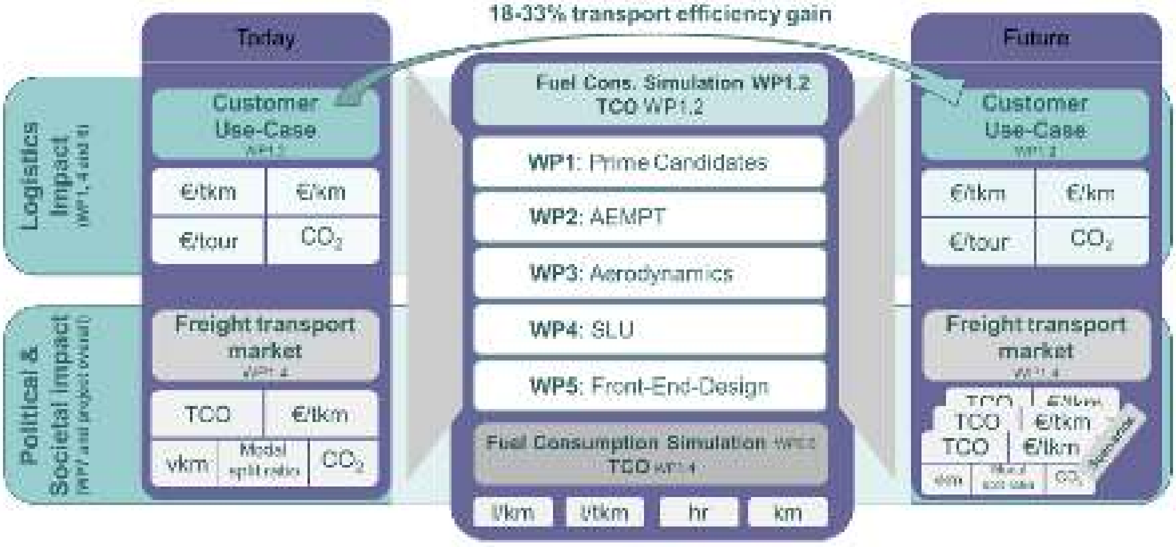

Figure 41 – AEROFLEX WP1 vehicle attribute prediction methodology

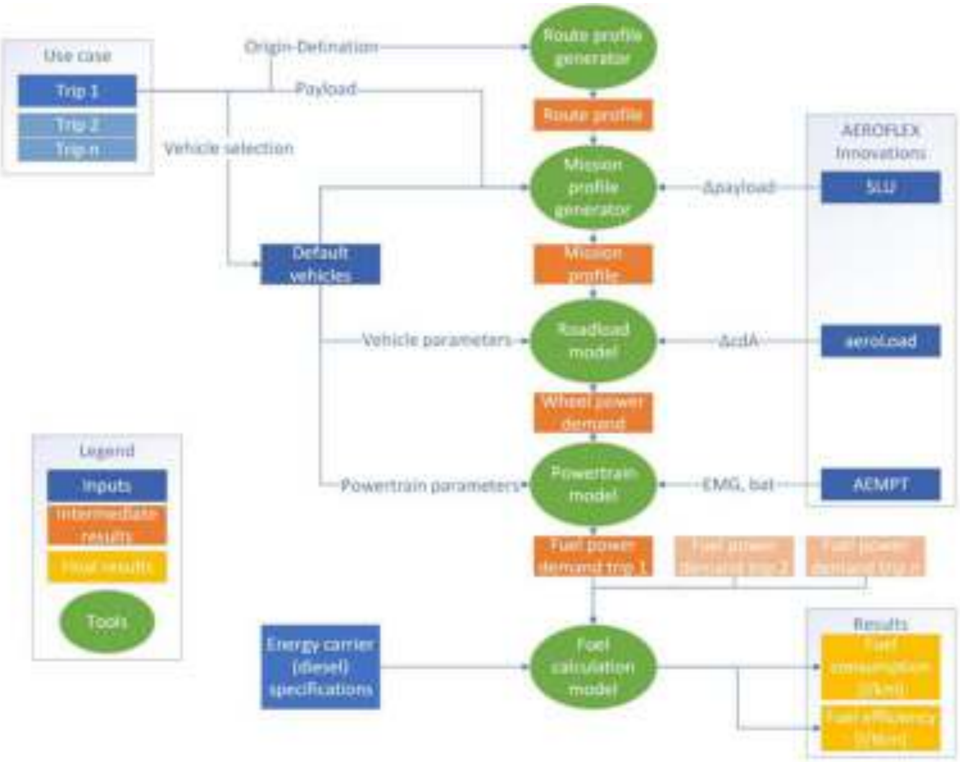

Figure 42 – AEROFLEX fuel consumption simulationmethodology

13.3.2 AEROFLEX – Advanced Energy Management Powertrain (AEMPT)

AEMPT consists of Global Energy and Torque Management System, the Smart Power Dolly (SPD) an electrically driven tow-axle dolly and a semi-trailer with an electric drivetrain, originally developed in the TRANSFORMERS project.

13.3.3AEROFLEX - WP1

Work package 1 has the task to map and quantify load in EU and potential for configurable truck. One of the deliverables is to calculate the impact of EMS on CO2 emissions on the EU freight transport market.

KPI to describe the potential for AEROFLEX innovations on the physical internet (PI):

- Cost (Euro)/tkm
- Cost/tour
- CO2 – TTW
- CO2 - WTW

Methods used:

Following the Global Logistics Emissions Council (GLEC) Framework , tools for delivery tour simulation and total cost of ownership (TCO) calculation were used to calculate the KPI values of selected prime candidates and related future increase in transport efficiency by European Modular System (EMS) vehicles.

Macroscopic freight model DEMO-GV for German transport was used.
The model DEMO-GV imports the data of average load factors and average transport costs (distinguishing between time and distance related costs) for every vehicle-type. Given the higher capacity of EMS 1 and EMS 2 vehicles, there are reduced costs per transported ton and a higher average load factor.

DEMO-GV is a six-step model, including the following steps:
(I) freight generation,
(II) distribution,
(III) transport costs,
(IV) utility,
(V) modal split related to transport modes (except air transport, pipeline, maritime and short sea shipping), and
(VI) mean split on road.

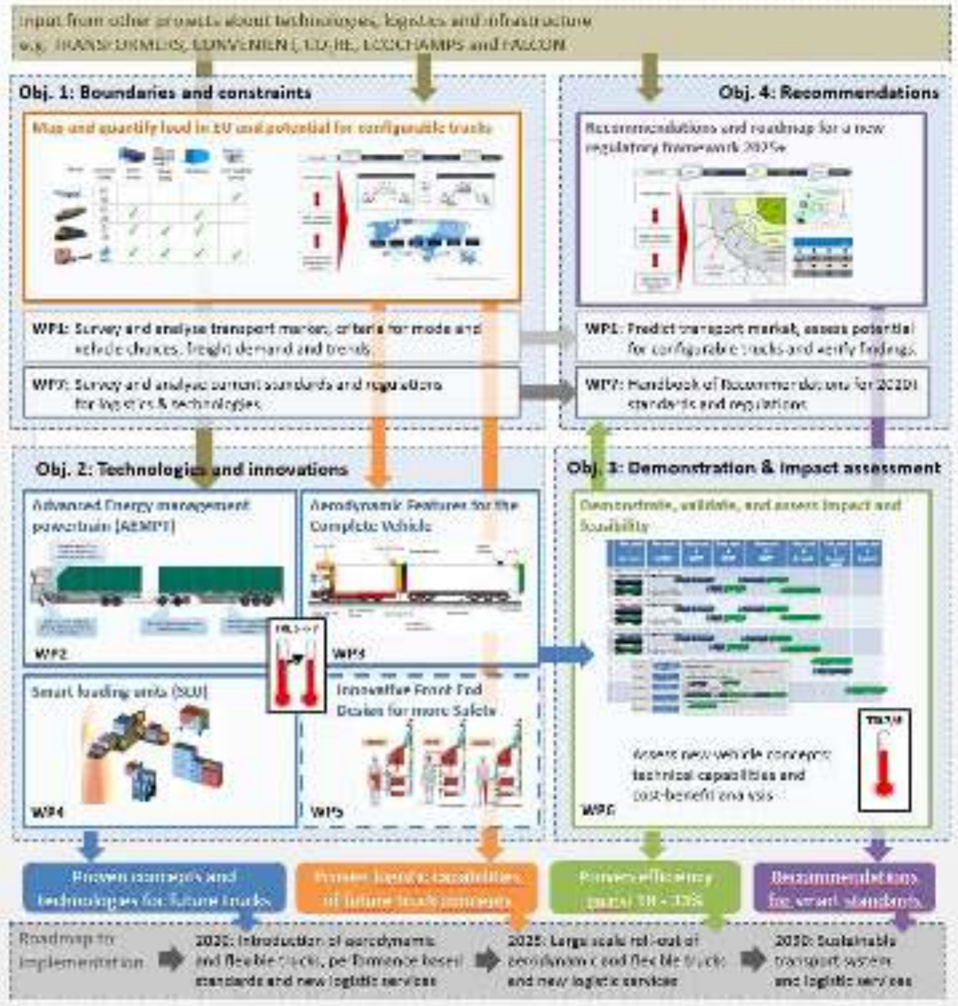

Figure 43 – Overall TRANSFORMERS project approach

14 Appendix B – Review of vehicle simulation models generated during previous EU funded projects

14.1 Summary of the ORCA Vehicle simulation platform

Generally, ORCA library consists of 2 types: open models and closed model. Both types of model require the accessible Matlab files containing component parameters. The closed model uses protected s-function file to protect the intellectual property (IP) of ORCA partners. In order to use easily the closed model, the interface signal and required signal in sensor bus are discussed in advance and agreed by ORCA partners. These different models and subsystems (operational system, powertrain system, waste heat recovery system, and thermal system) are merged together to form a simulation model as shown in Figure 44.

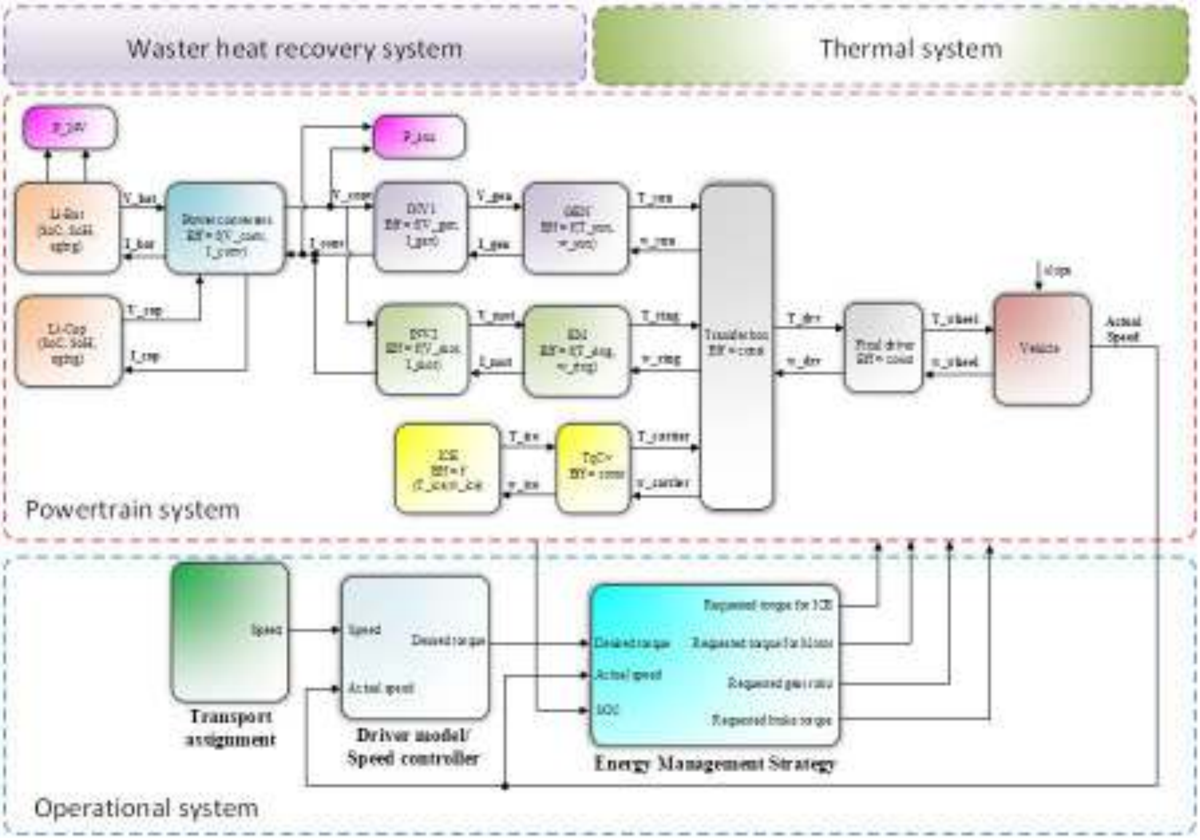

Figure 44 – Interconnection of sub-systems in the ORCA simulation model

For powertrain system, the electrical and mechanical models are developed by a forward-facing approach in Matlab-Simulink 2015b with the sampling time 0.1 seconds. The Matlab-Simulink simulation program of the hybrid VOLVO truck is illustrated in Figure 45. For each component model in the library, there is a corresponding parameter file associated to the model. The parameter file contains all parameters that should be initialized before the simulation run-time. If a component model is included in a powertrain model, the good practice is to copy the corresponding parameter file and modify the parameters according to the studied component. All the models are described in the different sections below.

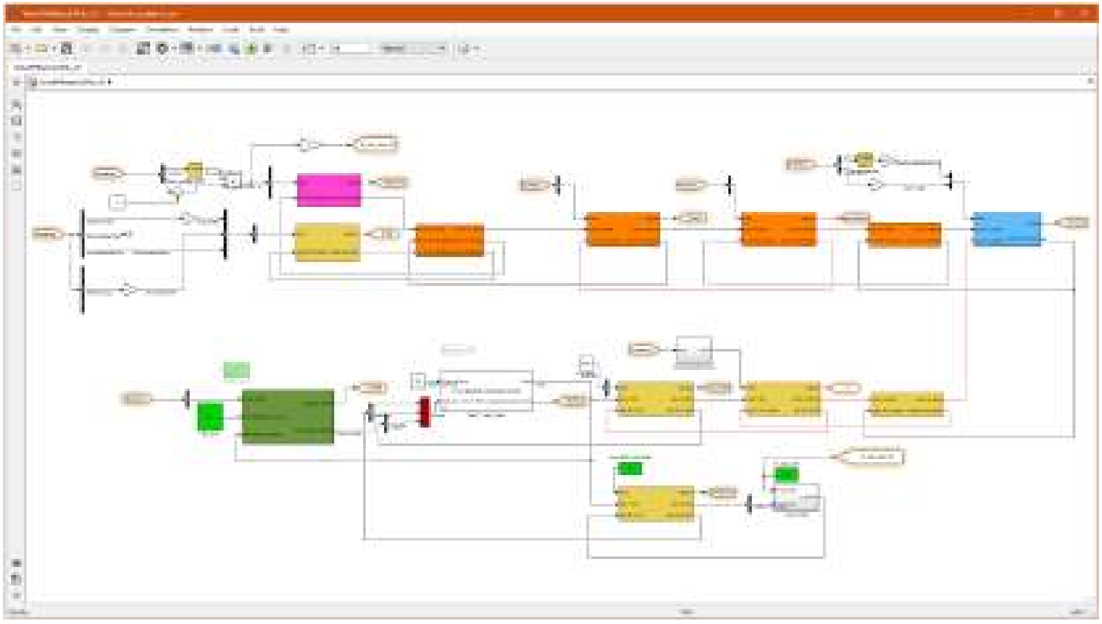

Figure 45 – Matlab-Simulink simulation program of the hybrid VOLVO truck powertrain forward model

Figure 46 shows the simulation results for a transport assignment of hybrid heavy-duty truck. A transport assignment for a distribution truck is generated to test features such as the energy content of the batteries, battery degradation, charging time, electric driving range and highway performance along with many other aspects. In between the driving shifts, battery is can be recharged from grid at a charging station. With each hardware combination (battery, EM, ICE), the control strategy in the hybrid mode is employed the Equivalent Consumption Minimization Strategy (ECMS) to minimize the operational cost.

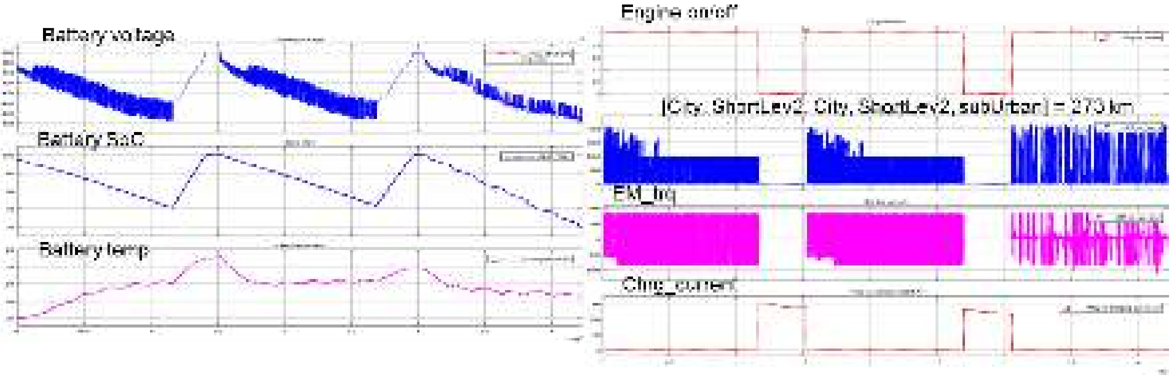

Figure 46 – Simulation result of a transport assignment for the Volvo distribution truck

14.2 Summary of the LONGRUN Vehicle simulation platform

The powertrain model block from the LONGRUN simulation platform follows forward-type vehicle modelling approach as same as ORCA with causal relationship, as shown in **Error! Reference source not found.**. The real-world cause-effect relation signifies that the drives or brakes the vehicle (drivetrain) through positive tractive or negative braking torque, and its speed in turn depends on the later.

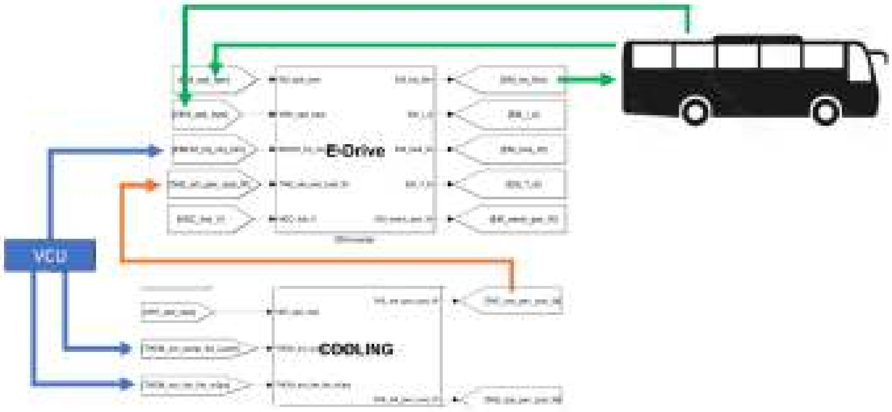

Figure 47 – Powertrain and cooling system interfaces

Aimed for system level simulations (0.01s step-size) the powertrain model block represents combined behaviour of the electric machine and inverter. The output torque of the eDrive is input to the gear box, reductor or wheel whereas rotational speed from these components is input to the eDrive. The eDrive outputs current drawn from the power supply (DC link, battery pack, fuel cell system, generator, etc.) in response to which it receives changing DC terminal voltage as the input. From the mechanical point of view, the eDrive features shaft friction, windage loss and rotational inertia to simulate close to real-world drivetrain behaviour. In terms of thermal aspects, the eDrive model is a zero dimensional lumped mass with ambient air cooling and liquid cooling. Electrically, the electric machine and inverter are represented by a combined electrical efficiency map (as shown in Figure 48).

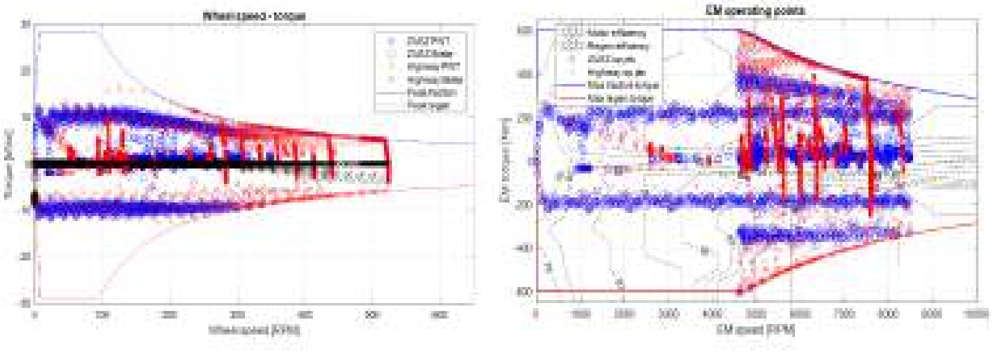

Figure 48 – eDrive and wheel operating points with brake blending

Cooling system modelling

For cooling, the eDrive block receives amount of heat being evacuated by the cooling system and outputs lumped mass average temperature. Vehicle speed is also an input to the eDrive model block to consider the effect of ambient airflow on eDrive body and its corresponding cooling effect.

The cooling system is modelled in a data-driven manner with representations for radiator heat evacuation based on fan air flow and pump coolant flow which are governed by their respective speeds. Auxiliary cooling power is also calculated using fan and pump operating speeds and their corresponding auxiliary load data. The cooling radiator performance is corrected for ambient temperature and if front mounted, the vehicle speed.

Control

Given the system level simulation approach (0.01s step size), the eDrive is controlled by a torque setpoint from the VCU. The torque setpoint is compensated for eDrive friction torque. The torque setpoint is controlled for safety functions such as speed limit, tractive and braking torque limits, eDrive derating in case of high temperature.

For following a desired heat evacuation rate, the cooling system is controlled by fan and pump speed setpoints from the VCU. These speed setpoints are calculated using optimal operating line of the given cooling system to minimize auxiliary load while achieving the desired heat evacuation (as shown in Figure 49)

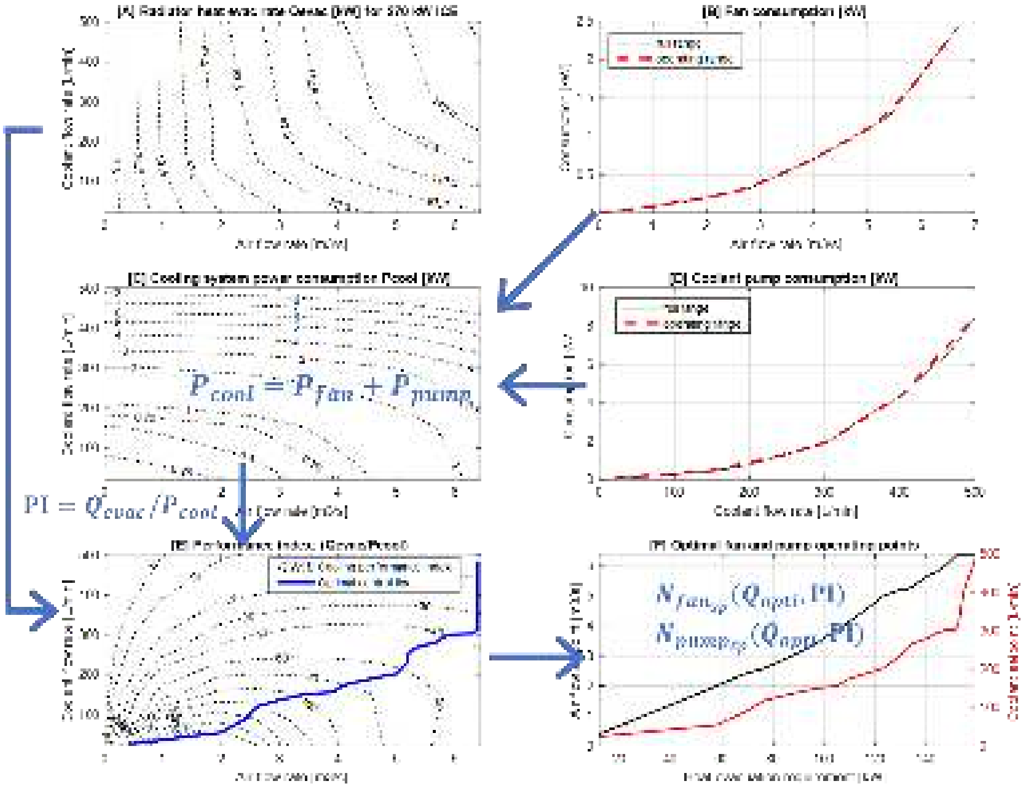

Figure 49 – Cooling system modelling and optimal control line

14.3 Summary of the ASSURED Vehicle simulation platform

A battery electric bus (BEB) is an electric vehicle (EV) that uses the electric motor (EM) and an energy storage system (ESS) in place of the internal combustion engine (ICE) as the source of tractive power in the vehicle’s powertrain. It is composed of the vehicle, the gears, the EM and inverter, the high-powered bi-directional DC-DC converter, and the energy storage system (ESS) in the traction system, as shown in Figure 50. The ESS can be battery-only or hybrid source, including both battery and supercapacitor. The same battery can be the energy source for both the tractive and auxiliary systems, or the auxiliary system can have a separate battery. The other part of the powertrain is the auxiliary system, composed of the auxiliary DC-DC converter, which is unidirectional, the heating, ventilation, and air conditioning system (HVAC), the various cooling fans, and other loads inside a vehicle. To complete the powertrain overview, there is also the charging system, which for larger EVs, like electric buses and trucks, are high-powered DC off-board fast chargers. The charging infrastructure consists of the electric grid, transformers, and the off-board chargers. The final part of the powertrain is the control system, that commands the energy flow between the tractive, the auxiliary and charging systems. The control system is composed of the driver model that commands the necessary torque and power from the EM required to track a given reference speed, the energy management system (EMS), the thermal management system (TMS), and the charging management system (CMS). The EMS is responsible the energy flow in the tractive powertrain, while the TMS directs the energy flow in the auxiliary powertrain, and the CMS directs the energy flow in the charging system. Finally, the powertrain model is designed to be modular and scalable to accept models of e-buses from different OEMs with different vehicle sizes, with batteries having different chemistries and capacities, with a wide range of PE power rating, and a scalable EM.

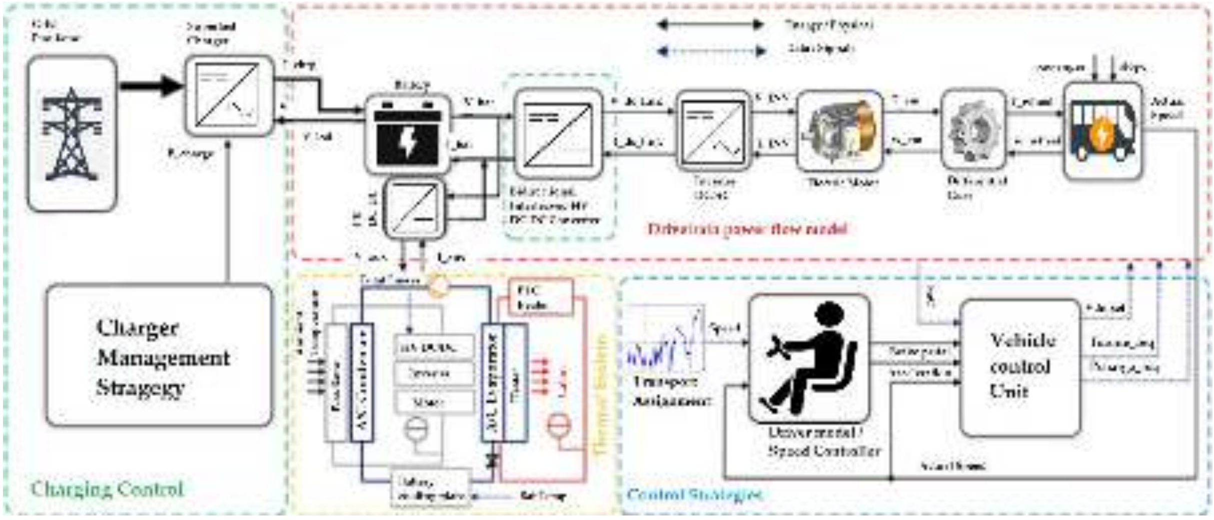

Figure 50 – Interconnection of sub-systems in the ASSURED simulation model

The completed powertrain model is shown in Figure 51.

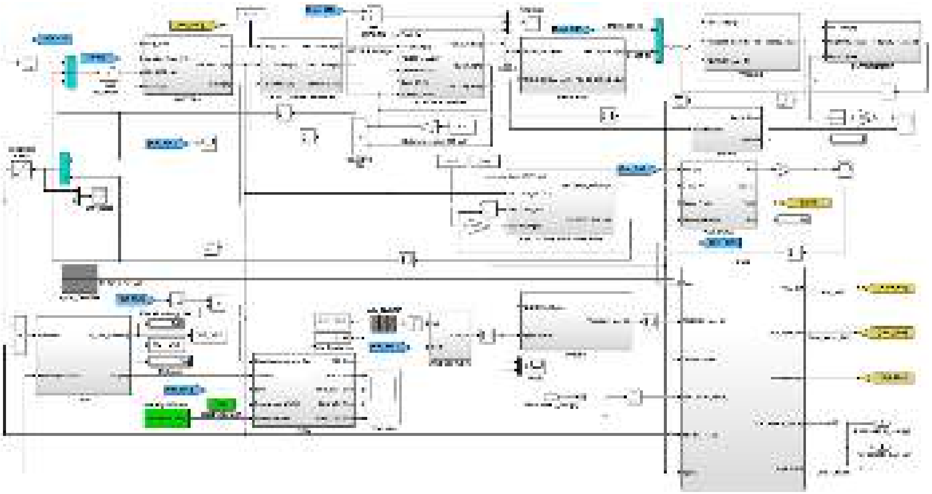

Figure 51 – ASSURED MATLAB simulation

14.4 Summary of the Cloud-Connected CEVOLVER Vehicle simulation platform

The vehicle simulation model has been designed for the CEVOLVER project using MATLAB/Simulink® and is basically a ‘Forward-facing’ model of an electric vehicle powertrain. In the CEVOLVER project, the Low-Fidelity (LoFi) map-based models are utilized, and to simulate the vehicle model, “Cevolver_base_vehicle.m” function needs to be initialized through a .mfile called the common parameters, which enables parameterizing the components according to the use cases. Initially, models were parametrized and calibrated with in-house data from the literature values or with OEMs’ component data. When more data from the components of the demonstrator vehicles were available, the models were reparametrized and calibrated to obtain a base vehicle model tuned to each demonstrator.

In CEVOLVER, the analysis of the vehicle powertrain is carried out based on a drive cycle or speed profile to which the vehicle is subjected during the operation. In the CEVOLVER simulation model, the desired vehicle speed input is fed into the driver model, which generates desired torque and brake commands. The torque command goes into the motor model, while the brake command first goes into the vehicle dynamics model. Afterward, the torque is translated into speed, with the required power that is discharged from the energy storage system. Component by component, this power flow is calculated forward through the drive train, considering losses. The final CEVOLVER vehicle model platform is shown in Figure 52.

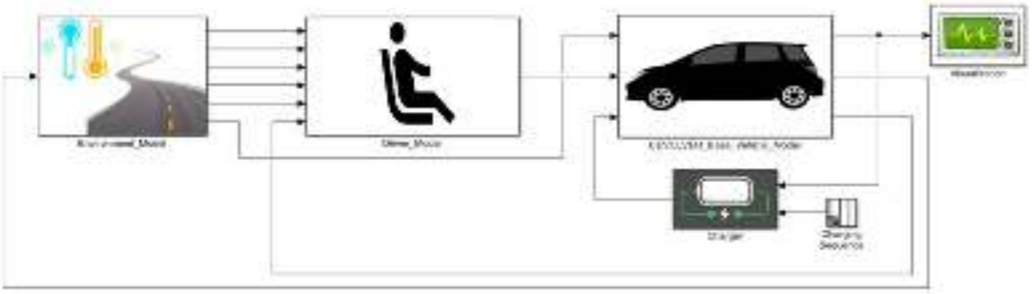

Figure 52 – Basic CEVOLVER vehicle simulation platform layout in MATLAB/Simulink®

An environment model was added to the base vehicle model in order to simulate the vehicle's surrounding driving conditions. That allowed testing the connected features with respect to their sensitivity and adaptability to exogenous impact factors. In CEVOLVER, the driver model interacted with the vehicle's environment to reproduce real driving conditions as closely as possible. The driver model was based on Gipps' car-following model and parameterized to fit with actual driving data.

To access the brand-independent cloud, authentication is required. Once the authentication data for using the brand-independent cloud has been entered, the simulation is launched. The user needs to select origin and destination coordinates on a map to run the simulation, which computes the eco-routing function for the route. After the chosen path is computed, information about the route, infrastructure, traffic, and weather forecast is received from the brand-independent cloud to the simulation through the environment model. Figure 53 depicts an exemplary long-haul trip simulation (~220 km) from Munich to Stuttgart. During the long trip, the vehicle stops charging three times (indicated by the yellow start mark).

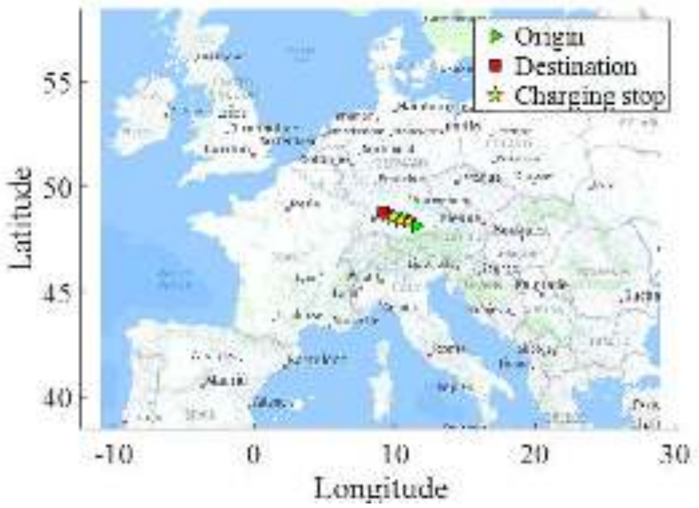

Figure 53 – Selected 200 km long trip for environment and driver simulation

Figure 54 presents the powertrain component's response during a long-haul trip. It shows the reference and controlled vehicle speed, instantaneous wind speed, battery temperature, battery SoC, battery power and mechanical wheel power and battery current. It can be seen from the figure that the estimated battery SoC reaches 57%, and battery temperature remains close to 250C within the 2.5 0C boundaries after a 220 km long-haul trip, which ensures a proper eco-routing, charging, and thermal strategy throughout the expedition.

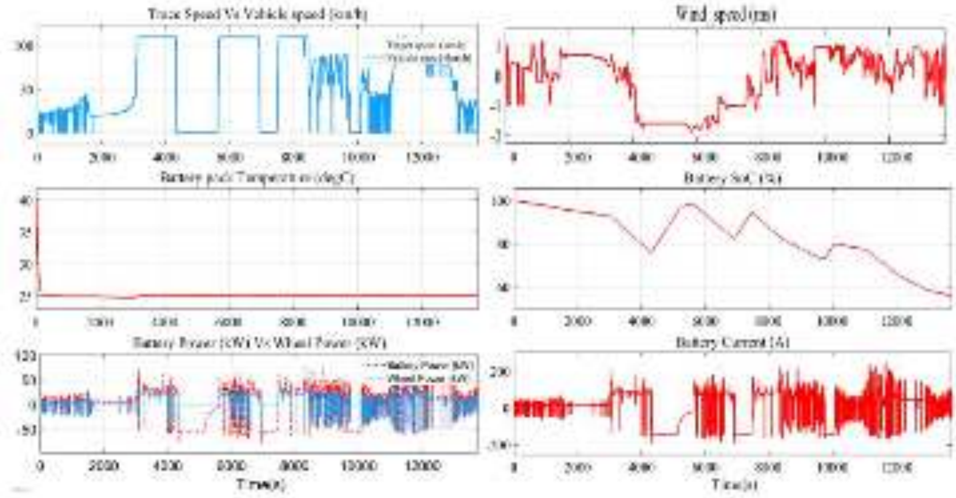

Figure 54 – BEV response during a 200 km trip from Munich to Stuttgart

Finally, validation of the estimated battery SoC from the vehicle platform was matched with respect to vehicle telematics data, and a high goodness of fit was found for two different trips at two different locations, as shown in Figure 55.

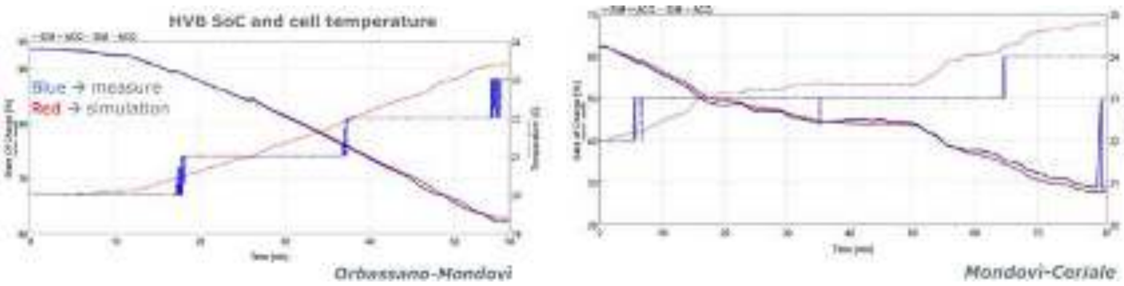

Figure 55 – A higher goodness-of-fit: simulation platform and telematics data for two different trips