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

ZEFES - Deliverable report

D2.7
Design of the interface between e-trailer and prime mover

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Author(s)	Henning Wittig (FHG) Gerd Schünemann (ZF) Reinhard Schmid (AVL)	
Checked by	Jordi Plana (IDI)	2024-05-30
Reviewed by (if applicable)	Emre Kurt (KAE) Johanna Axelsson (VOL)	2024-05-24
Approved by	Omar Hegazy (VUB) – Project coordinator	2024-05-30
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Publishable summary

Europe's commitment to be the first CO2-neutral continent by 2050 is going to impact the road transport industry, in part by requiring massive investments. To achieve EU CO2 reduction goals, research, policy, technology, and industry need to cooperate and ensure a smooth transition to ZE-HDVs. This objective requires that manufacturers of heavy-duty vehicles (HDV) deliver more efficient vehicles: a reduction of CO2 emissions for the newly produced fleet of 15% in 2025 and 30% in 2030. The use of zero tailpipe emissions vehicles (ZEV) for long distance heavy transport is an important part towards achieving the above targets. Such ZEV are Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs).

The use of truck-trailer-combinations with distributed powertrains, meaning different parts of the combination contain single powertrains or range extenders in terms of additional energy storage units, is one potential solution to reach the objectives stated above. This deliverable presents the development of a concept for an interoperable interface for communication and control purposes between the prime mover and the electrified trailer (e-trailer). Interoperability means the e-trailer is interchangeable between the prime movers of different OEMs, even if it is a vehicle with an ICE.

After the introduction of the concepts of an e-trailer and the interface to be developed, possible solutions of the interface that have been investigated in former R&D projects or by industrial companies. Furthermore, the e-trailer functionality to be controlled and the framework conditions for the application of the e-trailer in the ZEFES project and beyond are analysed. Based on this background the interface design process is presented, the interface realized in the project is described and an outlook for future development of a vehicle-to-vehicle interface is given.

For the development of a suitable interface between the prime mover and the e-trailer, different possibilities for realisation have been examined. The minimal interface is purely given via physical quantities. The e-trailer detects the need for positive or negative torque support based on measured driving status and environmental conditions. Necessary additional information exchange and related solutions were evaluated and realized. With this the minimal interface between prime mover and e-tailer was identified and will be validated within ZEFES. This results in a maximum of virtual interfaces for the interplay between the vehicles, supplemented by a minimum of data signal interfaces.

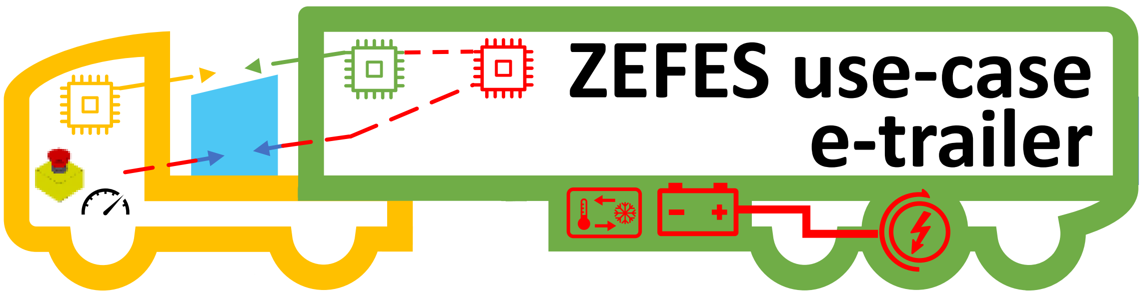

Figure 1-1: Interface between e-trailer and prime mover used in the ZEFES project

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Abbreviations & Definitions

Table 1-1: Abbreviations

Abbreviation	Explanation
AAEMP	AEROFLEX Advanced Energy Management Powertrain
AC	Alternating current
ACC	Adaptive cruise control
BEV	Battery electric vehicle
BMS	Battery management system
CO2	Carbon dioxide
DC	Direct current
EBI	Endurance brake integration
EBS	Electronic braking system

Abbreviation	Explanation
ECU	Electronic control unit
EMG	Electric motor/generator (e-drive)
EU	European Union
FCEV	Fuel cell electric vehicle
GETMS	Global energy and torque management system
HDV	Heavy duty vehicle
HEV	Hybrid engine vehicle
HoD	Hybrid-on-Demand
HRS	Hydrogen refuelling stations
HV	High voltage
ICE	Internal combustion engine
LV	Low voltage
LSM	Local system management
OEM	Original equipment manufacturer
PHEV	Plug-in hybrid engine vehicle
PECC	Predictive Economic Cruise Control
R&D	Research and development
SOC	State-of-charge
TEBS	Trailer Electronically controlled Braking System
TCO	Total costs of ownership
TDMS	Trailer Drivetrain Management System
TPMS	Tire pressure monitoring systems
VC	Verification criterion
VCA	Voltage class A (According to ISO 6469-3:2021 maximum working voltage 60 Vdc or 30 Vac)
VCB	Voltage class B (According to ISO 6469-3:2021 working voltage between 60 Vdc and 1500 Vdc or between 30 Vac and 1000 Vac)
VCU	Vehicle control unit
ZE	Zero emission
ZEFES	Zero Emission flexible vehicle platform with modular powertrains serving the long-haul Freight Eco System
ZEV	Long-haul zero emission vehicles

Table 1-2: Definitions

Item	Definition
b-trailer	Trailer with no driveable wheels but a traction battery which can be coupled to the towing vehicle.
e-trailer	Trailer with at least partial driveable wheels powered by a traction battery located in the trailer
O3/O4 trailer	Trailer with a maximum mass exceeding 3,5 tonnes as defined in EU directive 2007/46/EC

1 Introduction

Distributed powertrains in truck-trailer vehicle combinations are one possible solution to fulfil the needs of ZEV in the freight eco system. On the one hand, the sense and purpose of using an e-trailer is to store energy which cannot be used immediately or is recuperated. On the other hand, the e-axle of the e-trailer can either recuperate energy and simultaneously avoid braking losses or support the acceleration process of the towing vehicle. One goal of the project is to develop a standardized connection and control interface between trucks and so-called e-trailers. It includes the physical connection and the communication protocols between controllers of truck and e-trailer. If the standardized interfaces are used and kept, every e-trailer can be connected to any truck. The batteries of e-trailers are charged externally as well as by recuperation. They have stand-alone controllers for the driven axle, the battery, and the cooling system. However, the realized positive or negative torque must be in line with the driver demand or the driver assistance system's demand. Under any circumstances of regular driving, the e-tailer must remain a towed vehicle, with no additional pushing to the truck. Special emphasis will be given to (functional) safety aspects.

The activities described in this deliverable support the implementation of the verification criterion VC8: Developed connection for controlling the traction and recuperation from the trailer (e-trailers) […], suitable for prime movers of all original equipment manufacturers (OEMs). This is also valid for all vehicles which are driven by an internal combustion engine (ICE):

For the development of a suitable interface between the prime mover and the e-trailer, different possibilities for realisation have been examined.
The minimal interface is purely given via physical quantities. The e-trailer detects the need for positive or negative torque support based on measured driving status and environmental conditions. The next step is to consider also signals from existing data connections between truck and trailer. Up to this point, a compatibility to existing OEM prime movers is given for all kind of vehicles (ICE, BEV, FCEV).
The realisation of the practical use case in ZEFES starts with this simple “plug and play to any vehicle target” as described in section 2.1.4 “e-trailer with stand-alone powertrain management”. Necessary additional information exchange and related solutions are evaluated and realized. With this the minimal interface between prime mover and e-tailer is identified and validated within ZEFES. This results in a maximum of virtual interfaces for the interplay between the vehicles, supplemented by a minimum of data signal interfaces.
Finally, this report also gives an outlook and evaluates the possibilities of additional standardized physical connections and control interfaces.

For ZEFES only one towed vehicle with an electric axle after a towing vehicle is in scope. An extension to enable several electrified towed vehicles (e-trailer and/or e-dolly) after one towing vehicle is thinkable but can further investigated outside ZEFES. At least the e-dolly + e-trailer combination is referenced in the paragraph addressing the concept solution in a previous of EU project called AEROFLEX.

1.1 Description of e-trailer

An e-trailer is a trailer with at least partially propelled wheels. An e-axle consisting of an inverter, an electric motor/generator and a (switchable) transmission is a common solution, but the drive technology is not limited to an e-axle. Wheels could for example also be driven by a central drive or wheel hub motor, both in combination with inverters and transmissions. Furthermore, the powertrain consists of batteries serving as energy storage system and a cooling system. The powertrain is equipped with its own electronic control unit (ECU) to ensure the operation of the e-trailer. Subsystems like the cooling system are fully incorporated, hence there is no need for external control. Conditioning of the temperature of the battery or the e-drive consisting of inverter and motor is done by the system. A detailed description of the design of the system is not given in this deliverable as there is a big variety possible.

From the perspective of the towing vehicle the processes in the e-trailer powertrain are not relevant. For example, temperature conditioning of the e-trailers' batteries can be mentioned. Especially in stationary processes, like power up at low temperatures, the battery temperature can be outside the target range, which effects the current that can be drawn of it. Depending on a logic in the battery management system (BMS) of the e-trailer, values for maximum drawable currents are modelled. The e-trailer ECU uses the information for constantly calculating the performance/capability parameters of the powertrain. These parameters can be reported to e.g. the powertrain management of the prime mover. Whether the performance/capability parameters are limited by a fixed value based on fuses or cables, by values of the battery in optimal conditions, by derating of the drawable current caused by low temperatures like in the example or other reasons, are not of importance for other systems outside the e-trailer.

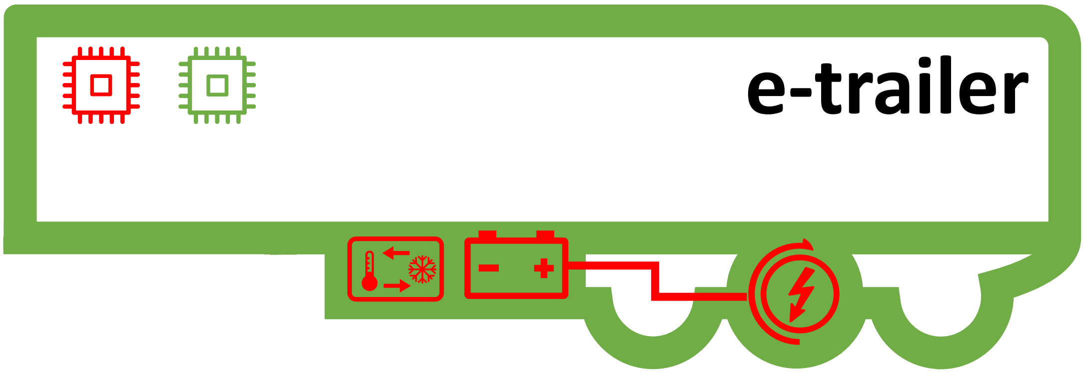

Figure 1-1: Main powertrain components of the e-trailer

Figure 1-1 shows the main powertrain components of the e-trailer. Although it is illustrated as a semi-trailer, the e-trailer can be understood as any kind of trailer or dolly. Also, combinations with more than one trailer behind a towing vehicle are possible for future applications.

1.2 Description of e-trailer interface

An interface refers to a point of interaction or communication between different systems.

For the interface between the e-trailer and the prime mover, we distinguish between two types of interfaces:

1. The interface between the towing vehicle and one e-trailer are attached to it.

2. The interface between the following e-trailers and the previous vehicle combination consists of at least one e-trailer.

This is important as if there is just one e-trailer in the combination, no kind of summarization or dividing is necessary. The deliverable focuses on the interface between the towing vehicle and the first e-trailer. If there are additional vehicle units between the towing vehicle and the e-trailer, like in an EMS 1 vehicle combination consisting of a rigid, a standard converter dolly and an e-(semi)trailer, the interface connection must be forwarded by the dolly.

In terms of interfaces there are various possibilities:

- Mechanical interface like saddle plate and kingpin for semi-trailers or trailer-coupling for standard trailers
- Pneumatic interface for supplying and activating the pneumatic brakes of the trailer from the towing vehicle.
- Low Voltage (LV) & Communication interface as standard in truck-trailer-combinations as needed for lights of the trailer or trailer electronic braking system (EBS).
- E-trailer communication interface

Beside the physical interfaces there is also a logical interface between the vehicle units. This logical interface describes the interplay between the prime mover and the e-trailer due to the kinematic characteristics of the vehicle combination. The deliverable focuses on the e-trailer interface. The interface design does not negatively influence the standard interfaces between prime mover and trailer and does only extend the existing signals.

In terms of interfaces the term VCA is used to describe the interface or connector. VCA stands for voltage class A and defines the range for voltage according to ISO 6469-2:2021. As shown in the illustration of the e-trailer in Figure 1-2, there is no dedicated power connection for transferring traction energy via the external interface of the e-trailer. Electric energy can't be transferred between truck and trailer. No Voltage Class B (VCB) connection, which covers all applications where high voltage (HV) is used, is part of the solely e-trailer concept and separates it from the b-trailer concept.

Recharging the battery of the e-trailer can either be done by recuperating during brake sequences of the vehicle combination, or recuperating while the truck is towing the e-trailer, or external charging during parking of the e-trailer. Details about the realization in ZEFES and in a general point of view will be handled in chapter 3.

Figure 1-2: Interface between e-trailer and prime mover

The colours in Figure 1-2 indicate the purpose of the subsystems.

Yellow for the towing vehicle, green for the basic trailer, red for items specific for e-trailers and blue indicating the e-trailer interface. All other interfaces like the pneumatic are not illustrated.
We focus on the partial red coloured controllers of towing vehicle and trailer. In the trailer there are functions which are controlled but not related to an e-trailer. The red part of the controller indicates that there are also e-trailer specific controller functions. The illustration does not indicate if the system consists of a single controller or use multiple controllers. The controller of the truck can be seen similarly. The red part indicates that by sharing data of the truck the control strategy can be optimized. This must be seen as an add-on. If there is no information from the truck, this is not hindering the basis functionality of the e-trailer. This is one important fact as otherwise the vehicle combination would only work with specifically equipped trucks.

1.2.1 Description of e-trailer interface in the ZEFES use-case

Figure 1-3 illustrates the interface planned for the e-tailers as used in the ZEFES use cases. No special e-trailer control functions are implemented in the system of the truck. The e-tailer operates “stand-alone” as described in chapter 1. Potential special interfacing is only related to the possibility of the driver to deactivate the e-tailer support and some basic e-tailer system information (e.g. SOC of e-tailer battery).

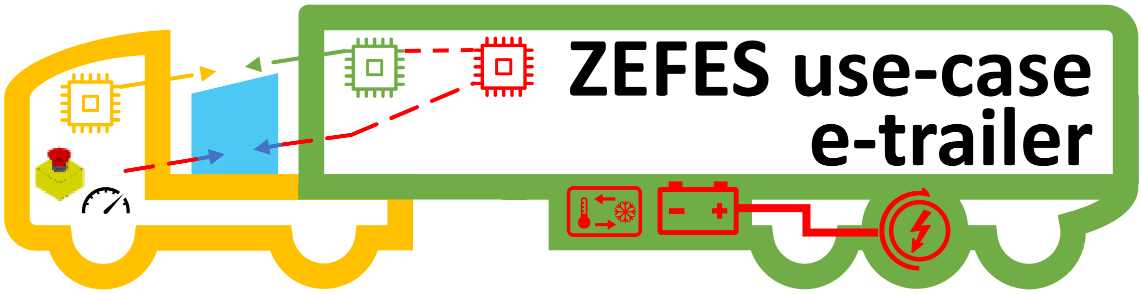

Figure 1-3: Interface between e-trailer and prime mover used in the ZEFES project

2 Background and Methods

2.1 State of the art e-trailer interfaces

Five different systems of e-trailers got identified in order to present current developments in research and market. The differentiation is made based on the communication between truck and trailer needed for controlling the system. Differentiations in terms of powertrain systems or its parameters are not distinguished in this segmentation.

First, the TRANSFORMERS Hybrid-on-Demand Trailer uses a combination of standardized ISO 11992-2 signals and ISO 11992-3 signals (Rev. 2007-09, AMD 1) to control the energy flows via the Trailer Drivetrain Management System (TDMS).

Another solution is represented by the AEROFLEX Advanced Energy Management Powertrain (AEMP). A central energy and torque management integrated in the vehicle control unit of the truck enables the distribution of torque requests to the driving axles of truck and trailers. The system is based on a sophisticated communication between the truck and the e-trailer via automotive ethernet (AE).

A similar concept is used by the e-trailer with integrated powertrain management that was tested by ZF. It also uses a central torque management located in the truck. In contrast to the AEROFLEX concept the communication between truck and e-trailer is based on the ISO 11992-2 EBS communication with an extended set of signals. These signals were introduced to the ISO standard in revision 2023-03.

To make the e-trailer retrofittable with conventional trucks already in the market, ZF also realized an e-trailer with stand-alone powertrain management. It only processes information available from the EBS (interfaced information by the truck as well as sensor evaluated information as wheel speed, weight, and inclination) and the corresponding e-trailer ECU distributes energy and torque to the driving axles. The advantage of this system is that any prime mover, even with outdated technology, can be used if ISO 11992-2 connections are available.

A similar system is represented by Trailer Dynamics / Krone e-trailer which is also an e-trailer solution without additional truck communication. This system uses a physical kingpin coupling force sensor, instead of the virtual coupling force computation by the ZF e-trailer. An updated system of the e-trailer with force measurement uses force sensors in the screws of the kingpin attachment instead of direct measurement of the kingpin as there are advantages in wear and robustness.

2.1.1 TRANSFORMERS Hybrid-on-Demand Trailer

The Trailer Drivetrain Management System (TDMS) controls the energy flow of and positive/negative torque requests to the e-axle in the trailer according to the current vehicle state and safety requirements [1]. As input information the TDMS uses a combination of ISO 11992-2 signals forwarded by the trailer EBS and ISO 11992-3 signals transmitted via a gateway in the truck and an additional connection (see **Error! Reference source not found.**). Thus, the Hybrid-on-Demand (HoD) Trailer is not completely retrofittable to a conventional truck.

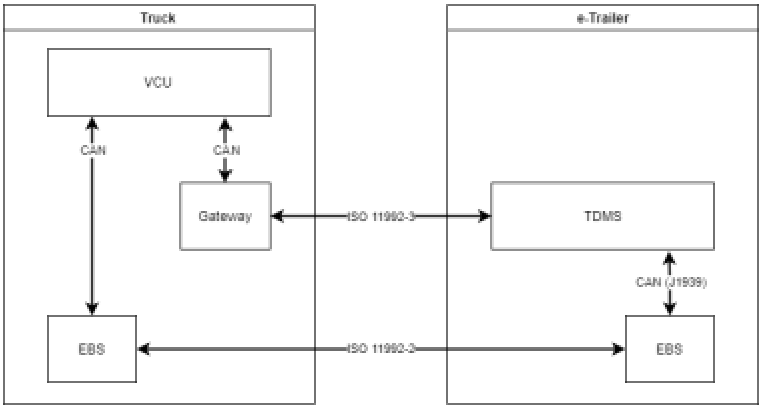

Figure 2-1: Communication system of TRANSFORMERS towing vehicle & Hybrid-on-Demand Trailer

The basic functions of the HoD-trailer are listed in Table 2-1. It includes the source that generates the request, the systems and interfaces that forward the request to the trailer and the systems that realize the request in the trailer.

Table 2-1: Energy & torque management functions of TRANSFORMERS HoD-Trailer

Function	Request	Forwarding	Actuation
Endurance brake blending: • Endurance brake requests in the truck are taken over by the trailer e-drive	• Retarder lever • Driver assistance system • Brake pedal + driver assistance system	• derived from truck actual retarder percent torque (ISO 11992-2)	• Retarder of the truck • EMG of the trailer
Service brake blending: • Service brake requests in the e-trailer are directed to its e-drive	• Brake pedal	• Trailer service brake demand value (ISO 11992-2)	• Service brakes of the trailer • Service brakes of the truck • EMGs of the trailer
Traction support: • Acceleration requests in the truck are taken over by the trailer e-drive	• Acceleration pedal • Driver assistance system	• Derived from truck actual engine percent torque (ISO 11992-3)	• ICE of the truck (should be valid also for EMG like in ZEFES) • EMG of the trailer

A characteristic between demanded torque in % and approved torque in % is used to calculate the torque that is realized by the e-drive (EMG) of the trailer (see Figure 2-2).

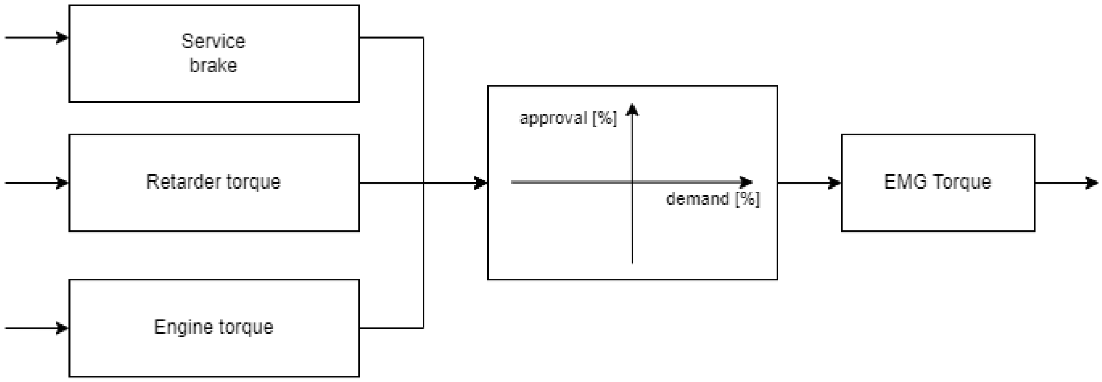

Figure 2-2: Simplified powertrain management to calculate EMG torque

2.1.2 AEROFLEX Advanced Energy Management Powertrain (AEMP)

The Global Energy and Torque Management System (GETMS) is implemented in the vehicle control unit (VCU) of the truck [2]. The GETMS distributes positive and negative torque requests to the powertrains in the truck and the trailers. The Local System Management (LSM) constantly reports the performance/capability parameters of the trailer e-drive regarding available acceleration and brake forces.

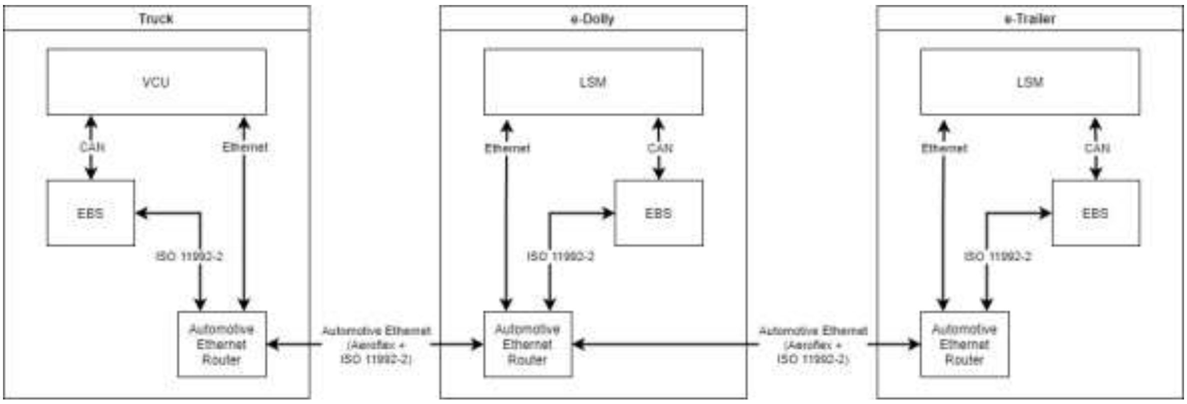

Figure 2-3: Communication architecture of AEMP

The ISO 11992 messages were extended by signals that allow an efficient operation of the distributed powertrain. All messages are combined by the automotive ethernet router to the AEROFLEX communication protocol based on the automotive ethernet (see Figure 2-3).

The basic functions of the AEMP are listed in Table 2-2. It includes the source that generates the request, the systems and interfaces that forward the request to the trailer and the systems that realize the request in the trailer.

Table 2-2: Energy & Torque management functions of AEMP

Function	Request	Forwarding	Actuation
Endurance brake blending:	• Retarder lever • Driver assistance system	• Truck VCU: force request motor	• Retarder of the truck (should be valid also

Function	Request	Forwarding	Actuation
• Endurance brake requests are directed from the truck to the dolly and trailer e-drives	• Brake pedal + driver assistance system	(AEROFLEX signal)	for EMG like in ZEFES) • EMGs of the trailers
Service brake blending: • Service brake requests in dolly and trailer are directed to its e-drives	• Brake pedal	• Trailer service brake demand value (ISO 11992-2) • Trailer EBS: force request motor (AEROFLEX signal)	• Service brakes of the trailers • Service brakes of the truck • EMGs of the trailers
Load point shifting: • Acceleration requests are directed from the truck to the dolly and trailer e-drives	• Acceleration pedal • Driver assistance system	• Truck VCU: force request motor (AEROFLEX signal)	• ICE of the truck (should be valid also for EMG like in ZEFES) • EMGs of the trailers

2.1.3 e-trailer with integrated powertrain management

The e-trailer with integrated powertrain management follows the concept of the AEROFLEX project that uses a central energy and torque management located in the truck. The communication between the truck and the e-trailer was reduces to a minimum set of information to implement the signals in the standard ISO 11992-2 CAN communication (see Figure 2-4). The concept was intensively tested by ZF and introduced several extensions to the ISO standard.

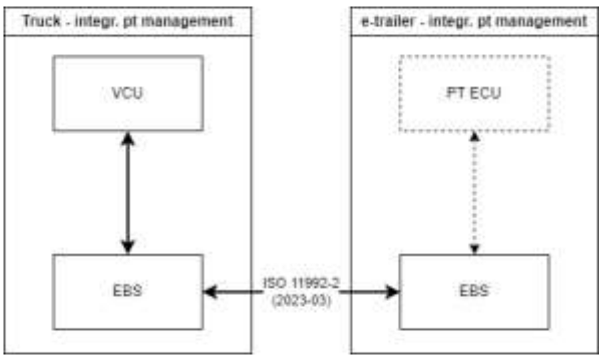

Figure 2-4: Communication architecture of e-trailer concept with integrated powertrain management

The ISO11992-2 fourth revision 2023-03 includes a set of new signals which allow the request of positive and negative torque by the towing vehicle. By using these signals, it is possible to integrate the e-drive of the trailer into the vehicle endurance brake management. The towing vehicle can actively balance endurance braking means of the towing vehicle with the capabilities of the e-drive in the trailer.

With the new signals it is also possible to send request for positive torque from the towing vehicle to the trailer to support acceleration of the vehicle combination.

The relevant changes that support the implementation of an integrated powertrain management are the following:

- Parameter "**Truck drive system control support**" in message RGE12: The parameter was added. Thus, the towing vehicle can indicate if it supports the control of a drive system or retarder installed in the towed vehicle.
- Parameter "**towed vehicle drive system capabilities**" in message EBS24: The parameter was added. Thus, the trailer can indicate the torque capabilities of its drive system or retarder.
- Parameter "**dynamic tire radius**" in message EBS24: The parameter was added. Thus, the trailer can report the dynamic tire radius of the wheels mounted to the axle connected with the retarder/drive system.
- Signal "**retarder demand relative torque**" in message EBS11: The permitted range of values was extended from -125% … 0% to -125% … +125%. Thus, also requests for positive values can be sent by the towing vehicle, which can be used to request traction support from a drivetrain located in the trailer.
- Signal "**retarder wheel torque reference**" in message EBS28: The signal was added to the standard. Thus, the trailer can report the 100% reference value for all retarder wheel torque signals (see next bullet points).
- Signal "**retarder relative peak torque**" in message EBS21: The permitted range of values was extended from -125% … 0% to -125% … +125%. Thus, the trailer can report the realized torque of its retarder function as a percentage of the retarder wheel torque reference to the towing vehicle.
- Signal "**retarder actual maximum positive/negative torque**" in message EBS27: The signals were added to the standard. Thus, the trailer can report the actual maximum available torque that its drivetrain can deliver as percentage of the retarder wheel torque reference to the towing vehicle.

The basic functions of the e-trailer energy and torque management are listed in Table 2-3. It includes the source that generates the request, the systems and interfaces that forward the request or information to the trailer and the systems that realize the request in the trailer.

Table 2-3: Energy and Torque management functions of the ZF e-trailer (integrated version)

Function	Request	Forwarding	Actuation
Endurance brake blending: • Endurance brake requests in the truck are taken over by the trailer e-drive	• Retarder lever • Driver assistance system • Brake pedal + driver assistance system	• Retarder demand relative torque request (negative) by towing vehicle via ISO11992-2 (2023-03)	• Retarder or EMG of the truck • EMG of the trailer
Service brake blending: • Service brake requests in the e-trailer are directed to its e-drive	• Brake pedal	• Trailer service brake demand value (ISO 11992-2)	• Service brakes of the truck. • Service brakes of the trailer • EMG of the trailer
Traction support: • Acceleration requests in the truck are taken over by the trailer e-drive	• Acceleration pedal • Driver assistance system	• Retarder demand relative torque request (positive) by towing vehicle via ISO11992-2 (2023-03)	• ICE or EMG of the truck • EMG of the trailer

2.1.4 e-trailer with stand-alone powertrain management (selected ZEFES solution)

An e-trailer with stand-alone powertrain management and thus without any additional communication interface to the towing vehicle is realized by the ZF “e-trailer only” concept. The ZF e-trailer e-drive system is controlled by an electronic control unit (ECU) in the trailer. The ECU controls the energy flow and positive/negative torque of the e-axle according to the current vehicle state and safety requirements. As input information the ECU uses the ISO 11992-2 (third revision 2014) signals forwarded by the trailer EBS (see Figure 2-5). By functional interaction of the ECU with the trailer EBS, the trailer local energy management for propulsion and recuperation is optimized, the states of e-drive system and braking system are verified to be plausible, and it is ensured that the braking system controls all sensible brake functions.

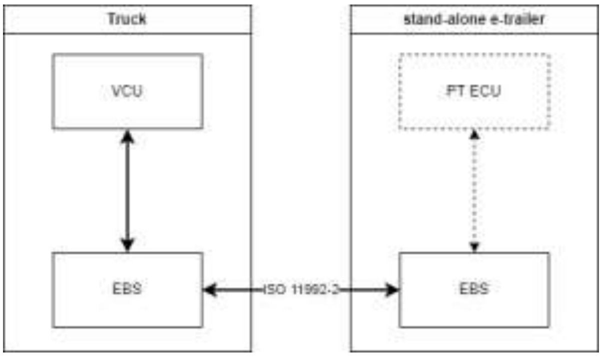

Figure 2-5: Communication architecture of stand-alone powertrain management concept

The e-trailer only functionality allows interoperability of the e-trailer with any towing vehicle, comprising the ISO 11992-2 interface.
Without receiving endurance brake or positive torque requests, the e-trailer function decides on recuperation or propulsion support on its own. The system does not use a coupling force sensor. The control of the system is based on available sensor signals (e.g. acceleration), validated for plausibility by available status signals (e.g. brake/retarder active). The function may be restricted by vehicle lateral information (e.g. speed or articulation angle).

The basic functions of the e-trailer energy and torque management are listed in Table 2-4. It includes the source that generates the request, the systems and interfaces that forward the request or information to the trailer and the systems that realize the request in the trailer.

Table 2-4: Energy and Torque management functions of the ZF e-trailer only

Function	Request	Forwarding	Actuation
Endurance brake blending: • Endurance brake requests in the truck are taken over by the trailer e-drive	• Retarder lever • Driver assistance system • Brake pedal + driver assistance system	• Derived from sensor-based detection of deceleration or downhill driving with constant speed. Retarder active signal on ISO11992-2	• Retarder or EMG of the truck • EMG of the trailer

Function	Request	Forwarding	Actuation
Service brake blending: • Service brake requests in the e-trailer are directed to its e-drive	• Brake pedal	• Trailer service brake demand value (ISO 11992-2)	• Service brakes of the towing vehicle • Service brakes of the trailer • EMGs of the trailer
Traction support: • Acceleration requests in the truck are taken over by the trailer e-drive	• Acceleration pedal • Driver assistance system	• Derived from sensor-based detection of acceleration or uphill driving with constant speed. • vehicle speed / lateral acceleration • articulation angle (sensor or derived from wheel speeds) • gear status • only active if no brake/retarder active	• ICE or EMG of the truck • EMG of the trailer

2.1.5 Sensor based e-trailer stand-alone concept

The sensor-based e-trailer stand-alone concept is similar to the concept of an e-trailer with stand-alone powertrain management (see 2.1.4), but with physical coupling force signal at the trailer kingpin, instead of virtual coupling force determination from other sensor signals [3]. As there is no need for data exchange between truck and trailer, the concept can be used with. any towing vehicle. In particular there is no need for an additional interface or additional dedicated signals being transferred.

2.2 Procedures

For developing the interface, the V-model approach is used. This deliverable focuses on the design and therefore it focuses on the left part of the V-model. Implementation, integration, verification, and validation are not in the focus of this deliverable and at this point of time within the ZEFES project it is not possible as for example use-cases needed for validation tasks will follow at a later point of time.

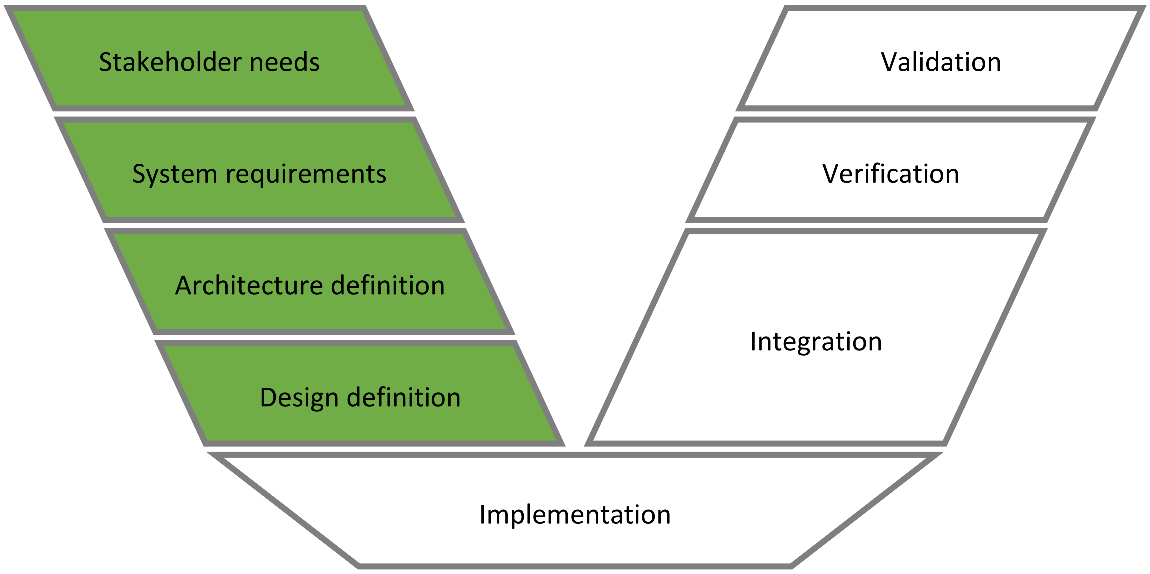

Figure 2-6: V-model illustration

The design is made for two aspects:

I. Interface design for the e-trailer with the focus of optimum usage
II. Interface design for the e-trailer in the ZEFES project

The difference is that certain optimum and future benefits and functions are not implemented by now and thus can't be realized in the ZEFES project on the one hand and on the other hand additional things have to be considered in the ZEFES project like a safety concept (like emergency stop line), dealing with the reachable maturity of the development in the ZEFES project.

3 Vehicle configuration and interfaces

3.1 Vehicle equipment

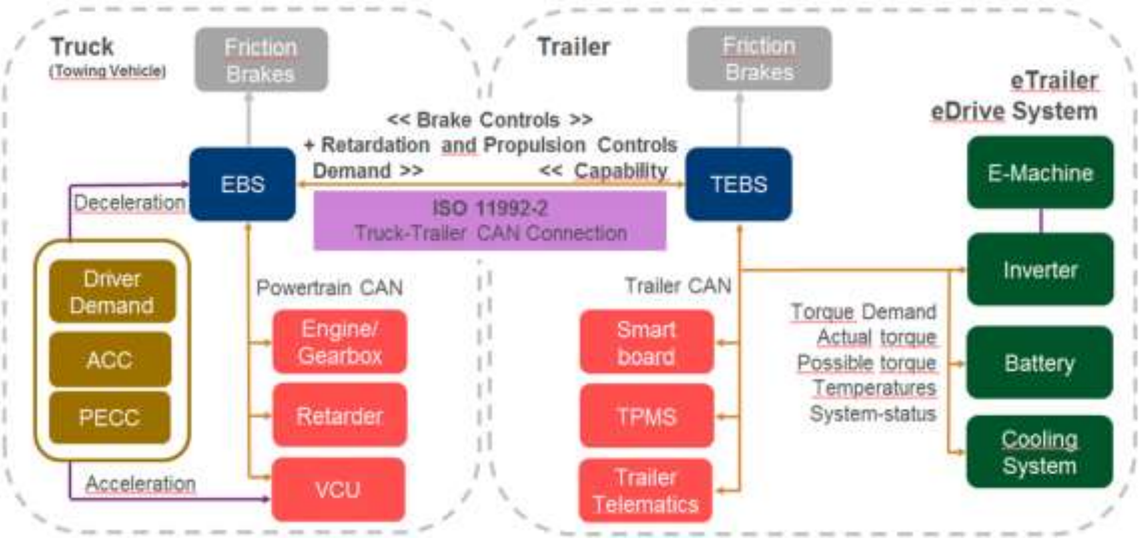

Figure 3-1: Detailed vehicle equipment of truck and e-trailer

Figure 3-1 shows the detailed equipment of a truck and an e-trailer. Not exactly all systems of the vehicle are included. The focus is on the relevant systems for the explanation of e-trailer operation.

A regular O3/O4 trailer with air suspension (not shown) comprises a Trailer Electronically controlled Braking System (TEBS). The TEBS controls the friction brakes of the trailer and incorporates stability functions for the vehicle.

Via the truck-trailer CAN connection the TEBS is connected to the Electronically controlled Braking System (EBS) of the truck. This ISO 11992-2 CAN is a point-to-point connection between EBS and TEBS. The EBS system computes the deceleration request by the driver (foot brake or retarder lever) or by driver assistance functions (Adaptive Cruise Control (ACC) or Predictive Eco Cruise Control (PECC)). Based on this input, the EBS applies the friction brakes in the truck and controls the pneumatic and the ISO 11992-2 signal brake request to the trailer. Pure electrically by-wire control of the pneumatic brake in the trailer would be possible. For safety purposes (e.g. when the electrical 24V supply for the trailer by the truck is interrupted) a redundant control via pneumatic is needed.

If the driver activates the retarder lever or the EBS decides that the brake request can be fulfilled by the retarder/endurance brake alone, the retarder is activated (Endurance Brake Integration (EBI)). Within the ISO 11992-2 third revision 2014, already signals are defined which would allow the truck to control a retarder in the trailer. But as the signals were introduced for a special trailer equipment, these signals are typically not used/controlled by today's EBS and a capability to provide deceleration by the trailer (besides the friction brakes) is not considered.

The ISO 11992-2 interface is dedicated to “brake and running gear” information. Besides the brake control signals some running gear information is submitted from truck to trailer and vice versa. This allows the TEBS/EBS to consider information in respect of other vehicles.
Within the last amendment of the ISO 11992-2 fourth revision 2023 e-trailer capabilities are considered, and information had been extended to request also positive trailer-torque by truck. Signals for identification inform the truck whether the coupled trailer is an e-trailer. Thus, the EBS can decide whether to consider the capability of the trailer to support the truck with negative/positive torque.

The TEBS spans a trailer internal CAN bus for other systems in the trailer like SmartBoard (user control and display panel mounted on frame of the trailer), Tire Pressure Monitoring System (TPMS) and telematic system. For the e-trailer the electric Trailer Control Unit (eTCU) is connected to the internal CAN for communication with the TEBS. As the TEBS maps (most of the) ISO 11992-2 signals (truck to trailer and vice versa) the eTCU can consider brake and running gear data of the truck and of the trailer for operation.

The eTCU hosts the function for high level control operation strategy of the e-trailer. As today’s trucks do not support the e-trailer controls from ISO 11992-2: 2023 yet, the first e-trailers which enter the market (and the ZEFES e-trailers) operate in “e-trailer only” mode (see section 2.1.4), to provide support for deceleration and acceleration for the truck. In some years, when the majority of trucks support ISO 11992-2: 2023, new or updated e-trailers can also be controlled directly by the deceleration/acceleration/energy-management of the truck.

Compared to a regular trailer the e-trailer comes with an electrical drive system. Main functional systems of the drive are the battery (including battery management system, high voltage controls and charging means) the inverter (with the low level e-drive electrical torque/speed controls) and the electrical machine (which can e.g. together with a gearbox be integrated in a drive axle) and a cooling system (respectively a thermal management system which could also include a heater).

3.2 Energy needs and energy management

Via simulation a good estimation is possible, of the total need of electric energy of a heavy-duty commercial vehicle truck-(dolly)-trailer combination for a dedicated mission.
In certain cases, the truck battery has not sufficient energy storage capacity for the reasonable long segments of the mission, which have to harmonize with driver resting times and acceptable charging times. The difference between the energy needs from simulation and the given truck capacity directly leads to the proposed e-trailer battery capacity.

Within the ZEFES project the e-trailer is used in two use-cases. The use case with more demanding requirements is use case 7.2.4 VOL/DPD. In this use case the e-trailer is applied in an EMS1 vehicle combination with a Volvo BEV and a standard converter dolly on the Rhine-Alpine corridor between Germany and the Netherlands that is operated by DPD. Here the longest segment of 310km leads to a needed e-trailer battery capacity of ~200 kWh.
Exemplary calculation:

- Trip Length Neuss-Wertheim: 304 km
- Average speed: ~72 km/h
- Duration of Trip : 4 h 15 min
- Total truck&e-trailer energy needs for trip: 475 kWh
- **Separated energy needs: 300 kWh truck / 175 kWh e-trailer**
- Average energy needed for 100km: 99 kWh truck / 57kWh e-trailer
- Average truck&e-trailer power for the trip: 112 kW.
- Average power of the vehicles: 71 kW truck / 51 kW e-trailer.

Details of the design and dimensioning of the e-trailer powertrain components are not in the scope of this deliverable and will be presented in deliverable D5.4.

A challenge for the e-trailer controls is to optimize the traction support of the towing vehicle. The energy in the e-trailer should be spend that way that the energy in the truck does not run empty before the available energy in the trailer battery is consumed.

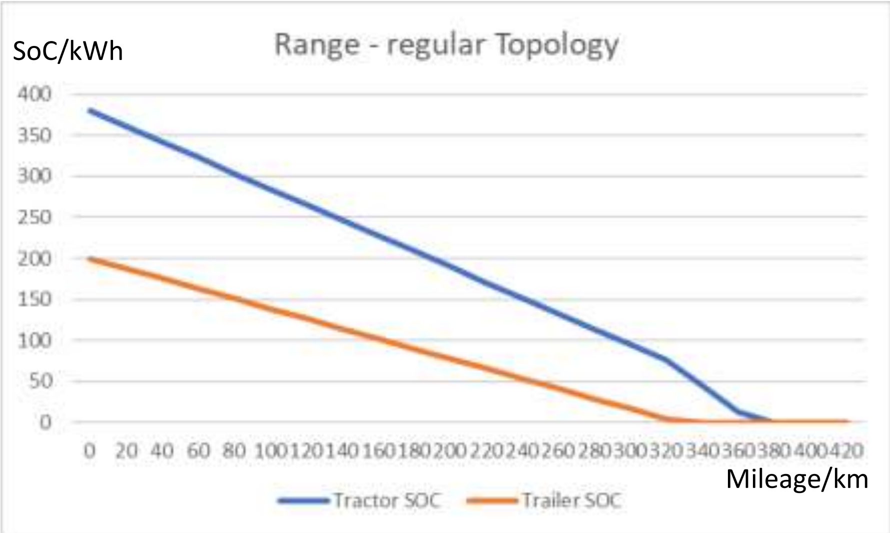

Figure 3-2: Schematic development of the State of Charge over the driving range of truck and e-trailer

Figure 3-2 shows the usage of Energy during the trip.
The operation strategy of the e-trailer and the resulting scenario can be described as follows:

- After overnight charging both vehicles start with 100% SOC.
- At destination after ~300km the energy in the e-trailer should completely be spend (with > 10% remaining SOC)
- The sizing of the battery of the e-trailer leads to energy savings in the truck, so that at destination the truck has still ~ 80 kWh energy reserve available.
- The remaining truck energy allows us to drive an additional ~ 60 km, even though the truck now has to propel the entire vehicle combination alone, without e-trailer support.
- The remaining 60 km driving range adds sufficient reserve to the use case.

A challenge for the dimensioning of the system and for the operation strategy will be a potentially degraded performance of the electrical power system during cold period in wintertime and the possible increase of necessary driving power due to worse road conditions. A reserve to cover these points is foreseen for validation during practical use cases.

3.3 Driving operation scenarios

The distributed powertrain supports three basic operational scenarios derived from the standard operation modes of regular vehicles. Within the scenarios it has to be considered that operation modes “accelerating”, “braking / decelerating” and “rolling / constant speed” are overlapping with the effects from “downhill driving”, “uphill driving” and “flat driving”.

This chapter is intended to figure out the basic expectations to support by an electrified trailer to the driving modes. Qualitatively these expectations can be fulfilled by an e-trailer with integrated powertrain management (see section 2.1.3) as well as by an e-trailer with stand-alone powertrain management concept (see section 2.1.4). Depending on the mission profile, qualitative differences may occur. For an e-trailer in combination with a battery electric vehicle only minor differences in terms of range extension are expected. For an e-trailer in combination with a combustion engine truck without ability for recuperation, the efficiency of the e-trailer regarding charged electrical energy versus fuel savings is increased by the level of integration of the powertrain management in the controls of the truck.

Note: For regular on-road driving, the support for acceleration by the e-trailer is usually restricted to speeds above a certain limit (e.g. > 30 km/h).

3.3.1 Accelerating

If acceleration is caused by demand of the driver or drive assistance system, in flat area or when going uphill, then the e-trailer provides positive torque to support the acceleration.
If the e-trailer is controlled by the truck, the driver's demand is splitted by the energy management system in the truck between truck and trailer.
If the e-trailer is not controlled via interface by the truck, it tunes the support by own controls, depending on measured acceleration and/or measured coupling forces to the truck. Immediately but smoothly when the e-trailer support applies, the driver or the assistance system will reduce the torque demand, so that truck-torque and supplemental trailer torque result in desired acceleration.

When the vehicle is accelerating while going downhill, typically no support by the e-trailer is provided. A benefit from additional positive torque by the e-trailer is not expected in this driving situation, as the gravity forces are already supporting. It is rather expected that the operation scenario will change to a braking request soon when the vehicle reaches the allowed speed limit.

3.3.2 Braking / Decelerating / Recuperation

Generally, the e-trailer can support the desired braking or deceleration of the vehicle by negative torque on the drive axle. In this case if the vehicle is moving, the electrical machine is acting as a generator and the recuperated energy is stored (recuperated) in the battery of the e-trailer.
In combination with an ICE truck, the recuperation potential by the e-trailer is the highest compared to vehicle combinations with other prime movers, since only the e- trailer can recuperate in this combination. Braking energy which otherwise would be wasted in heat is recuperated by the e-trailer. For optimal efficiency the recuperation by the e-trailer must be directly controlled by the ICE truck.

Thus, it is ensured that the recuperation potential of the e-trailer during a deceleration phase is prioritized above any lossy braking or retardation means in the vehicle.
Nevertheless, savings and CO_2 reduction result from the energy which is taken from the battery for traction support. If the e-trailer has a large battery which is completely charged before the vehicle starts its mission, most of the CO_2 reduction is gained by using the pre-charged electrical energy.

In combination with a battery electric vehicle, the recuperation potential can be shared among the BEV truck and the e-trailer. If the characteristics of the e-drive system of the truck are sufficient to manage most braking and deceleration events, including constant speed downhill driving, then it might not be necessary that the e-trailer supports by own recuperation at all. If the electric drivetrain of the towing vehicle is not able to consume all the available power during recuperation events, then the e-trailer should be supported.
But, for the total energy balance of a full electric vehicle combination there is no difference, whether the energy is recuperated by the truck or by the trailer. In principle it does not matter in which part the recuperated energy is stored and in which part of the vehicle it is re-used for propulsion.
Finally, the constraints from section 3.2 Energy needs and energy management have influence to the operation strategy for distribution of recuperation between truck and trailer:

- On the one hand the truck battery may never run empty, before the energy stored in the e-trailer is used. (It must be avoided that energy is still available in the e-trailer, but the vehicle is not drivable because the truck has no energy left.)
- On the other hand, the e-trailer battery should not run empty before reaching the destination, to avoid losses in the idling mode (incl. e.g. supplying pumps for lubrication) of the e-trailer drive.

But recuperation is only a correcting element for that target in operation strategy. Mainly the points above are related to the energy in the batteries charged from grid. There is only minor influence from recuperation to the related balancing operation strategy for the e-trailer.

In summary, for vehicle combination with BEV trucks the benefit of managed recuperation by the e-trailer is very limited.

3.3.3 Rolling / Constant Speed / Coasting / Compensation of Driving Resistance

On flat terrain a 40t truck-trailer combination needs about 95kW power to keep on running at 80km/h. The power is only needed to overcome rolling resistance and air drag. Looking on truck and trailer separately, the truck has to overcome the majority of the air-drag while usually the trailer shares more rolling resistance as it has 3 axles compared to 2 axles at the truck. An assumption of a share of power loss of 50kW truck versus 45kW trailer is reasonable.

Especially for a combination of BEV and e-trailer, the compensation of trailer power losses by propulsion by the e-trailer makes sense. At slope above 0% (uphill), this would lead to a basic offset drive support by the e-trailer. At the negative slope the support by the e-trailer is decreased till the downhill-slope force compensates the drive resistances. When this point is reached, the vehicle is “coasting” without any propulsion by the drivetrains.

When the vehicle is going uphill with constant speed, not only the rolling resistance and air drag but also the downhill-slope forces have to be conquered by the drivetrains of the vehicle combination. Thus, it makes sense that the e-trailer contributes to a share of necessary power. The e-trailer itself, knowing its mass and the inclination (or knowing the coupling force directly) can control reasonable supportive power.

When going downhill at constant speed, usually an endurance brake is active in the towing vehicle. As already discussed with recuperation above, for BEV there is no need for recuperation by the e-trailer, as this would just result in shifting a share of recuperation from the towing vehicle to the e-trailer without resulting in range extension. For ICE vehicles, the e-trailer should recuperate the energy which otherwise would be wasted.

3.3.4 Constraints for driving operation scenarios

While leveling the propulsion support by the e-trailer, it must be avoided, that the e-trailer actively increases its pushing force on the towing vehicle. Per definition (for regular driving situations) the e-trailer remains a towed vehicle. This means the e-trailer support may not lead to higher positive coupling forces between the truck and the trailer than with a regular trailer. (Allowance to do so at low speed for maneuvering and drive off assist are under discussion regarding type approval and associated standards.)
In the other direction negative (pulling) forces may be reduced by e-trailer propulsion and regular positive coupling forces (downhill with retarder of towing vehicle on) may be reduced by e-trailer recuperation.

E-trailer development must ensure that functional details like latency timing and max limits in supporting power by the e-trailer have no negative effect to vehicle driving stability. Especially for ZEFES negative effects will be limited by the operation strategy which targets balanced support power for range extension purposes and not on boosting or recuperation with high power.

3.4 Operation requirements beside the driving support

Above the core functionality of the e-trailer to support the towing vehicle regarding retardation and propulsion according to rules and dependencies, other dependencies must be considered and additional functions are required.

3.4.1 Consideration of brake and running gear status

As a result from hazard analysis and risk assessment, reflected in the functional safety concept, the e-trailer may not provide positive or negative torque when vehicle stability control systems in the prime mover are active.

The e-trailer may also not act against the demand of the driver or of a driver assistance system. Consequently, positive torque by e-trailer must be avoided when endurance brake, service brake or parking brake are active.

The required information is exchanged on the ISO 11992-2 CAN connection between the EBS of the prime mover and the trailer EBS. The trailer EBS forwards the required information to the e-drive system.

3.4.2 Signalization of malfunction to the driver

Faults in the e-trailer e-drive system which require immediate save stopping (red warning lamp) must be signalized to the driver.
The signaling should be similar to the red warning lamp status sent by the trailer EBS on ISO 11992-2 CAN line.

3.4.3 (Temporarily) disabled e-trailer support from truck

Especially for the evaluation phase in ZEFES, the driver should have the possibility to disable retardation and propulsion support by the e-trailer. The driver should have the possibility to use the energy in the e-trailer when needed. This must be controlled from a button in the cab. The background is that the e-trailer most likely cannot be charged at all places where the truck can be charged. Therefore, the e-trailer energy should be saved for the leg of the route that cannot be covered with the energy in the truck only.

Also, for systems in the prime mover it must be possible to suppress traction support by the e-trailer temporarily. This is needed for truck functions which might be influenced by e-trailer behavior. An example is the estimation of vehicle mass. If a system in the prime mover e.g., estimates the vehicle mass via the ratio of truck propulsion forces and measured acceleration, the overlaying torque by the e-trailer would falsify the result. Thus, the systems in the prime mover must have the possibility to set the support by the e-trailer to zero while sensitive calculations are processed.

Both requirements can be fulfilled by the same mechanism. For system interaction it would be beneficial if a solution using the existing brake and running gear interface is identified.

3.4.4 Driver information on e-trailer system status

In general, the driver may not get distracted because of too much information. Nevertheless, the information on current SOC of the e-trailer battery, whether all systems are working within their parameters and limits, and the current operation mode (recuperation/support) should be visualized to the driver.
An appropriate comfort interface (using proprietary or available communication lines or maybe via wireless local systems or via telematics and fleet management system) should be installed in vehicles.

For development, validation, and use-case supervision by the driver in ZEFES, a direct wired interface with messages directly filtered and routed from the internal trailer CAN could be an appropriate solution. The possibility to use the CAN lines on the ISO 12098 light and signaling plug will be checked. Compatibility with the existing ISO 11992-3 standard is beneficial.

3.4.5 Emergency button

An emergency button in the truck is realized for deactivating the e-trailer functionality, especially an appropriate deactivation of the high voltage system. The e-trailers will be used within the ZEFES project before the serial development is finalized, including all certificates are concluded for the intrinsic operation of the e-trailer. As last safeguarding measure, an instructed driver will have the possibility to deactivate e-trailer functionality on low level via an emergency button.

3.5 Interface design process

Within this chapter, the requirements resulting from the operation scenarios (see section 3.4) to the interaction/interfacing between BEV and e-trailer are reflected. This leads to a definition of the functional architecture. The resulting need on functional, virtual, and logical interfaces between the vehicles is then mapped to interface solutions. Finally, options will be discussed and a solution for the physical realisation is concluded and needs for design are identified.

3.5.1 Architecture definition

To define the architecture of the necessary interaction between the BEV and the e-trailer, the following table discusses the necessary functions as described in the chapter before and distinguishes between BEV, FCEV and ICE-truck.

Table 3-1 discusses the necessity of an integrated powertrain management including a dedicated vehicle-to-vehicle interface depending on the ability of the e-trailer to support different driving operation scenarios (see section 3.3) and further operation requirements and interaction between truck and trailer (see section 3.4). Within the table it is indicated whether the control need between truck and trailer is

- m: mandatory
- r: recommended but not mandatory
- a: may have some special advantages but not mandatory
- n: not needed, since it has only negligible effect
- pm: mandatory for prototype state of vehicle
- pr: recommended for prototype

Table 3-1: Necessity of an integrated powertrain management depending on the ability of the e-trailer to support different driving scenarios and necessity of other interaction between truck and trailer.

Driving operation scenario / operation requirements	**Necessity of a control via integrated powertrain management**			**Rationale**
	BEV Truck (e-range)	**FCE Truck (H2-range)**	**ICE Truck (CO2)**	
Acceleration	a	a	r	• For ICE truck the engine should be supported according to load characteristics of the ICE. This can to a certain degree be estimated via acceleration, but truck controls recommended. • For FCEV the e-trailer can support the truck battery, which is compensating power peaks, which cannot be powered from fuel cell stack directly. But the benefit of an e-trailer control interface is minor, as the truck battery is dimensioned to cover most of the driving situations. • For BEV as well as for FCEV a moderate support dependent on mass of e-trailer and acceleration of vehicle is sufficient for range extension. This can be controlled locally on e-trailer.
Recuperation	n	a	r	• For BEV controlled recuperation by e-trailer supplemental to recuperation by truck is typically not needed to extend driving range. • For ICE truck the e-trailer is the only recuperation means in the vehicle. Recuperation controls by the e-trailer with stand-alone powertrain management

				results in reasonable contribution to savings, but direct prioritized controls from truck can lead to further optimizations. • For FCEV the battery is dimensioned to cover most of the driving situations, and the effect of an interface to truck is minor.
Compensate tire friction and air drag	n	n	a	• Compensating trailer related tire friction and air drag is more a trailer local issue. Trailer mass, tire characteristics and aerodynamic characteristics are information which is locally available on the trailer. A control by truck is not necessary. • Nevertheless, for ICE truck a control connection could have advantages for fine-tuning especially in low-load conditions. • Remark: The input for the local controls in the trailer may be a measured coupling force. But the propulsion support by e-trailer may also be computed from mass, speed, and acceleration of the trailer, with consideration of the measured road inclination.
Compensate slope forces	n	a	r	• Slope forces are overlapping with the forces from acceleration/recuperation/drag. All information is available on the trailer to consider adapted controls for uphill/flat/downhill driving. • For BEV e-trailer local controls as for compensation of drag/friction are sufficient to support range extension. • For FCEV a control may be advantageous to balance the smaller battery in the truck with the e-trailer battery for longer uphill/downhill slopes. • For ICE truck the control interface is recommended to manage load conditions of the ICE.
Brake and running gear information from truck	m	m	m	• Information on braking status of truck and trailer must be available in the e-trailer to prioritize friction brake controls by the electronic braking system above e-drive system and for plausibility checks of the state of the e-drive system itself.
Warning lamp status from trailer to truck	m	m	m	• Faults in the e-trailer e-drive system which require maintenance (yellow warning) or immediate save stopping (red warning lamp) must be signalized to the driver.
(Temporarily) disabled support by the e-trailer	r / pr	r	a	• Systems in the truck may be influenced from the torque support by the e-trailer. These systems should have the possibility to deactivate temporarily the support by e-trailer to avoid interference. • Especially for ZEFES use-cases the possibility is recommended to disable e-trailer support for dedicated mission segments by driver.
Information on system status details of the e-trailer e-drive system	a / pm	a / pm	a / pm	• For e-trailer as a series product in daily regular operation, it is regularly not mandatory that the driver monitors running e-trailer system data which is directly transmitted. SOC to plan next charging stop is rather considered via telematics in mission management. • For ZEFES research project some more system information must be transferred between the vehicles.
Emergency button	n / pm	n / pm	n / pm	• For e-trailer as a series product in daily regular operation, emergency button is not mandatory. The e-trailer is intrinsically safe. Malfunctions and system states out of range are detected and especially the high voltage system will be shut down in case of danger. • As the e-trailer as used in ZEFES does not have passed full series qualification, an instructed driver shall have the possibility to shut down the e-trailer in case of serious malfunction.

3.5.2 Design definition

The previous section analysed the qualitative necessity of interfaces between truck and e-trailer for BEV, FCEV add ICE trucks. The next step is the specific view on the interface in ZEFES context for an e-trailer in combination with BEV trucks and on identification of the physical solution for that interface.

Table 3-2: Definition of Interfaces between BEV and e-trailer in ZEFES context.

Function	BEV Truck	used truck-trailer interface in ZEFES	Rationale
Acceleration directly controlled by truck	a	none	• For BEV a moderate support dependent on mass of e-trailer and acceleration of vehicle is sufficient for range extension. This will be controlled locally on trailer.
Recuperation directly controlled by truck	n	none	• For BEV, recuperation by e-trailer supplemental to recuperation by truck is typically not needed to extend driving range. Local controls by e-trailer (based on mass, acceleration, and slope) are present, but they will be disabled or only considered with a small factor.
Compensate tire friction and air drag	n	none	• Compensating trailer related tire friction and air drag is more a trailer local issue. Trailer mass, tire characteristics and aerodynamic characteristics are information which is locally available on the trailer. A control by truck is not necessary.
Compensate slope forces	n	none	• For BEV e-trailer local controls as for compensation of drag/friction are sufficient to support range extension.
Brake and running gear information from truck	m	ISO11992-2:2014 as available on ISO 7638-1 7-pole 24V ABS/EBS-connector	• Information on braking status of truck and trailer have to be available in the e-trailer to prioritize friction brake controls by the electronic braking system above e-drive system and for plausibility check of state of the e-drive system itself and to deactivate e-trailer functionality in case braking system related stabilization functions become active.
Warning lamp status from trailer to truck	m	hardwired via brake and running gear fault indication on pin 5 and with warning lamp signals in EBS22 on ISO11992-2 CAN on ISO7638-1 connector	• faults in the e-trailer e-drive system which require maintenance (yellow warning) or immediate save stopping (red warning lamp) have to be signalized to the driver
(Temporarily) disabled support by the e-trailer	r / pr	use of parameter "retarder demand relative torque" in EBS11 on ISO 11992-2. // or // proprietary hardwired signal for ZEFES : TBD-1: free/not-used pin on ISO12098 conn. TBD-2: separate custom wire TBD-3: back channel on a proprietary driver display/HMI device connected to a proprietary CAN (see next position in this table)	• Systems in the truck may be influenced from the torque support by the e-trailer. These systems should have the possibility to deactivate temporarily the support by e-trailer to avoid interference. • Especially for ZEFES use-cases the possibility is recommended to disable e-trailer support for dedicated mission segments by driver.
Information on system status details of the e-trailer drive system	a / pm	Data can be made available on trailer by connecting a gateway to the internal e-trailer system CAN. This extracted data can be	• For ZEFES research project some system information should be transferred between the vehicles. It should be possible to connect a driver display in the truck to display e-trailer

		transferred to the truck in different ways: TBD-3: Use the existing, (typically not used) CAN wires on the ISO12098 connector TBD-4: separate custom CAN cable	system data (battery condition / SOC, temperatures, power, …)
Emergency button	n / pm	The connection to emergency button should be a physically hardwired connection. Options are : TBD-5: proprietary use of a free/not-used pin on ISO12098 connector TBD-6: separate custom wire connection.	• As the e-trailer as used in ZEFES does not have passed full series qualification, an instructed driver shall have the possibility to shut down the e-trailer in case of serious malfunction.

The following sub sections conclude the interface decision and selects the option which is targeted in ZEFES

3.5.2.1 Interface for powertrain management

No Interface for Powertrain management needed.

3.5.2.2 Brake and running information from truck

No Interface is necessary, above the existing ISO11992-2:2014 interface as available on ISO 7638-1 7-pole 24V ABS/EBS-connector.

3.5.2.3 Warning lamp status from trailer to truck

No Interface is necessary, above the hardwired brake and running gear fault indication on pin 5 of ISO7638-1 connector and with warning signal request parameters in EBS22 on ISO11992-2 CAN on same connector.

3.5.2.4 Interface to disable (temporarily) the support by the e-trailer

If the disabling of the e-trailer function (propulsion and recuperation) shall be controlled by a system in the truck, then this function should be assigned to an already existing channel of truck-trailer communication. Therefore, the targeted solution for switching on/off by system function should be via the parameter “retarder demand relative torque” in EBS11 on ISO 11992-2.

The manual on/off functionality should be separated from the system controls. Here, the interface via the separate CAN communication line for driver information (see next section) should be used in the ZEFES context.

This solution avoids extra hardware connection needs. Therefore, it is preferred over a separately installed wire. In addition, this offers the opportunity to realize optional separate on/off controls for recuperation and propulsion.

3.5.2.5 Information on system status details of the e-trailer drive system / driver Interface

A proprietary CAN connection should forward system information from trailer to truck. This connection can also be used to send information from truck to trailer. A programmable graphic display with control inputs can be connected to the e-trailer CAN interface in the truck to visualize e-trailer status and allow e-trailer controls by the driver.

The proprietary truck-trailer control interface should physically use the pins reserved on the ISO12098 connection. This solution would allow to use an available and robust physical connection.

3.5.2.6 Emergency button

For the emergency button a robust connection is required. A proprietary connection should be avoided which would have to be managed by the driver when coupling/uncoupling truck and e-trailer in the ZEFES use-cases. Therefore, the emergency button should use the robust connection via a free respectively not used pin on ISO12098 connector of the ZEFES vehicles. Present evaluation show that pin 11 of the ISO12098 connection is not used by the towing vehicles in both ZEFES use-cases with e-trailer.

3.5.3 Physical interface description / design needs

According to the design definition in section 3.5.2, the truck trailer interface for connection between e-trailer and prime mover in the ZEFES use-cases does not need any proprietary additional physical connection.

No connection is needed for:

- control of the e-trailer powertrain for propulsion and recuperation.

The existing ISO7638 (ABS/EBS) plug/connection covers/contains:

- the brake and running gear information to be considered for e-trailer available on the ISO 11992-2 CAN connection,
- the red/amber warning signal request parameters on the ISO 11992-2 CAN connection,
- the possibility to use the available “retarder demand relative torque” parameter in EBS11 on ISO 11992-2 for inter-system control to disable recuperation/propulsion on e-trailer,
- the warning lamp hardware signal on pin 5 of the connector.

From the existing ISO12098 (light and not running gear controls) plug/connection

- a regular free/not-used pin is used to connect an emergency switch in the truck,
- the CAN connection pins are used for a proprietary CAN connection for interaction with the driver in both directions by sending information from and to the e-trailer system.

The solution is not only the realisation in the ZEFES research environment, but also a basis for a future series solution. An emergency button will not be needed for series e-trailers. For the driver information signals and the driver interaction it may be necessary to map the information to tunnelling signals on the ISO11992-3 connection which is defined for the CAN connection on ISO12098 connector. The other solutions can directly be transferred to a series solution.

4 Contribution to the project

4.1 Contribution to project (linked) objectives

The work done in subtask 2.9.2 and documented in this deliverable contributes reaching several objectives that have been defined in the ZEFES description of action. The definition of the interface between the prime mover and the e-trailer is mainly input to Task 5.4 “Adaptation and implementation of powertrain components for next generation e-trailers and b-trailers” in WP5.

The interface definition enables the development of vehicle concepts with enhanced energy storage and e-axles in the prime mover and the trailer (Sub-objective 1.2). By using only a logical interface the interoperability of the e-trailer with prime movers of different OEMs is guaranteed, even if it is a prime mover with an ICE.

The objective O.2.6: “Develop a standardized control interface between BEV and FCEV prime mover and electrified trailers” is fulfilled by the logical interface which does not need a hardware-based connection including a dedicated communication between the prime mover and the e-trailer. Thus, the e-trailer as part of the ZEFES multi-modular powertrain concept can be operated based on the existing standardized interfaces, e.g. the ISO 11992 EBS interface.

4.2 Contribution to major project exploitable result

The work done in subtask 2.9.2 and documented in this deliverable contributes to the project exploitable results. The further development of know-how on interoperable interfaces for battery-powered trailers in a multi brand context will help OEMs to secure a leading position in the automotive industry by introducing leading edge technology to the market.

The development of the interface for an e-trailer further contributes to major project results. It enables the realization of modular vehicles and connected trailers suitable for use in selected regional and national long haulage missions that meet the customer needs in terms of vehicle range. The design of the interface also takes into account several identified barriers to the widespread implementation of heavy-duty battery electric vehicles. One important criterion is the ease-of-use of the e-trailer, which is considered by not introducing new physical interfaces. Thereby also the compliance with European standards regarding vehicles and trailers is maintained.

5 Conclusion and Recommendation

5.1 Conclusion

As written in the chapter 2, the design of the interface was limited to technical aspects. For bringing this technology to the market, economic aspects should be considered as well. Particularly commercial vehicles, but also vehicles in general are used to fulfil a task. Using the example of pure transportation of goods with a truck-trailer combination, a very simplified business model description is bringing goods (volume and weight) from A to B and getting money for.
Costs could be divided in following segments:

- Fuel/Energy
- Vehicle depreciation
- Driver
- Insurances
- Toll
- Tires
- Service
- Operating materials
- Organizational
- Others

As long as a vehicle combination stays the same there is no big change but only a shift in total costs of ownership (TCO) between truck and trailer. As soon as trucks and trailers are interchanged, we have to focus also on economic aspects. This is indicated as there is a significant amount of energy which could be transferred between truck and trailer. The share of energy costs is dependent on the application, but energy costs are a significant share across all applications and thus economic aspects have also to be considered in the interface design.

Assuming company X tows an e-trailer with their truck from place A to place B and company Y tows the same e-trailer with their truck back from place B to A. If the energy content of the e-trailer battery is the same at the start and at the end everything is OK. The control of the e-trailer cannot ensure that the energy content is the same all the time as exactly the opposite is the basic idea as benefit of the e-trailer being able storing energy in beneficial phases (like recuperating going downhill) and reusing energy in other phases (like going uphill). It will be the case that if there would not be an e-trailer, the truck of company X could recuperate more or the consumption of the truck of company Y is reduced due to the fact, that the e-trailer battery was charged during the tour with the truck of company X. There are many different examples where a shift of energy and thus a shift of money could be seen. In this price sensitive business this will probably lead to discussions, which must be pre-empted by solutions. Although the overall efficiency will rise in most use cases and thus costs and environmental impact will reduce, this shift in an economic view has to be overcome.
Furthermore, of importance are these investigations if there is an altitude difference causing significant unbalancing.
The above-mentioned thoughts are limited to the energy consumption and relating economic aspects. Driven Tires have a different slip based on the torque and following higher wear. Components which are used have also higher wear. Especial to mention is the aging of batteries which is not trivial function of a huge variety of influencing factors. The magnitude of this aspects seems like currently use-cases

without e-trailers. Some standard trailers have for example better tires reducing rolling resistance or different axles with variating moment of inertia influencing rotational acceleration resistances. Those and similar factors also influence the economic situation for the business model but are tolerated as the magnitude is limited. Therefore, such slight differences using e-trailers could be also tolerated as now.

Possible solutions could be implemented based on connectivity were differences of energy content at the start and end of a tour could be calculated and accounted for. Also digital twin models as basic models developed within ZEFES could be a potential solution overcoming the issue with shift in energy costs.

5.2 Recommendation

Probably most important for successfully rolling out sophisticated e-trailer vehicle combinations is a universal interface allowing functional operability between all truck-trailer combinations on the one hand and enabling advanced special features for further improvement if truck and trailer are capable of on the other hand. The deliverable shows that a minimalistic truck-trailer interface for an e-trailer with stand-alone powertrain management is a sufficient and flexible solution to enable the use of vehicle combinations with a modular distributed powertrain. One of the advantages is the retrofitability of such an interface and thus, the universal applicability of these kind of e-trailers with prime movers independent of their driveline technology.

To enhance the potential benefits of an e-trailer in terms of reduced energy consumption and CO2 emissions of the vehicle combination, especially with ICE prime movers, it is recommended to establish a sophisticated truck-trailer interface. The signals to fulfil the requirements of such a communication interface were already presented in the last amendment of the ISO 11992-2: 2023. It is highly recommended to adapt the standardized EBS CAN communication of newly built trucks to this amendment.

5.3 Outlook

Recent developments in vehicle and drive technologies do also influence the standardized vehicle to vehicle interfaces. To support new technologies and functions, these interfaces, especially the ISO 11992 EBS CAN, are continuously developed. The adoption of these extended standards by the OEMs enables a more sophisticated management of distributed powertrains following the concepts presented in sections 2.1.3 and 2.1.2. A centralized energy and torque management is advantageous in particular for conventional prime movers equipped with an ICE (see section 3.5.1). It increases the potential of reduction of fuel consumption and thus the reduction of CO2 emissions that is brought in by the application of an e-trailer.

Since the prime movers used in the ZEFES project will not support the interface extensions of the latest ISO 11992-2 revision, the realisation of the interface between the towing vehicle and the e-trailer will be based on the concept of an e-trailer with stand-alone powertrain management. Since the prime movers are zero-emission vehicles, this is not a drawback in terms of potential reduction of energy consumption. Nevertheless, after conclusion of the ZEFES project, the new generation of braking systems will be available in new built trucks, comprising the recently published version of ISO 11992 (2023-03). This will make the version of an e-trailer with integrated powertrain management (see section 2.1.3) possible.

As soon as a new standard for the truck-trailer interface (automotive ethernet) is available, not only the present ISO11992-2/-3/-4 standards will be mapped to this high bandwidth interface, but also enhanced e-trailer information can be transmitted, for improved driver information and for extended vehicle energy management.

6 Risks and interconnections

6.1 Risks/problems encountered

Risk No.	What is the risk	Probability of risk occurrence[1]	Effect of risk[1]	Solutions to overcome the risk
1	Complete definition of the vehicle-to-vehicle interface between prime mover and e-trailer finalized too late for integration/implementation in the ZEFES vehicles	2	1	The developed solution of an e-trailer with stand-alone powertrain management requires no additional communication interface beyond the standardized ISO 11992-2/3 vehicle-to-vehicle interfaces. Only minor adaptations at the prime mover are necessary to fulfil the operational requirements of the ZEFES use cases (see chapter 3).

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

6.2 Interconnections with other deliverables

The design of the vehicle-to-vehicle interface presented in this deliverable is input to the investigation of functional safety in Task 5.2 and the corresponding deliverable D5.2. Furthermore, the interface will be realized in the ZEFES e-trailer in Task 5.4 that will be presented in deliverable D5.4.

7 Deviations from Annex 1

Content-wise no deviations from Annex 1 were made. The deliverable was finalized with a delay of two month compared to the description of action/ the due date in the GA, which does not affect the tasks dealing with the realization of the e-trailer or other tasks in the projects in other WPs.

8 References

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Project partners:

#	Partner short name	Partner Full Name
1	VUB	VRIJE UNIVERSITEIT BRUSSEL
2	FRD	FORD OTOMOTIV SANAYI ANONIM SIRKETI
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
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