Aerodynamic and Flexible Trucks for Next Generation of Long Distance Road Transport

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Publishable Executive Summary

The final technical assessment plays an important role in the AEROFLEX project. Not only as a deliverable in itself but also as input to the impact analysis related to European freight transport performed by Work Package (WP) 1 and the book of recommendations written by WP7. The final technical assessment plays an important role in the translation of the results of the individual work packages to the overall project results. Since the last inputs are only expected shortly before the due date of the project, it is of great importance that the approach of this technical assessment is known and agreed upon by all project partners well before the final critical months of the project so that these months can be used efficiently for performing the actual assessments. This alignment within the project is the main goal of the actions performed in task 6.2 and this report.

Based on the role of the final technical assessment within the project and the relation to other WP's, the functional description of the final technical assessment can be summarized in one sentence:
To assess the efficiency improvement potential of AEROFLEX innovations in typical European long-haul road operations, building on the reference and demonstrator test results, using realistic simulations and providing input to the impact assessment of the EU freight transport and book of recommendations.
Following this functional description, a set of requirements to the final technical assessment is derived, grouped in the following categories:

- Type of results
- Representation of AEROFLEX innovation
- Definition of European long-haul road operations
- Usage of on-road test results
- Representativity of simulations
- Input to other WP's

The assessment framework is designed in such a way that it enables ***calculating the energy efficiency for any given vehicle, equipped with any given AEROFLEX innovation or combination of innovations, used in any given transport application.*** A stepwise assessment approach is proposed, shown in Figure 1-1. A transport application or use-case can be described by a set of origins and destinations; the cargo that is shipped between each origin-destination and the vehicles that are used to ship the cargo. Based on an origin-destination a route profile is generated. The route profile is a distance-based profile of the route including slope, direction and speed limit. The vehicle with the cargo (payload) is simulated over this route to generate a mission profile; a time-based profile including slope of the road and speed of the vehicle. Since this mission profile depends on the weight of the vehicle combination, the Smart Loading Units (SLU) innovations are an input to this model. These innovations influence the weight of the vehicle combination by increasing the load factor. This mission profile is the basis on which the road load (power required at the wheels) is calculated with a physical model (road load model in the figure). This model calculates the power at the wheels from the drag, inertia, gradient and rolling resistance working at the wheels. Drag resistance depends on the shape of the vehicle which is influenced by the aerodynamic features designed in WP3 (AeroLoad). From the wheel power demand, the fuel power demand is calculated (power required from the fuel) with the powertrain model. This model includes the engine and drivetrain efficiency and, if equipped, the efficiency of the hybrid systems. The specifications of the hybrid systems are an input from WP2, where the Advanced Energy Management Powertrain (AEMPT) related innovations are developed. Using the same mission profiles for these calculations allows for a fair comparison between different scenarios (e.g. AEROFLEX innovations equipped to the vehicles). From the fuel power demand, the fuel consumption (l/km) and fuel efficiency (l/tkm) is calculated. Multiplying the results with the number of vehicles used allows for fuel efficiency comparisons between different vehicle fleets (for example to calculate the fuel efficiency effect of logistic innovations that increase the payload capacity of a vehicle).

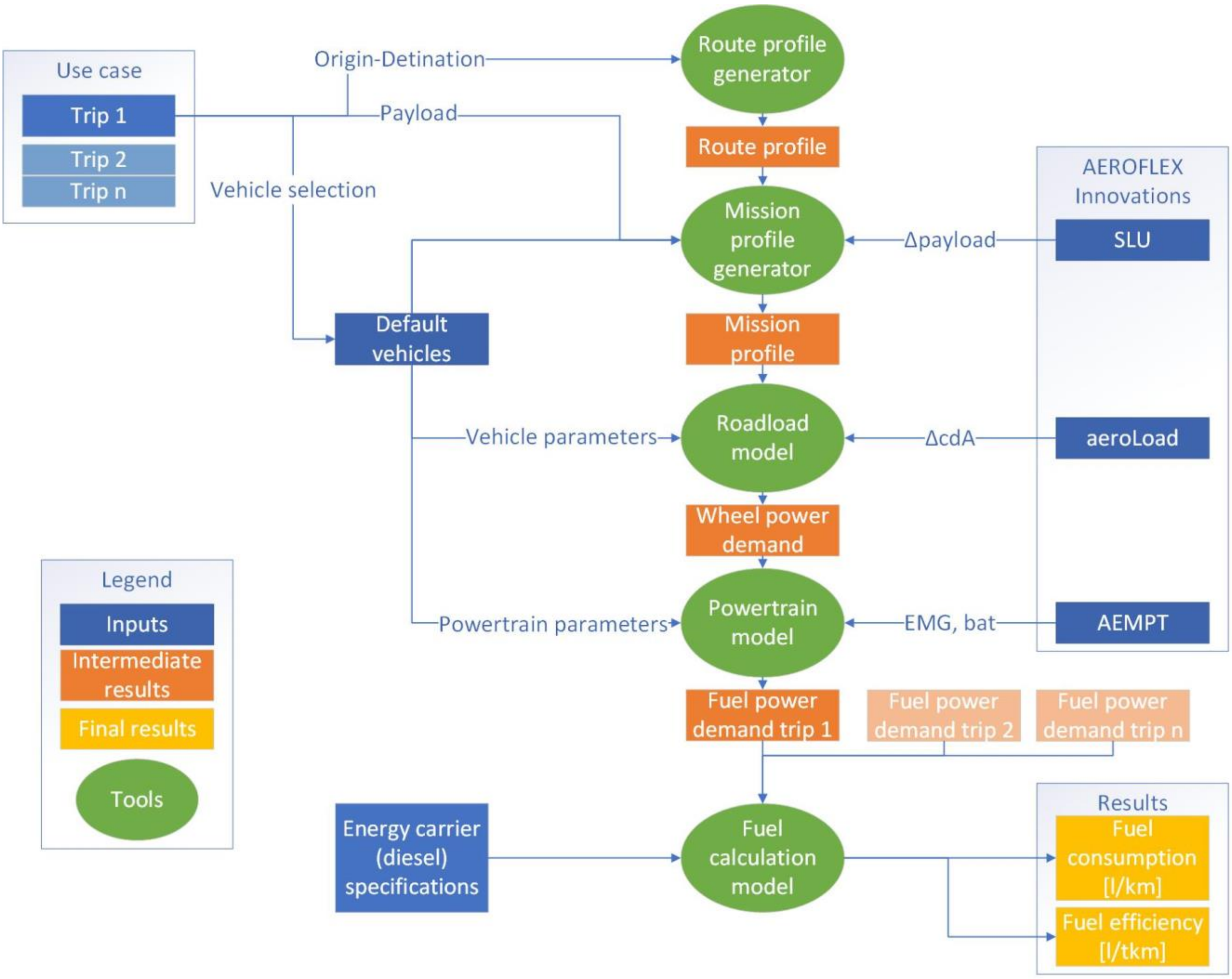

Figure 1-1 Stepwise approach used for the assessment of a use-case

The assessments that will be performed with the assessment framework and the deliverables in which the results will be shown are summarized in Figure 1-2. In the pilot assessment, which is subject of the current deliverable, the assessment framework is demonstrated on the Fraga-route[1] and a customer use-case. In the calibration and validation phase, the reference and demonstrator tests on the Fraga route and highspeed test-track are simulated in order to tune the model and test its validity. In the sensitivity analysis, the representativity of these routes is tested. The final technical assessment consists of two parts. First, the demonstrator vehicles are tested on different missions and compared to the reference vehicles. Second, the customer use-cases are simulated. Here, real logistic use-cases are used to compare the currently used vehicles to future prime candidates with and without AEROFLEX innovations[2] applied. The selected customer use-cases provide a large variation in typical transport applications and routes. This allows for an assessment of the AEROFLEX innovations in various situations including e.g. flat and hilly routes, free flowing and congested roads, fully loaded and empty vehicles, motorways and urban roads.

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[1] The Fraga-route is a route in the South of Spain that is used by IDIADA for the on-road tests of reference and demonstrator vehicles.

[2] Innovations developed within the project, i.e. Advanced Energy Management Powertrain, Aerodynamic features, Smart Loading Units, Innovative Front-end design (see section 3.2)

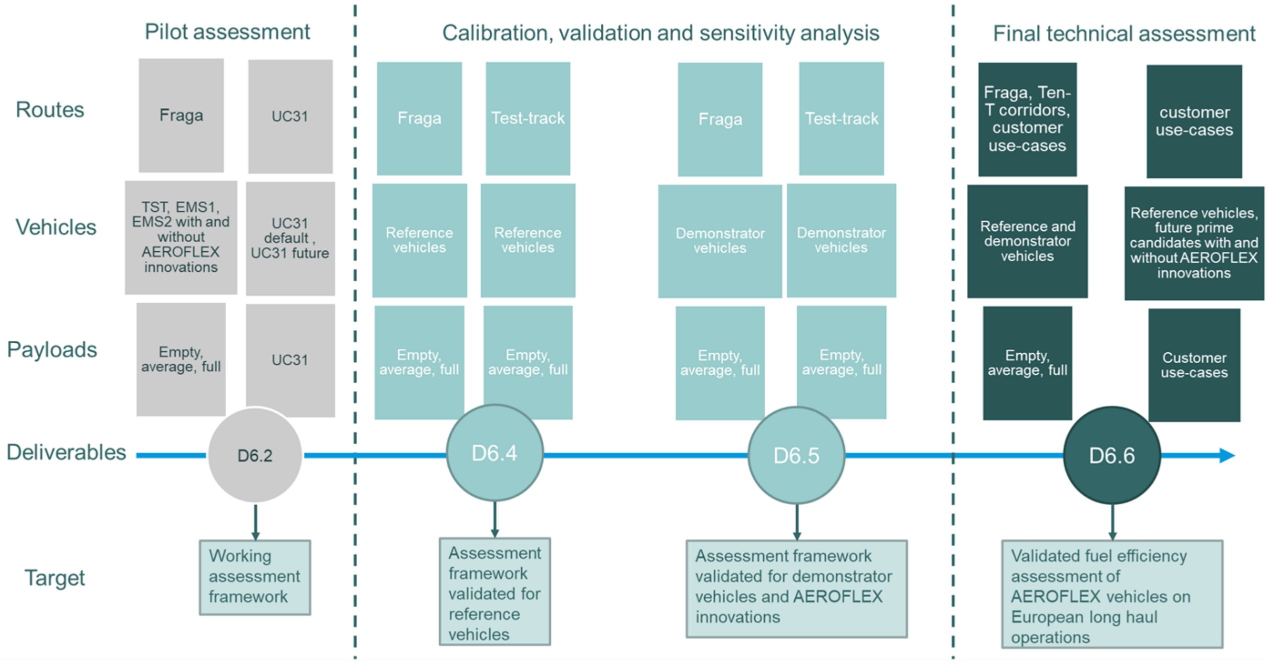

Figure 1-2 Assessment matrix, the results of the technical assessments will be delivered in D6.2 (due 2019-11), D6.4 (2020-3). D6.5 (2021-1) and D6.6 (2021-3)

The assessment framework is tested on the Fraga route and a customer use-case as a pilot assessment case. The Fraga-route is used, since it is a well-known route within the project and it plays an important role in the reference and demonstrator tests as well. The Fraga-assessment shows that the assessment framework can produce sensible results when comparing different vehicles with different payloads and innovations on a single route. Calibration and validation of the models are required to show how well the absolute fuel consumption results meet the measured values. Therefore, the results of the pilot assessment are not yet representative for the final result of the assessment and are therefore not mentioned in this summary. The customer use-case assessment shows that it is possible to compare the currently used vehicle configuration with a future vehicle configuration. However, the result strongly depends on the assumptions made about the applicability of AEROFLEX innovations and (future) regulations. In the final technical assessment multiple assessment scenarios should be defined in close cooperation with project partners and stakeholders from the transport sector.

Finally, it can be concluded that all requirements can be met by the assessment framework and the planned assessments. Table 1-1 lists all requirements and the chapter in which the conformity to the requirement is described. The final technical assessment can only be completed when the following conditions are met:

- Test results will be shared within a week after completion of the tests;
- Adaption of the hybrid powertrain model to simulate multiple hybrid systems working in parallel;
- Inclusion of formulas from the VECTO model to calculate wind-averaged C_d*A values;
- Calibration of the models with the test results;
- Validation of the models with the test results;
- Sensitivity analysis on the representativeness of the Fraga route for the customer use-cases;
- Innovations and parameters for the innovations will be shared before the reference tests are finished;
- Before the General Assembly in May 2020, a decision should be made on the innovations applied on the future prime candidates for the customer use-cases.

Table 1-1 Requirements to the final technical assessment

Group	Requirements	Chapter /reference
Fuel 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;	4.5
AEROFLEX innovations	• The assessment framework should allow for the simulation of hybrid drivetrains; • The assessment framework should allow for the simulation of torque management systems; • The assessment framework should be able to simulate passive flow control systems; • The assessment framework should be able to simulate active flow control systems, where the aerodynamics of the vehicle depend on speed or direction of the vehicle; • The assessment framework should allow for fleet level simulations.	4.4
Typical European long-haul road transport operations	• 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.	(Eijk, Mentink, & Freixas, 2019)
Test results	• The assessment framework should be calibrated with reference and demonstrator test results; • The assessment framework should be validated with reference and demonstrator test results.	5
Realistic simulations	• The sensitivity analysis should include variation of traffic conditions • The sensitivity analysis should include variations in weather conditions • The sensitivity analysis should include variations in road conditions • The sensitivity analysis should include variations in vehicle characteristics	5

Contents

Figures

Tables

1 Purpose of the document

Within the AEROFLEX project innovative vehicles and vehicle configurations are designed, developed, demonstrated, tested and assessed in a period of less than 4 years. In the final months of the project, the results need to be analysed and translated to recommendations on the implementation of these new vehicle concepts. In this period three different work packages (WPs) will produce three deliverables to conclude the work of the project:

- D1.3: Market analysis and GHG emission changes by new vehicle concepts
- D6.6 Final technical assessment results
- D7.2 Book of Recommendation. Models validation and future regulatory framework proposals.

The final technical assessment is not only a deliverable on its own but provides input to the other two deliverables by analysing and generalizing the developed technologies and reference and demonstrator tests performed in WP6. This means that the final technical assessment plays an important role in the translation of the results of the individual work packages to the overall project results. Figure 1-1 shows these interdependencies schematically.

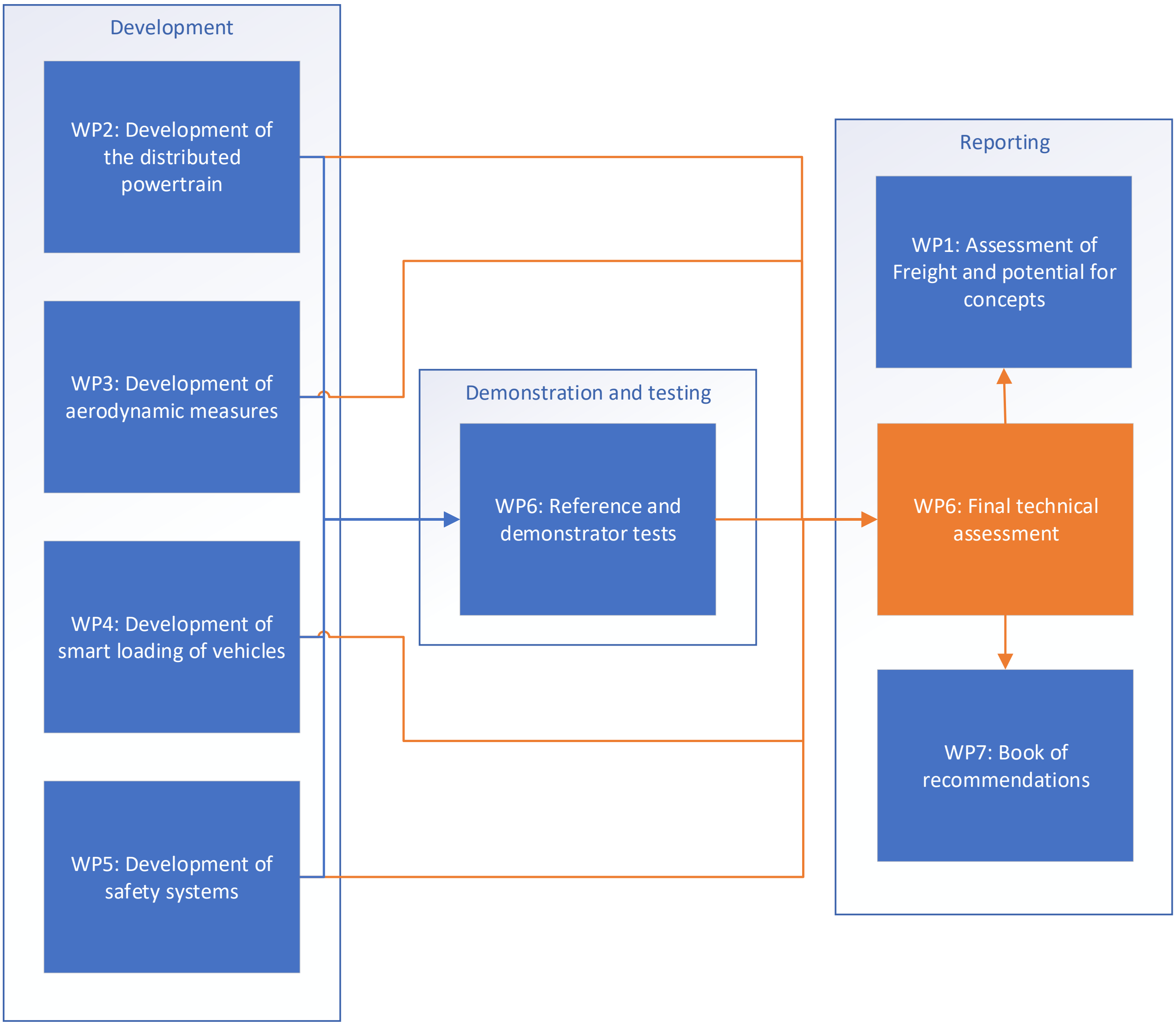

Figure 1-1 Dependencies between the final technical assessment and other actions within the AEROFLEX project.

The short time period in which the analyses need to be performed and the large impact on the final result of the project necessitate that the assessment framework needs to be explained and agreed upon with all project partners well before the critical final months of the project. This alignment within the project is the main goal of the actions performed in task 6.2 and the report to be written based on these actions.

2 Introduction

In this document the final technical assessment, that will be performed in task 6.6, is defined. It describes the existing data and models that will be used but also the models and scenarios that still need to be developed. For the other work packages, it provides an overview on what to expect from the final technical assessment but also on what is expected from these WP's. It gives an opportunity to reflect on the methods and inputs used while there is still enough time to make changes if necessary.

For this reason, a pilot assessment was added to the scope of the deliverable. This pilot assessment serves to conform the project partners with potential outcomes of the technical assessment, which already have the appearance of potential end results. Obviously, the goal of these potential outcomes is to have an in-depth discussion on the potential results and the way they are calculated and presented versus the objectives of the project and the expectations of the project partners.

In chapter 3 the **requirements and constraints** of the final technical assessment are described. The assessment is a deliverable which is described in the Grant Agreement of the project. Secondly, the assessment provides results to other work packages. Finally, the assessment is part of the final result of the project. Since there are multiple deliverables belonging to this final result it should be clear what is reported by the technical assessment and what is reported by the other deliverables.

Chapter 4 describes in detail the **assessment framework** that is proposed to be used in the final technical assessment of the AEROFLEX project. The framework shows the validity of the approach and includes at least the used assessment methods, the input parameters and the outputs.

Chapter 5 describes the planned simulations with the assessment framework. These consist of the pilot assessment, the calibration and validation of the models, a sensitivity analysis and finally the final technical assessment.

A **pilot assessment** is carried out with the inputs already available and supplemented with assumptions. As said, the pilot assessment shows the type of results to be generated by the technical assessment and allows project partners to give feedback on these results so that the results from the actual technical assessment reflect their wishes. The results of the pilot assessment are given in chapter 6.

Finally, in chapter 7 the assessment framework and matrix are tested against the requirements and constraints stated in the third chapter. This will prove if the proposed assessment framework is fit for the task it needs to perform.

3 Requirements and constraints to the final technical assessment

The first step in the definition of the assessment framework is to look at the requirements and constraints. This is done by looking at the function of the technical assessment within the AEROFLEX project. The total project is shown in Figure 3-1.

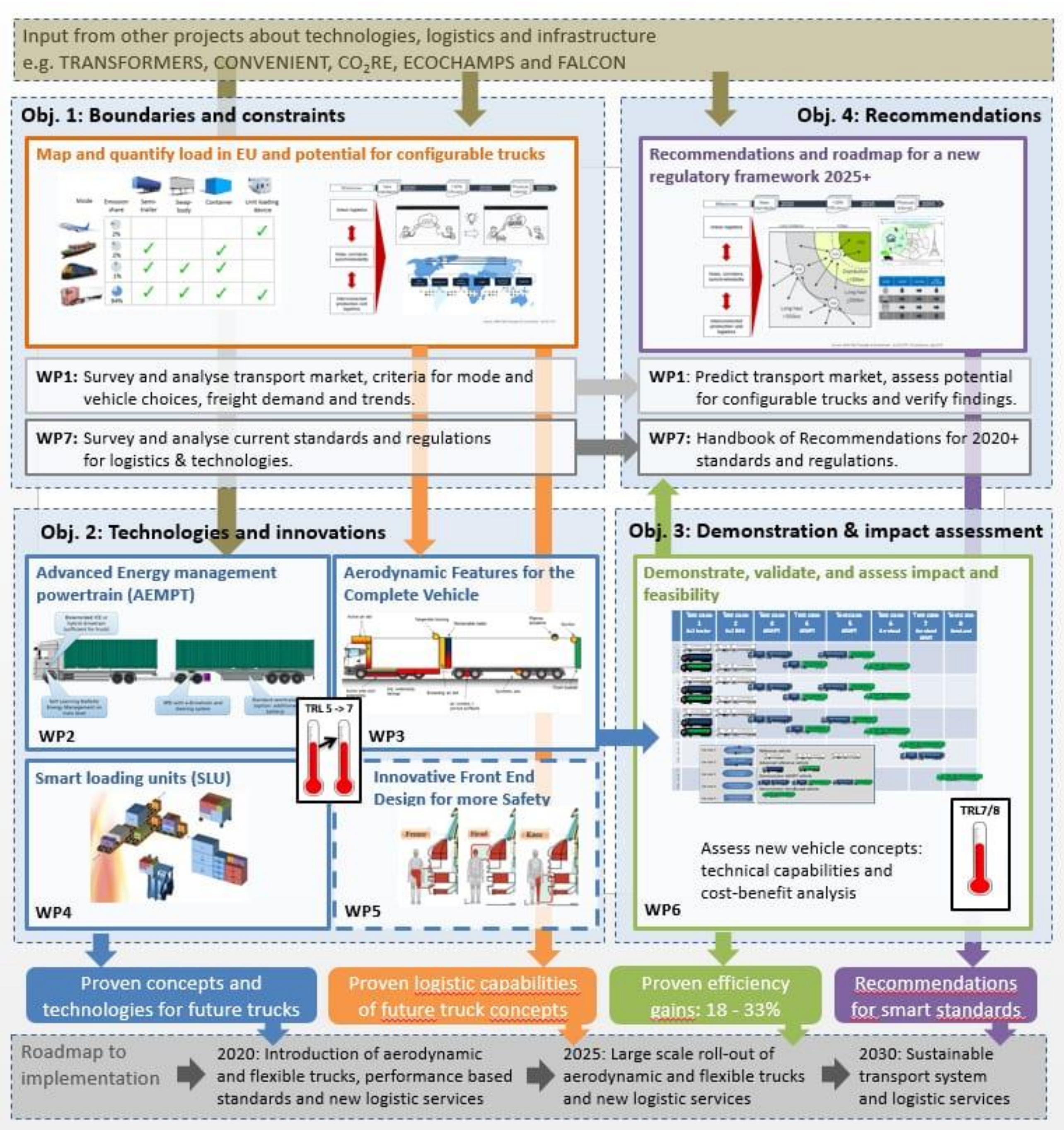

Figure 3-1 Overview of the AEROFLEX project (source (Kraaijenhagen, 2019))

The main objective of the AEROFLEX project is to develop and demonstrate innovations and technologies for the next generation of long-distance road transport. This objective is divided into four sub-objectives being:

- Objective 1: Setting the boundaries and constraints
- Objective 2: Developing technologies and innovations

- Objective 3: Demonstration and impact assessment
- Objective 4: Recommendations

The technical assessment is part of objective 3, demonstration and impact assessment. This objective, being performed by Work Package (WP) 6, is concerned with the demonstration, validation and assessment of impact and feasibility of the technologies and innovations developed by WP2,3,4 and 5. The outputs of WP6 are:

- Proven efficiency gains (target 18-33%)
- Providing input for WP1 and WP7 that can be used for the definition of recommendations and roadmap for a new regulatory framework.

The role of the final technical assessment within WP6 is to build on the results of the reference and demonstrator tests, being performed with the actual vehicles on the road. These tests are the most realistic means to actually measure the efficiency of the vehicles. However, the efficiency of a vehicle concept is affected by numerous factors depending on e.g. the road-transport applications (e.g. length of the routes, payload, number of stops, multimodality), the location (temperature, weather conditions, regulations) and the routes (speed limit, elevation, traffic) in which the vehicle concept is being deployed. It may be clear that it is impossible to test all possible combinations of factors within the limited time and resources of the project. The simulation studies performed within the final technical assessment are meant to identify those factors that influence the performance of the vehicle combinations and to assess them if they have not been assessed by the on-road tests.

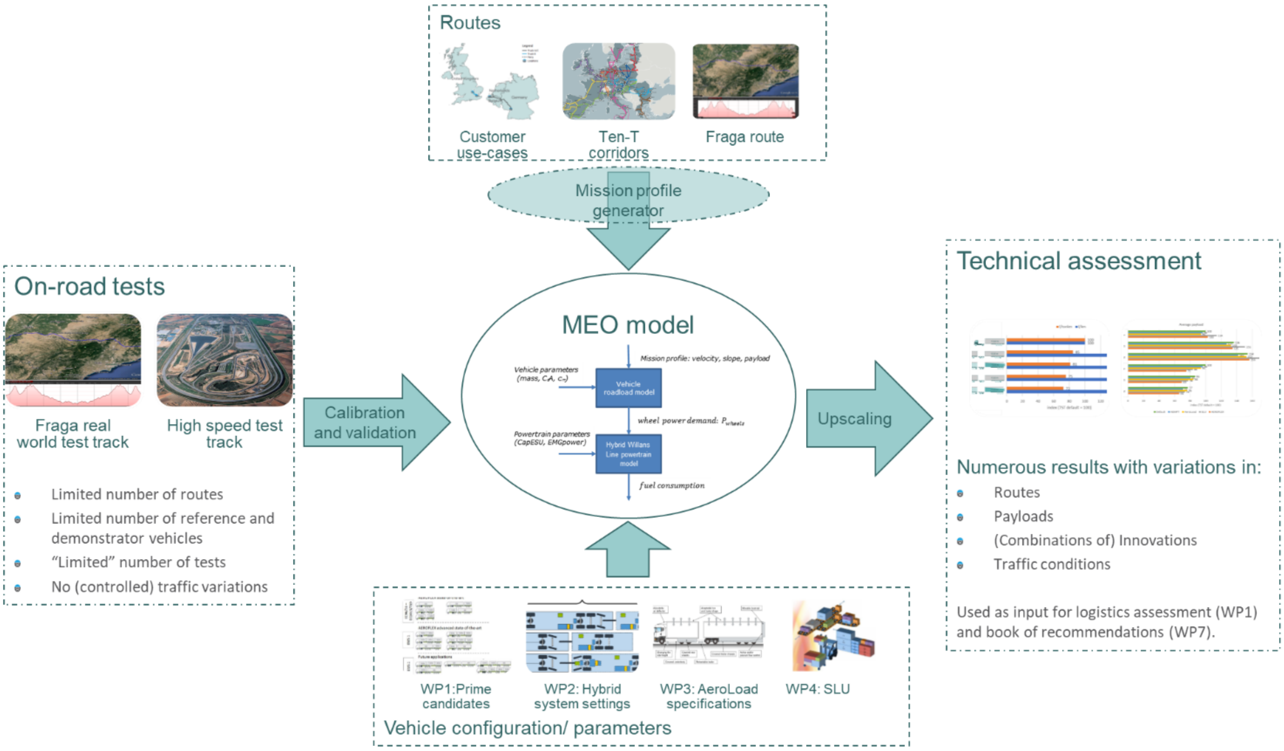

Figure 3-2 Schematic overview of the assessment framework

Figure 3-2 summarizes the assessment framework and its relation to other WPs and tasks within the project. In one sentence the functional description of the assessment framework is

To assess the efficiency improvement potential of AEROFLEX innovations in typical European long-haul road operations, building on the reference and demonstrator test results, using realistic simulations and providing input to the impact assessment of the EU freight transport and book of recommendations.

The next sections zoom in on the separate sections of this description and generate functional requirements to the assessment framework. In chapter 7 will be concluded to what extend the developed framework complies to these requirements.

3.1 Efficiency assessment

The main target of the AEROFLEX innovations and technologies is to improve efficiency of long-haul road transport by 18-33%. Depending on the definition, efficiency can be measured with various indicators, e.g. fuel efficiency, cost efficiency or time efficiency. The definition of efficiency within the AEROFLEX project is described in deliverable 6.1 (Eijk, Mentink, & Freixas, 2019). A distinction is made between transport efficiency, measured in €/(t)km and fuel efficiency, measured in l/(t)km. The transport efficiency will be assessed in the impact assessment in WP1 while the fuel efficiency is being assessed in the technical assessment. This is summarized in Figure 3-3.

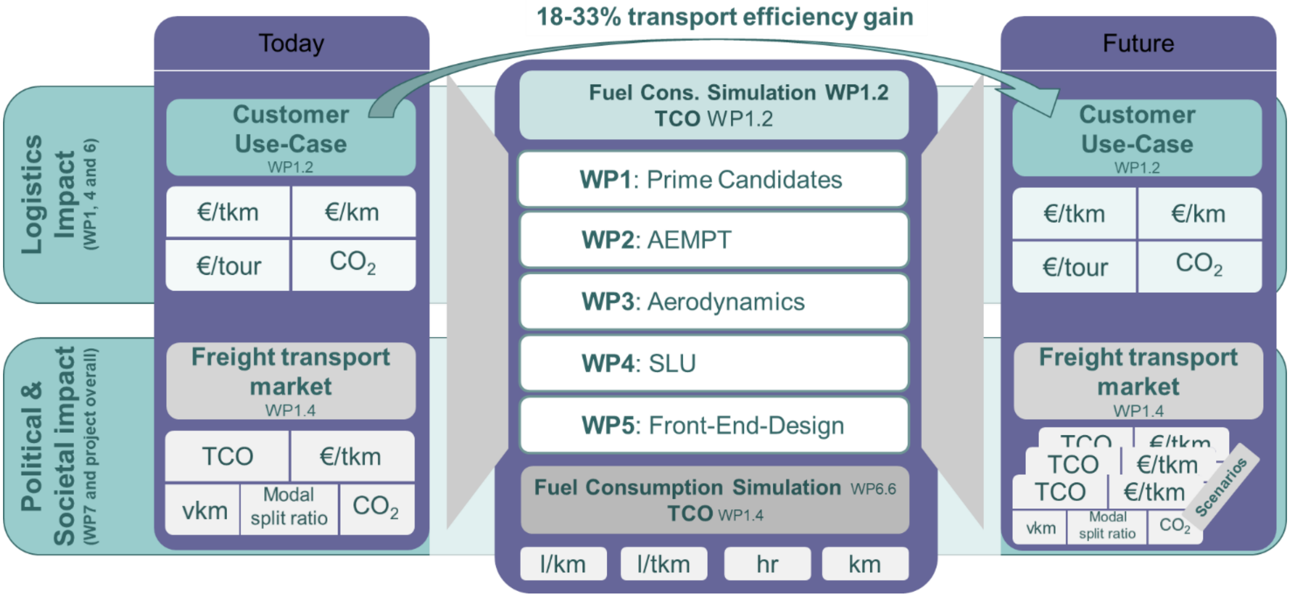

Figure 3-3 Efficiency assessments within AEROFLEX (Eijk, Mentink, & Freixas, 2019)

The focus within the technical assessment is thus on fuel efficiency, more specific how many litres of fuel are required to drive the vehicle for one kilometre (l/km) or to move one tonne of payload for one kilometre (l/tkm). Of course, the fuel consumption depends on a lot of other factors than just the vehicle that is being used. In order to make a fair comparison, and only assess that efficiency gain that is caused by using a different vehicle concept, the efficiency comparison will only be made between vehicle concepts that:

- Ship the same amount of payload;
- Over the same routes;
- In the same conditions;
- With the same average speed.

The last bullet makes that not only the distance but also the time should be considered in the assessment. This is also visible in Figure 3-3, where time is an output of the fuel consumption simulations.

In conclusion, the following functional requirements to the assessment framework can be defined:

- 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;

3.2 AEROFLEX innovations

All technologies and innovations, developed within the AEROFLEX project should be assessed in the final technical assessment, if they contribute to a change in fuel consumption or fuel efficiency. In this section the different WPs that develop technologies and innovations are discussed:

- WP2: Advanced Energy Management Powertrain (AEMPT)
- WP3: Aerodynamic features for the complete vehicle
- WP4: Smart Loading Units (SLU)
- WP5: Innovative front-end design for more safety.

WP2 focusses on the design and development of an Advanced Energy Management Powertrain (AEMPT). The design builds on the hybrid powertrain solution developed in the TRANSFORMERS project (Zyl, et al., 2017). In the TRANSFORMERS project the hybrid powertrain consisted of a tractor with an e-trailer that was used for brake energy recuperation. In WP2 the focus is on an EMS1 vehicle with the AEROFLEX e-trailer, and electric dolly and a Global Energy and Torque Management (GETMS) system to divide the work between the 3 driven axles. The design is shown in Figure 3-4. For the final technical assessment this means that the simulations should include a hybrid drivetrain and a torque split control system.

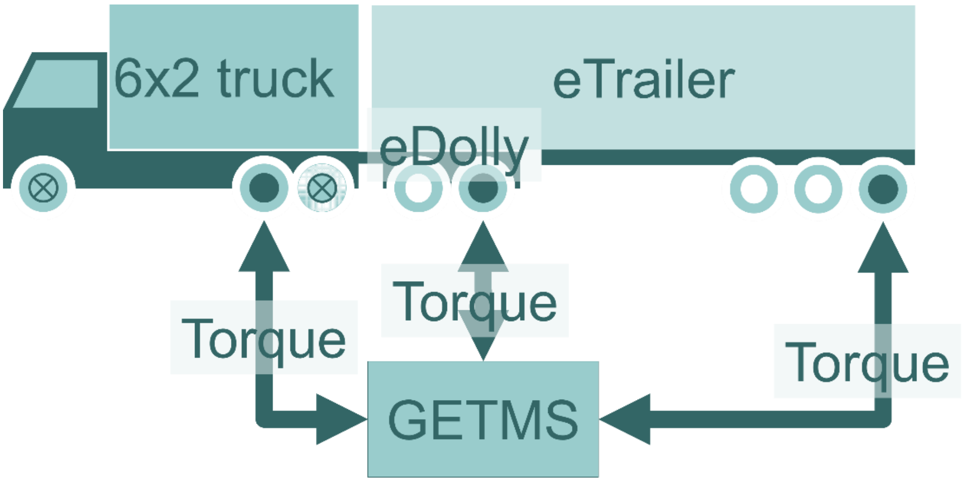

Figure 3-4 AEMPT demonstrator vehicle

In WP3 aerodynamic features are developed in order to reduce the air drag of the vehicle. The considered solutions for the demonstrator vehicle are shown in Figure 3-5. The figure shows passive flow control systems such as the underbody panel and dolly skirt. These features are fixed onto the vehicle and reduce the drag coefficient. But the figure also shows active flow control systems like the gap reducer and active ride height. These systems are only activated if the driving conditions allow it. For example, the gap reducer will only be activated on motorways since it decreases the manoeuvrability of the vehicle. For the technical assessment this means that not only passive flow control systems should be simulated but also active flow control systems, of which the effect depends on e.g. the speed of the vehicle.

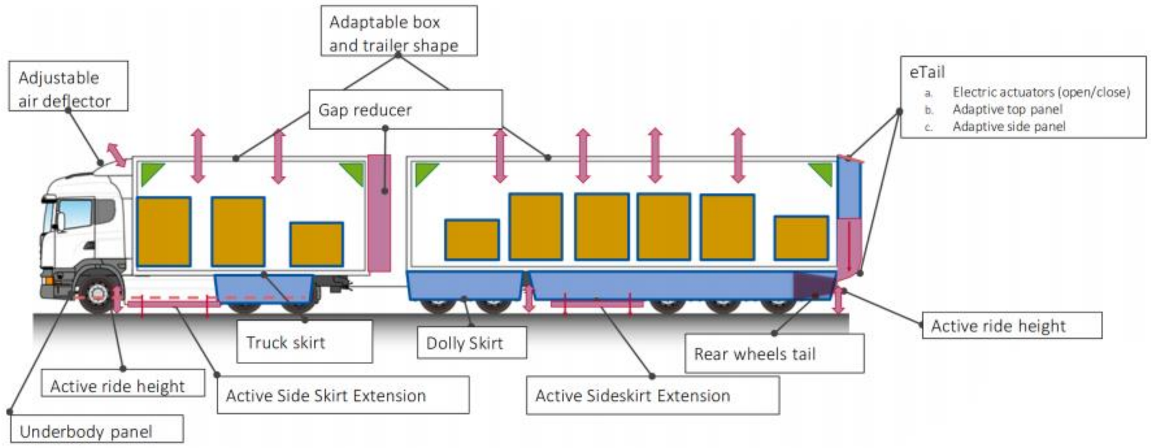

Figure 3-5 WP3 demonstrator vehicle

The focus of WP4 is not on the vehicle itself but on the cargo that it transports and the way in which this is loaded to the vehicle. Within WP4 three different concepts are considered (Eibrand, 2019). The first concept is the concept of multimodality. The main idea behind this concept is that a trailer should be designed in such a way that it is possible to load it onto a train or ferry. The second concept is the concept of loading space efficiency. The concept focusses on decreasing the empty space inside a trailer. Different solutions are considered such as a double load floor and cargo planning software. The third concept is horizontal collaboration. The idea behind this concept is that shipments of heavy but low volume goods are combined with shipments of high volume but low weight goods (see example in Figure 3-6). Other than the WP2 and 3 innovations it is impossible to simulate a “SLU vehicle” since each concept is only applicable for some logistic operations. However, what the concepts have in common is that the average load factor increases and less vehicles are required to ship the same amount of goods. In order to capture this efficiency gain in the assessment framework, it is not enough to simulate a single vehicle. Therefore, the assessment framework should include the capability to perform fleet level analyses.

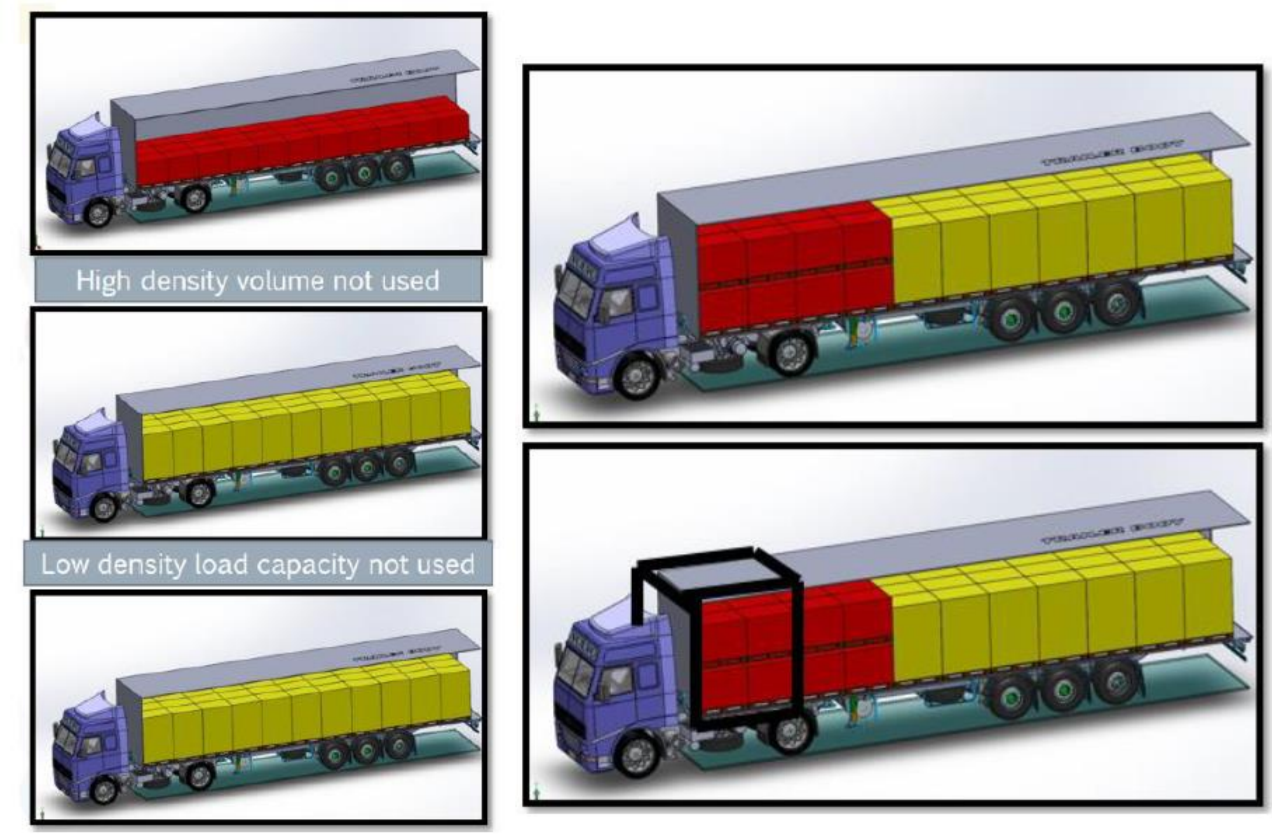

Figure 3-6 Horizontal collaboration with the use of Smart Loading Units (Eibrand, 2019)

WP5 focusses on increasing the safety of the vehicle. The main purpose of this WP is to reduce the number of fatalities and seriously injured persons from accidents with heavy duty vehicles by an innovative front-end design. Although this does not seem to affect the fuel consumption of a vehicle, the front-end design might influence the shape and aerodynamics of the vehicle. Therefore, it should be included in the final technical assessment.

In conclusion, simulation of AEROFLEX innovations induces the following requirements to the final technical assessment:

- The assessment framework should allow for the simulation of hybrid drivetrains;
- The assessment framework should allow for the simulation of torque management systems;
- The assessment framework should be able to simulate passive flow control systems;
- The assessment framework should be able to simulate active flow control systems, where the aerodynamics of the vehicle depend on speed or direction of the vehicle;
- The assessment framework should allow for fleet level simulations.
- The assessment matrix should include simulations of trucks and tractors with extended fronts.

3.3 Typical European long-haul road transport operations

With the final technical assessment, the potential fuel efficiency gains of the AEROFLEX innovations for typical European long-haul operations should be estimated. In (Eijk, Mentink, & Freixas, 2019) a set of customer use-cases has been selected as representative for this cause. This means that the requirement regarding typical European long-haul operations has already been satisfied and will not be elaborated on further in this document. For completeness sake the requirement that the final technical assessment should satisfy is the following:

- 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.

3.4 On-road test results

The AEROFLEX innovations will be tested extensively in the test program described in (Freixas & Mentink, 2019). In the reference tests current state-of-the-art vehicles without AEROFLEX innovations are tested while in the demonstrator tests demonstrator vehicles with AEROFLEX innovations are tested. The final technical assessment will simulate a lot more vehicles on a lot more routes but for the vehicles that are tested in the test program, similar results should be calculated. Therefore, the models should be calibrated and validated with the reference and demonstrator test results:

- The assessment framework should be calibrated with reference and demonstrator test results;
- The assessment framework should be validated with reference and demonstrator test results.

3.5 Realistic simulations

Calibration and validation with the test program ensures that the assessment framework generates good results for routes similar to the ones driven in the test program. However, the conditions of the routes in the test program do not necessarily represent typical conditions. First, the test program is conducted on a test track, closed for other traffic and a test route on the open road with very little traffic. This means that traffic conditions such as congestion play little to no role in the test program. Second, the test program is conducted in the South of Europe, meaning warm and predominantly warm weather conditions. Third, as mentioned above, only one on-road route is included in the test program. This route is almost only on highways and has quite some elevation changes. Finally, only a small set of vehicles is used with specific characteristics such as powertrain and trailer design. All these factors should be analysed in a sensitivity analysis:

- The sensitivity analysis should include variation of traffic conditions
- The sensitivity analysis should include variations in weather conditions
- The sensitivity analysis should include variations in road conditions
- The sensitivity analysis should include variations in vehicle characteristics

3.6 Conclusion

In the introduction of this chapter the functional description of the assessment framework was summarized as in the following sentence:

To assess the efficiency improvement potential of AEROFLEX innovations in typical European long-haul road operations, building on the reference and demonstrator test results, using realistic simulations and providing input to the impact assessment of the EU freight transport and book of recommendations.

In the sections following this introduction, a set of requirements is composed. Table 3-1 shows these requirements and the chapter in which the satisfaction of each requirement is described. In chapter 7 each requirement and the way in which it is or will be met is discussed.

Table 3-1 Requirements to the assessment framework

Group	Requirements	Chapter /reference
Fuel 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;	4.5
AEROFLEX innovations	• The assessment framework should allow for the simulation of hybrid drivetrains; • The assessment framework should allow for the simulation of torque management systems; • The assessment framework should be able to simulate passive flow control systems; • The assessment framework should be able to simulate active flow control systems, where the aerodynamics of the vehicle depend on speed or direction of the vehicle; • The assessment framework should allow for fleet level simulations.	4.4
Typical European long-haul road transport operations	• The assessment matrix should consist of selected use-cases for typical long-haul road transports in Europe, representing at least major goods categories and applications.	(Eijk, Mentink, & Freixas, 2019)
Test results	• The assessment framework should be calibrated with reference and demonstrator test results; • The assessment framework should be validated with reference and demonstrator test results.	5
Realistic simulations	• The sensitivity analysis should include variation of traffic conditions • The sensitivity analysis should include variations in weather conditions • The sensitivity analysis should include variations in road conditions • The sensitivity analysis should include variations in vehicle characteristics	5

4 Definition of the Assessment framework

Considering the requirements and constraints from chapter 3, an assessment framework has been defined in order to perform the final technical assessment. This chapter describes the proposed assessment framework and includes all inputs, models and results. First the objective of the assessment framework is given in section 4.1. In section 4.2 an overview of the entire assessment framework is given. In the sections after that, the inputs, models and outputs of the assessment framework are described step by step, e.g. 4.3, 4.4, 4.5 and 4.6 respectively.

4.1 Objective of the assessment framework

In the AEROFLEX project new vehicle concepts are designed, developed, demonstrated, tested, simulated and assessed. These vehicles are supposed to improve the total efficiency of the transport network: The same amount of goods can be transported with less energy, fuel and consequently CO_2-emissions and other harmful emissions such as NO_x.

The technical assessment is in between the real-world measurement tests at IDIADA and the impact assessment to EU freight transport performed by WP1. The real-world tests will test the vehicle efficiency targets set by the different WP's for specific transport applications (as explained in (Freixas & Mentink, 2019)). In the impact assessment, the total transport efficiency gains from introducing new vehicle concepts will be analysed. In other words, what will be the effect on the total of all vehicles and all transport applications in Europe? The technical assessment will look at the impact of the AEROFLEX innovations on transport efficiency for transport applications, other than the ones tested in the on-road tests. Furthermore, the technical assessment will also look at vehicles and vehicle configurations, other than the demonstrator vehicles, equipped with AEROFLEX innovations. The objective of the assessment framework should thus be ***to enable calculating the energy efficiency for any given vehicle, equipped with any given AEROFLEX innovation or combination of innovations, used in any given transport application.***

4.2 Overview

Following the objective stated in the previous section and the requirements to the assessment framework, the assessment framework has been defined. Figure 3-2 gives a schematic overview of the assessment framework and the relations with the other work packages. The Multi-model Energy Optimization (MEO)-tool (consisting of a physical road load model and a powertrain model) is used to calculate fuel consumption for individual transport applications. This model is calibrated and validated with the test results from task 6.4 and task 6.5, the real-world reference and demonstrator tests performed by IDIADA. Input on the vehicles, vehicle components and vehicle contents (payload) come from work package 1-5. The routes that these vehicles drive on are generated based on the on-road test cycles, customer use-cases and on the TEN-T corridors (see explanation in sub-section 4.3.1.3). The result will be a matrix with fuel consumption and fuel efficiency figures for a range of vehicles, AEROFLEX innovations and use-cases.

Figure 4-1 shows the steps taken in the fuel efficiency and transport efficiency calculations for a single trip. A trip is defined as a vehicle driving a single trip from origin to destination with a particular payload. A use-case can consist of multiple trips. Each step is summarized below:

- Based on the origin and destination of the trip, a route profile is generated. This is a schematic representation of the physical road that the vehicle drives on and consists of distance, elevation and speed limit.
- The vehicle with a certain payload, as used in the use-case, is simulated over the route profile in order to get a mission profile: a time-based speed/slope profile of a driven (or simulated) mission. Note that Smart Loading Units (SLU) innovations influence the assessment on this step by changing the payload or the selected vehicle.
- For each instance of the mission profile, a backwards facing road load model is utilized to calculate the power required from the wheels if the selected vehicle would have driven this mission. Aeroload innovations (drag reduction systems) developed by WP3 influence the assessment in this step by changing the drag working on the vehicle.
- With the use of a powertrain model, the fuel consumption [g/s] is calculated from the road-load. In this step, hybrid innovations influence the powertrain of the vehicle.
- Finally, the fuel consumption is integrated over time in the fuel calculation model and the energy consumption [l/km] and energy efficiency [l/tonne-km] is calculated.

In the following chapters each element of the figure will be described. In section 4.3 the inputs to the models are described, these are the blue and orange blocks in the picture. In section 4.4 the tools and models are described (the green ovals in the picture). Additional to the models in the picture, the upscaling to fleet and European transport level is described in this section. In section 4.5 finally, the results are described.

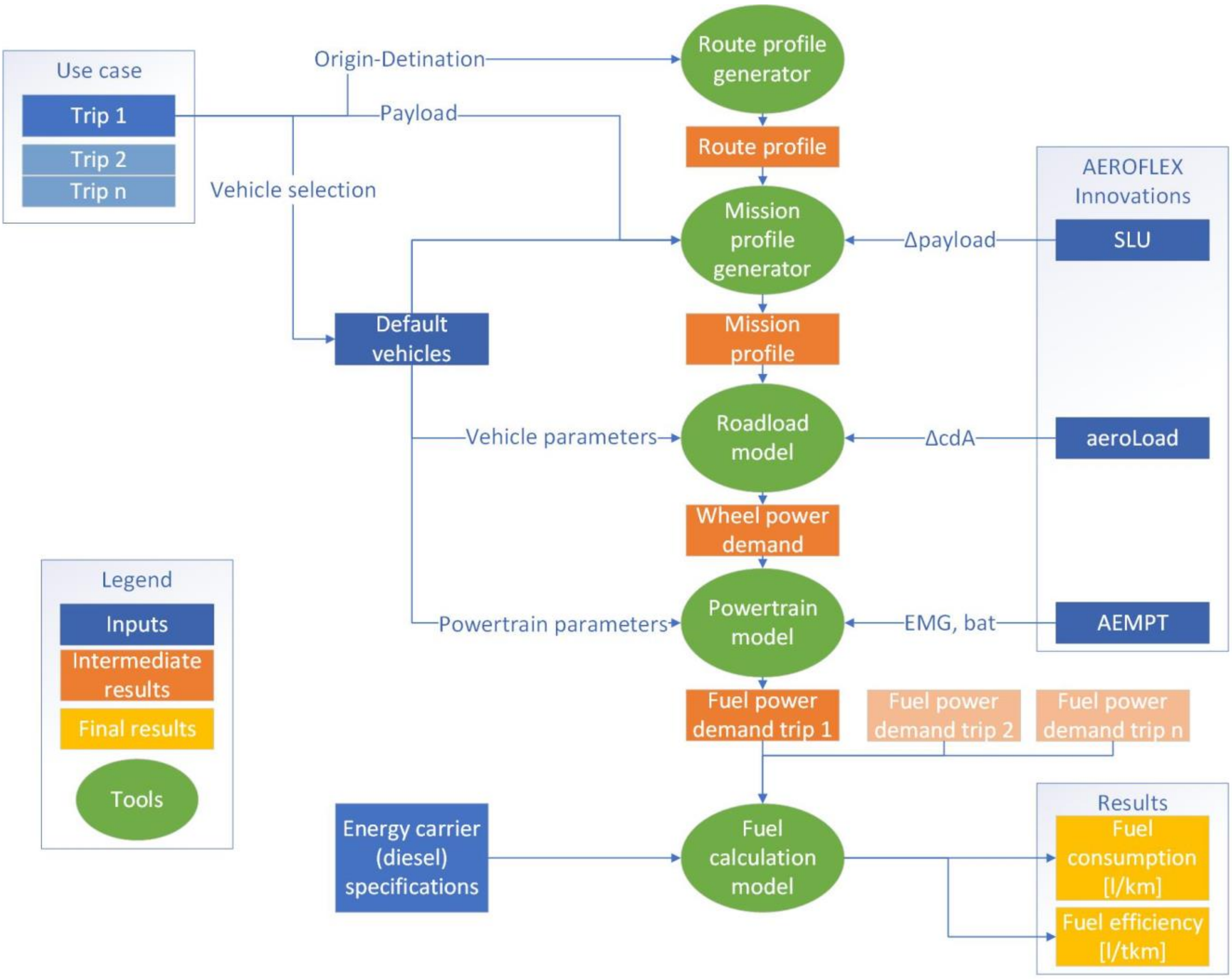

Figure 4-1: Overview of the assessment of a single vehicle driving a single trip. The results for single vehicles can be used for further assessment on fleet or European transport level.

4.3 Inputs

In this section the inputs, required by each of the tools, displayed as green ovals in Figure 4-1 are described in detail. For each input the source (or sources) and (if already known) values are given. Some models use the output of other models as input, these are described in this section as well.

4.3.1 Use-cases

A use-case describes the default inputs for the simulation study. A use-case specifies one or more vehicles, driving one or more trips, with loading, unloading or transhipment between the trips. A trip is defined as a route with an origin and a destination, driven by a single vehicle with a fixed payload.

4.3.1.1 Test use-cases

Test use-cases are used in the reference tests and demonstrator tests as performed by IDIADA in task 6.4 and 6.5. They consist of single vehicles, driving a single route. The route can be a steady-state speed test on a high-speed test track or an on-road test on the so-called Fraga route (the attributes of the routes are given in sub-section 4.3.4). The payload is either the average payload[3] or 100% payload (e.g. up to Gross Combination Weight). The vehicles are either reference vehicles or demonstrator vehicles (see sub-section 4.3.2.1 for a list of vehicles tested). The test use-cases are used for calibration and validation of the models used in the final technical assessment.

4.3.1.2 Customer use-cases

Customer use-cases are use-cases, given by logistics companies in expert interviews. They reflect typical use-cases that represent a selected example of their daily operations. The customer use-cases are gathered for task 1.2 but will be used throughout the project to assess the performance of AEROFLEX innovations on real logistics operations. For the final technical assessment eight of these customer use-cases are selected to be assessed in detail. The selection process that was used and a detailed description of each of the customer use-cases can be found in deliverable 6.1. The selected customer use-cases are summarized in Table 4-1.

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[3] 156.3 kg/m^3 loading space, as reported in the FALCON project (de Saxe, et al., 2018)

Table 4-1 Customer use-cases selected for technical assessment

Name	Description	Goods categorie	Location	Total distance	Total elevation change[4]	WP4 innovations	Current Prime Candidate	Desired future Prime Candidates
UC8	Germany short distance, heavy load	3: Metal ores and other mining and quarrying products; peat; uranium and thorium ores	Western Europe	115 km	1700 m		Truck-trailer	Tractor-semitrailer
UC10	Germany flat palettized	4: Food, beverages and tobacco	Western Europe	500 km	5400 m		Tractor-semitrailer	Tractor-semitrailer-dolly-semitrailer/Tractor-semitrailer-fulltrailer
UC15a	Austrian mountains	20: Other goods n.e.c.	Western Europe	630 km	20000 m		Rigid truck	Truck-trailer-(trailer)
UC19	Germany - Spain	12: Transport equipment	Southern Europe	1300 km	29500 m		Tractor-semitrailer	Truck-dolly-semitrailer
UC20	Turkey - Sweden shortsea, long distance	4: Food, beverages and tobacco	Eastern Europe	2960 km	39000 m	3. Horizontal Collaboration	Tractor-semitrailer	Tractor-semitrailer/ Tractor-linktrailer-semitrailer/Truck-dolly-semitrailer
UC22	Germany - England shortsea intermodal	18: Grouped goods: a mixture of types of goods which are transported together	Western Europe	1330 km	16300 m		Tractor-semitrailer	Tractor-semitrailer-dolly-semitrailer/Tractor-semitrailer-fulltrailer
UC31	Netherlands - Sweden truck-train intermodal	18: Grouped goods: a mixture of types of goods which are transported together	Northern Europe	830 km	6600 m	1. Multimodal Clusters2.0	Tractor-semitrailer	Tractor-semitrailer-dolly-semitrailer
UC99	Germany heavy and light weight	18: Grouped goods: a mixture of types of goods which are transported together	Western Europe	720 km	14000 m	2. Heavy and light weight palletized goods	Tractor-semitrailer	Tractor-semitrailer-dolly-semitrailer

Customer use-cases consist of a large variation of logistics patterns. The one thing they have in common is that at least a part of each use-case consists of long-haul road transport. For some of them part of the journey is performed by rail or ferry. The logistics companies that brought in the customer use-cases have stated the type of goods that are transported (including weight and volume), the origins, destinations and transhipment locations, the vehicles and loading units that are used and the number of times per day (or week) that these use-cases are performed. Additionally, they have stated which (longer or heavier) vehicles they would consider to use if regulations would allow them to do so.

4.3.1.3 TEN-T corridors

The Trans European Transport Networks (TEN-T) is a Europe-wide transport network consisting of roads, railway lines, inland waterways, maritime shipping routes, ports, airports and railroad terminals (European commission, 2019). The European Union promotes this network to perform as a high-speed intermodal long-distance connection through all member states. The network consists of 9 corridors as displayed in Figure 4-2. (Parts of) these corridors can be used to assess the performance of AEROFLEX vehicles and loading units in an intermodal context. In the final technical assessment at least two, to be selected, TEN-T corridors will be used for the analysis of long-distance intermodal transport.

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[4] The sum of the total ascent and descent of the route.

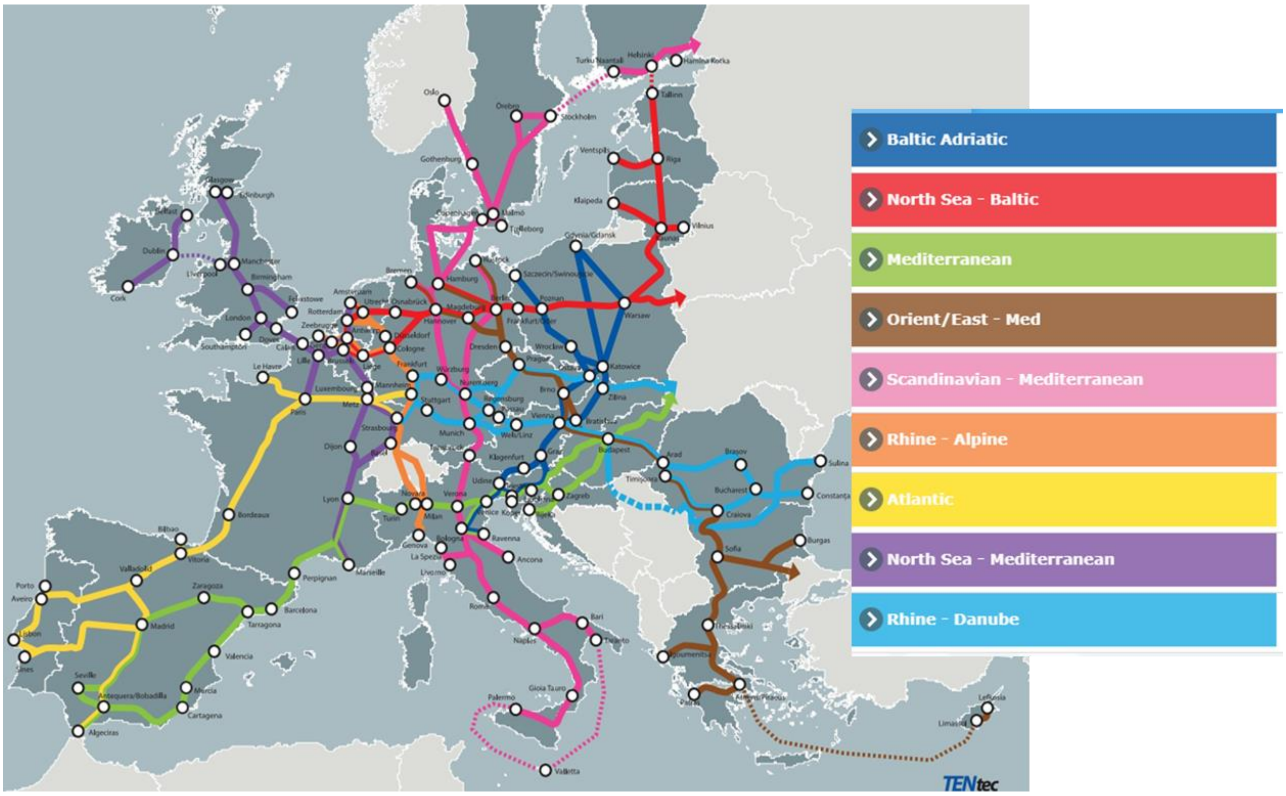


Figure 4-2 The TEN-T corridors (European commission, 2019)

4.3.2 Default Vehicles

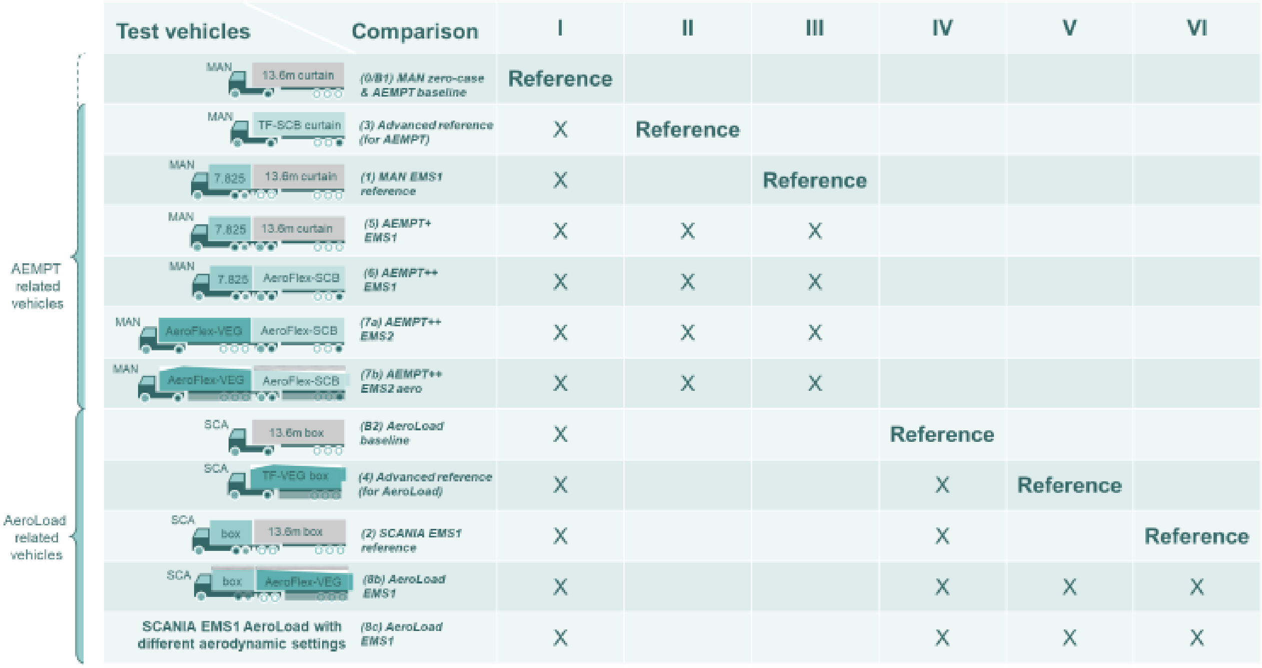
In the assessment framework the default vehicle consists of all properties of a vehicle before any AEROFLEX innovations are applied to the vehicle. In Table 4-2 all needed parameters of the vehicles are described.

Table 4-2 Default (conventional) vehicle parameters

Name	Unit	Description
Vehicle weight	kg	Empty weight of the vehicle combination
GCW	kg	Gross combination weight. Maximum allowable weight of the vehicle combination
N_{axles}	-	Number of axles
C_{rr}	-	Rolling resistance coefficient
C_{w}	-	Drag resistance coefficient (wind averaged)
A	m^2	Frontal area of the vehicle
η_{tm}	%	Transmission efficiency of drivetrain including gearbox and final drive (lumped)
η_{engine}	%	Internal Combustion Engine (ICE) efficiency
P_{rated} **engine**	kW	Rated power of the ICE
P_{aux}	kW	Averaged auxiliary power demand

4.3.2.1 Test vehicles

For the calibration and validation of the models the properties of the test vehicles need to be known. Figure 4-3 shows all vehicles that are tested in the reference and demonstrator tests by IDIADA. The reference columns indicate which vehicles can be compared to which reference vehicles for different efficiency comparisons.



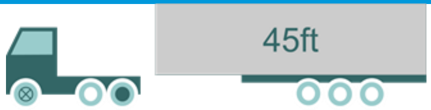
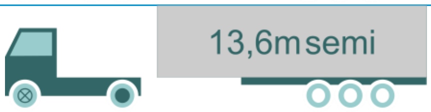
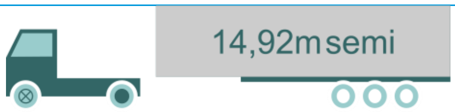
	Test vehicles	Comparison	I	II	III	IV	V	VI
	MAN 13.6m curtain	*(0/B1) MAN zero-case & AEMPT baseline*	Reference					
AEMPT related vehicles	MAN TF-SCB curtain	*(3) Advanced reference (for AEMPT)*	X	Reference				
	MAN 7.825 13.6m curtain	*(1) MAN EMS1 reference*	X		Reference			
	MAN 7.825 13.6m curtain	*(5) AEMPT+ EMS1*	X	X	X			
	MAN 7.825 AeroFlex-SCB	*(6) AEMPT++ EMS1*	X	X	X			
	MAN AeroFlex-VEG AeroFlex-SCB	*(7a) AEMPT++ EMS2*	X	X	X			
	MAN AeroFlex-VEG AeroFlex-SCB	*(7b) AEMPT++ EMS2 aero*	X	X	X			
AeroLoad related vehicles	SCA 13.6m box	*(B2) AeroLoad baseline*	X			Reference		
	SCA TF-VEG box	*(4) Advanced reference (for AeroLoad)*	X			X	Reference	
	SCA box 13.6m box	*(2) SCANIA EMS1 reference*	X			X		Reference
	SCA box AeroFlex-VEG	*(8b) AeroLoad EMS1*	X			X	X	X
	SCANIA EMS1 AeroLoad with different aerodynamic settings	*(8c) AeroLoad EMS1*	X			X	X	X

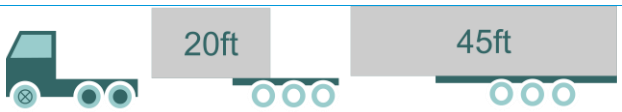
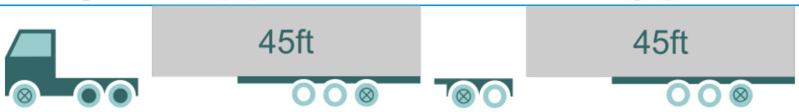
Figure 4-3 Test vehicles (Freixas & Mentink, 2019)

4.3.2.2 Prime Candidates

The main purpose of the final technical assessment is to assess the performance of the AEROFLEX innovations beyond the limited number of test cases that can be performed with real vehicles on real roads. As explained in section 4.3.1.2 the customer use cases are defined with a vehicle that is currently used and a vehicle that could potentially be used in the future. These vehicles are selected from a set of vehicle combinations called Prime Candidates. Prime Candidates are vehicle combinations built up from standardized towing vehicles and loading units, resulting from the FALCON (de Saxe, et al., 2018) project. Table 4-3 shows the prime candidates used in the AEROFLEX use-cases. For each use-case in the technical assessment, one of these vehicles will be simulated, as indicated in table 4-1.

Table 4-3 Prime candidates used in the assessment. The size in the loading units is the maximum possible length of the loading unit. I.e. a smaller loading unit might be used as well.

PC	Towing vehicle	Icon	Used for use-cases
1.1	Tractor		UC8 (future)
1.3	Tractor		Fraga, UC10, UC19, UC20, UC22, UC31, UC99 (reference), UC8 (future)
1.4	Tractor		UC20 (future)
2.1	Rigid truck		UC15a (future)
2.2	Rigid truck		UC8 (reference), UC15a (future)

3.4	Tractor		UC20 (future)
4.3	Rigid truck		Fraga, UC19, UC20, UC99 (future)
4.5	Rigid truck		UC15a (future)
6.1	Tractor		Fraga, UC10, UC19, UC20, UC22, UC31, UC99 (future)
6.2	Tractor		UC10, UC22 (future)

4.3.3 Route profiles

A route profile is a distance-based profile of a route that contains all information that is needed to simulate a vehicle driving on that route. Table 4-4 shows all variables in a route profile.

Table 4-4 Variables of a route profile

Name	Unit	Description
d_cum	m	Cumulative distance
elevation	m	Elevation
Speed_limit	km/h	Speed limit
Latitude	°	Latitude
Longitude	°	Longitude

4.3.4 Mission profiles

A mission profile is a recorded or simulated profile of a route travelled by a vehicle. The mission profile consists of the vehicle speed [km/h], road slope [rad] of the vehicle for each second of the route (i.e. a 1Hz signal). Figure 4-4 shows a simulated mission profile of the Fraga route.

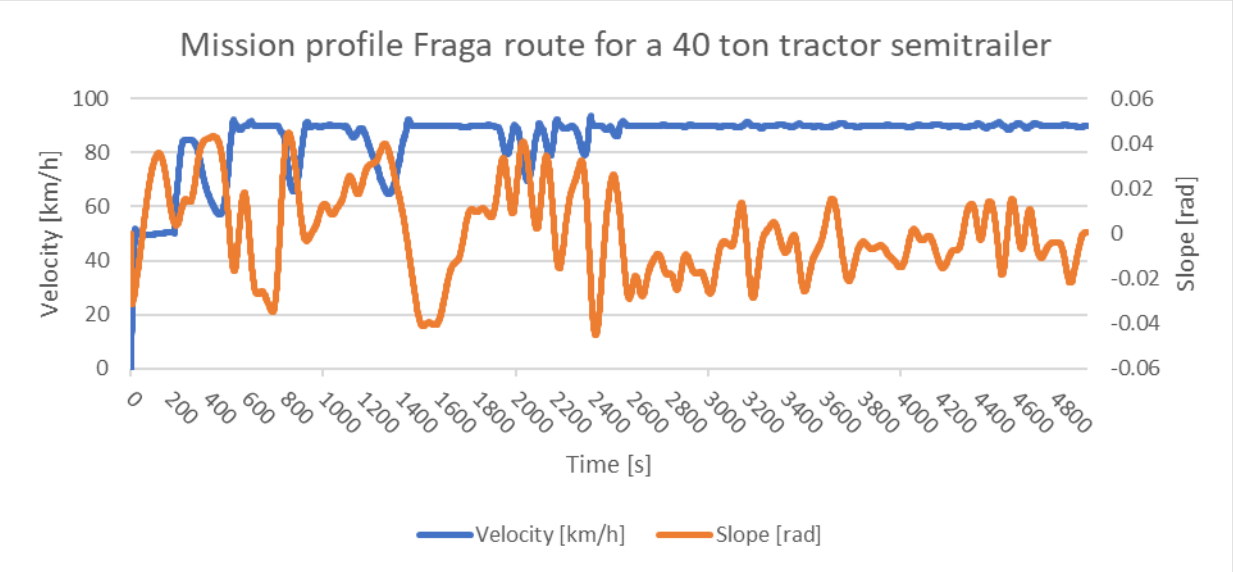


Figure 4-4 Simulated mission profile of a 40t tractor semitrailer on the Fraga route

4.3.5 Energy carriers

The energy carrier (fuel) that is used affects the amount of fuel required for 1 kWh of energy. For all assessments Diesel B7 meeting the EN590 standard will be used as energy carrier. This is the same fuel used by IDIADA in the on-road tests. The following energy carrier properties are used in the simulations[5]:

- Energy density at 15 °C [MJ/l]: 35.9
- CO2 Tank-To-Wheel [g/MJ]: 73.4
- CO2 Well-To-Wheel [g/MJ]: 89.0

Although mentioned here, the results of the technical assessment will not be reported in CO_2 emissions, but only in litres of fuel used. WP1 translates calculated fuel consumption to CO_2 emissions for the different scenario's being modelled using macroscopic simulations.

WP1 also requires AdBlue consumption as input to the impact assessment. The AdBlue consumption will be estimated linear to the diesel consumption at 5.2 litres per 100 litres diesel. This number is the average of a large set of fuelling registrations from Euro VI vehicles, analysed by TNO.

4.3.6 Innovations

When AEROFLEX innovations are applied to the vehicles, the parameters of these vehicles are changed and possibly new parameters or even models are required in order to model the innovations properly. In the following sections the required parameters per innovation type are listed.

4.3.6.1 AEMPT

The installation of an AEMPT system to a vehicle means that one or more trailer units of the vehicle combination (e.g. dolly and/or trailer) are electrified. This means that brake energy is recuperated and stored in a battery until it can be used by an electric motor to support the combustion engine. In order to model these systems, the size of the battery and maximum power of the electric motor are required, as well as the added weight of these components. Beside these hardware parameters software parameters are required to configure the power split controller used to simulate the AEMPT system (for an explanation see (Engasser, Mentink, Wagner, Kural, & Hierlmeier, 2019), chapter 3.6). The hardware parameters will need to be delivered by WP2 and the software parameters need to be tuned during the calibration of the model.

Table 4-5 Required parameters for the assessment of AEMPT innovations

Name	Unit	Description	Hardware/software
Battery capacity	kWh	Total capacity of all installed batteries	Hardware
Electric power	kW	Maximum electric power of the E-motor	Hardware
Weight	kg	Additional weight of the AEMPT system (possibly as a function of kWh and kW	Hardware
η_{motor}	%	Power conversion in motor mode	Software
$\eta_{generator}$	%	Power conversion in generator mode	Software
Battery loss factor	1/Wh	Battery loss factor	Software
η_{regen}	%	Regenerative braking efficiency	Software
$\eta_{battery}$	%	Battery efficiency	Software
I	-	I parameter for the PI controller	Software
P	-	P parameter for the PI controller	Software

4.3.6.2 Aerodynamic innovations

The aim of the aerodynamic measures is to reduce air drag experienced by the vehicle so by definition the air drag coefficient and frontal area of the vehicle could be reduced (or increased). Since aerodynamic features are installed on the vehicle the weight of the vehicle could also change. The measures also include active flow control measure which could increase auxiliary power use of the vehicle.

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[5] These properties are aligned with WP1 so that the same values will be used in the impact assessment and originates from JEC2014.

Table 4-6 Required parameters for the assessment of aerodynamic measures

Name	Unit	Description
ΔC_D	%	Relative change to the drag coefficient of the vehicle
ΔA	%	Relative change to the frontal area of the vehicle
Weight	Kg	Weight of the aerodynamic measures
ΔP_{aux}	kW	Averaged additional auxiliary power used by the aerodynamic measures

The ΔC_D value that is mentioned above is the wind-averaged ΔC_D while the air-drag test results from IDIADA give the air-drag at 0 yaw angle. These values will be translated to wind-averaged values by using the VECTO formulas.

4.3.6.3 Smart loading of vehicles

As is described in 3.2, the innovations proposed by WP4 do not change the performance of the vehicle itself but change the way in which the vehicle is used. Assessment of these innovations will be done by comparing a reference use-case with a future use-case. The future use-case might be that a larger share of the cargo space of the vehicle can be utilized due to smart loading units. Or larger, and thus less, vehicles might be used to transport the same cargo. One proposed innovation does change the vehicle: The use of a double load floor increases the empty weight of the vehicle. This is summarized in Table 4-7.

Table 4-7 Required parameters for the assessment of efficient loading of vehicles

Name	Unit	Description
Weight	Kg	Additional weight of the double load floor.

4.4 Tools and methods

4.4.1 Route profile generator

The route profile generator is a set of routines to generate a route profile from an origin, a destination and possibly intermediate locations using different type of databases both open and closed source. First a route is planned, which provides the longitudinal and lateral coordinates of the route. Consequently, additional information for each coordinate of the route is downloaded from the different databases and interpreted.

4.4.2 Mission profile generation

The TNO in-house modular powertrain simulation and design tool TNO-ADVANCE (Tillaart, Eelkema, & Vink, 2002; Eelkema, Vink, & Tillaart, 2002) is used to simulate default vehicles and generate mission profiles. The vehicles are simulated with a target speed approach, i.e. the vehicles aim at maintaining a given vehicle speed. The target speed in this case is the speed limit. The ADVANCE model is also capable of estimating the fuel efficiency for a given route. However, simulating all combinations of mission profiles, innovations and payloads would require to setup new simulation environments for each combination. This would take too much time and therefore a decision is made to use the ADVANCE simulation tool only for the default vehicles. The resulting mission profile will be used in further analysis to determine what would have been the fuel use if a vehicle would drive this mission profile (a backward simulation approach). In the calibration and validation of the mission profile generator a decision is made if different mission profiles should be created for different payloads and if so, how many (only for the empty and the full vehicle or also for a slight change in payload).

Driver behaviour, traffic density, road type and weather conditions are kept constant for all simulations. In the sensitivity analysis, prior to the technical assessment, the impact of these factors will be analysed.

4.4.3 Vehicle road load model and powertrain model

A hybrid Willan's line powertrain model will be used to calculate the fuel consumption. The approach has been used by TNO in the past to calculate CO_2-emissions of heavy-duty vehicles (van Zyl, Heijne, & Ligterink, 2017).

First, the power at the wheels vector is calculated with the road-load equation for each time instance of the mission profile:

$$P_{wheels} = P_{rolling} + P_{drag} + P_{inertia} + P_{gradient} \qquad \textbf{Eq.: 1}$$

$$P_{wheels} = mgC_{rr}\cos(\theta)\,v \; + \frac{1}{2} * \rho C_d A v^3 + ma^+ v + mgsin(\theta)v \qquad \text{Eq.: 2}$$

With the following parameters:
C_{rr} = coefficient of rolling resistance [-]
C_d = wind averaged drag coefficient [-]→ See section 4.4.5
g = earth's acceleration [m/s^2]
ρ = air density [kg/m^3]
A = frontal area of the vehicle [m^2]→ See section 4.4.5
m = vehicle mass (empty weight + payload) [kg]
θ = road gradient [rad]
v = instantaneous velocity [m/s]
a^+ = vehicle acceleration [m/s^2]

The power at the wheels vector can be split up into a positive part ($P_{traction}$) and a negative part ($P_{braking}$).

$$P_{traction} = P^+_{Wheels}$$
$$P_{braking} = P^-_{Wheels}$$

4.4.4 Powertrain model

In case of a conventional powertrain, e.g. diesel-powered combustion engine, a Willan's line approach is used. In case of AEMPT vehicles, the method as described in D2.1 is applied. Below a summary of that method is given. Electric trailers are lumped into a single electric unit consisting of a electric motor and battery model including torque split controller.

The battery model is as follows:

$$P_s = P_b - \beta P_b^2 \qquad \text{Eq.: 3}$$

$$S\dot{O}E = \frac{P_s}{E_{s\_cap} \times 3600 \times 1000} * 100\% \qquad \text{Eq.: 4}$$

where

P_b [W]:	Battery (dis-)charge at its terminal
P_s [W]:	Battery net stored power
β [-]:	Battery power conversion efficiency
E_{s_cap} [kWh]:	Initial battery capacity
$S\dot{O}E$ [%/s]:	Rate of change of State of Energy (SOE)

The power split controller is shown in Figure 4-5. The mode is chosen, based on the value of the equivalent electric power cost λ. A more detailed explanation can be found in (Engasser, Mentink, Wagner, Kural, & Hierlmeier, 2019).

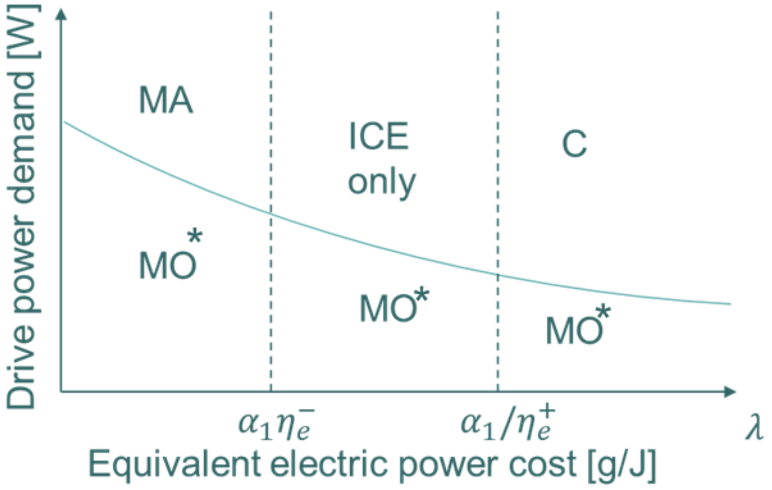


Figure 4-5 Hybrid modes allowed by the power split controller (Engasser, Mentink, Wagner, Kural, & Hierlmeier, 2019)

The possible modes are:

- **Charging while driving(C):** The internal combustion engine provides energy such that the battery can be charged. This can only occur if the engine is also used to propel the vehicle at the same time.
- **Internal combustion engine only (ICE only):** Only the internal combustion engine is used to propel the vehicle. The battery does not provide nor receive energy.
- **Motor assist (MA):** Both the internal combustion engine and the electric motor generator are used to propel the vehicle simultaneously. This mode uses energy from the battery.
- **Motor only (MO*):** Only the electric motor generator is used to propel the vehicle. The internal combustion engine is used only to power the auxiliaries. This mode uses energy from the battery.
- **Regeneration (R):** This mode occurs only when the demanded power from the powertrain is negative. In this mode, the battery is charged. If limits on the battery capacity or EMG are reached, the remaining energy is provided by the disc brakes. This mode is not displayed in Figure 4-5

Depending on the configuration of the controller all of these modes or a subset can be used. The AEMPT controller used in the project will probably not include the charging while driving and motor only modes, which means that the a trade-off is made between Motor-assist and ICE only.

4.4.5 Vehicles air drag model

The measures which will be developed by WP3 include active flow control measures. This means that the shape of the vehicle can change, depending on the wind direction or the speed of the vehicle. This means that fixed C_d and A values are no longer realistic. In a meeting with WP3 it has been decided that only variations in drag due to speed will be taken into consideration. This means that the air drag coefficient is a function of the speed of the vehicle. This will most likely be a threshold function, one value for vehicle speed lower than 50 km/h and one value for vehicle speeds above 50 km/h.

4.4.6 Fuel calculation model

Resulting from the powertrain model is a vector with the fuel mass flow $\dot{m}_{fuel}\ [kg/s]$ for each second of the mission profile. The fuel consumption, $FC\ [l]$ can now be calculated by integrating this vector over time and dividing by the density of the fuel:

$$FC\ [l] = \frac{1}{\rho_{fuel}} \int_{t_{start}}^{t_{end}} \dot{m}_{fuel}\, dt$$

Eq.: 5

Where $\dot{m}_{fuel}$ is the fuel mass flow at time t, ρ_{fuel} the diesel fuel density and FC is the fuel consumption.

The energy efficiency, $FC\ [l/tkm]$ is calculated by dividing the fuel consumption by the payload, $PL\ [t]$ and the distance, $d\ [km]$:

$$EE = \frac{FC}{PL \cdot d}$$

Eq.: 6

4.4.7 Transport application level analysis

The final technical assessment should also include assessments at the transport application level for innovations that change the payload of the vehicle. A transport application is defined here as the task of transporting a specific set of goods from an origin to a destination. In contrast to a use-case the vehicle (or vehicles) that is used and the route from origin to destination is not defined for a transport application.

The transport application level is used, when the upscaling to larger vehicles or loading units that allow for higher load factors, is analysed. An old situation (which can be a use-case!) where a fleet of existing vehicles transports a given amount of cargo is compared to a new situation where either the vehicle capacity or the load factor is increased. The total fuel consumption for the transport application can be calculated with the simple formula:

$$FC = \frac{l}{km} * \frac{km}{veh} * \#veh$$

Eq.: 7

FC = Total fuel consumption [l]
$\frac{l}{km}$ = fuel consumption per kilometre. Can be calculated by simulating the vehicle, route and payload
$\frac{km}{veh}$ = Travel distance. Known from the route of the use-case.
$\#veh$ = Number of vehicles

The number of vehicles that are needed depends on the load factor of the vehicle and the number of products that need to be shipped:

$$\#veh = \frac{veh}{ton} * \frac{ton}{m^3} * \frac{m^3}{prod} * \#prod$$

Eq.: 8

$\frac{veh}{ton}$ = Payload capacity of the vehicle.
$\frac{ton}{m^3}$ = Volume to weight ratio of the loading unit.
$\frac{m^3}{prod}$ = Volume that the loaded product takes inside the loading unit.
$\#prod$ = Number of products. Fixed

The second formula can best be explained by a couple of examples:

- When a larger vehicle is used the GCW of the vehicle could be increased: An EMS1 vehicle has a GCW capacity of 60 tons while a tractor semitrailer has a GCW of 40 tons.
- The use of a different loading unit could change the volume to weight ratio of the loading unit. I.e. the payload capacity stays the same but the volume capacity increases.
- When a double load floor is used, this means that more products can be loaded into the loading unit of the vehicle because of the increased pallets space.

The volume of the product inside the loading unit depends on the packaging, the handling unit (e.g. pallets), the loading unit and the way that it is all loaded into the vehicle. This should not be confused with the actual size of the product itself.

4.5 Outputs

For each analysis of a use-case the outputs generated are summarized in Table 4-8.

Table 4-8 outputs of the assessment framework

Model	Output	unit
Route profile generator	Travel distance	km
Mission profile generator	Travel time	s
Road-load model	Wheel power demand	kW
Powertrain model	Fuel consumption	l or l/km
Fuel consumption model	Energy efficiency	l/tonne-km
Transport application model	Energy efficiency	l/transport application
Fuel consumption model	AdBlue consumption	l/km

4.6 Conclusions

In the introduction of this chapter is stated that the assessment framework should be designed in such a way that it enables ***calculating the energy efficiency for any given vehicle, equipped with any given AEROFLEX innovation or combination of innovations, used in any given transport application.***

In this chapter a stepwise approach is proposed, which is depicted in Figure 4-1. A transport application or use-case can be described by a set of origins and destinations; the cargo that is shipped between each origin-destination pair and the vehicles that are used to ship the cargo. Based on an origin-destination pair a route profile is generated. The route profile is a distance-based profile of the route including slope, direction and speed limit. The vehicle with the cargo (payload) is simulated over this route to generate a mission profile; a time-based profile including slope of the road and speed of the vehicle. This mission profile is the basis on which the road load (power to wheels) and fuel power demand are calculated with the road load and powertrain models respectively. Using the same mission profiles for these calculations allows for a fair comparison between different scenarios (AEROFLEX innovations). From the fuel power demand, the fuel consumption (l/km) and fuel efficiency (l/tkm) is calculated. Multiplying the results with the number of vehicles used allows for fuel efficiency comparisons between different vehicle fleets (for example to calculate the fuel efficiency effect of logistic innovations).

5 Planned simulations with the assessment framework

In the previous chapter, the design of the assessment framework has been described. In this chapter all simulations that will be performed with this assessment framework will be described. This will be done based on the planning of the final technical assessment. The planning is shown in Figure 5-1. The first simulation results are included in the current document, namely the pilot assessment results. The main target of the pilot assessment is to show how the assessment framework works and what kind of results can be generated with the assessment framework. After completion of the pilot assessment, the calibration and validation phase starts. In this phase the model is tuned with the results from the reference and demonstrator tests at IDIADA. The main purpose of the phase is to have an assessment framework that is tuned to the results from the test matrix. At the very end of the project the actual final technical assessment is performed. The target of this assessment is to assess the developed AEROFLEX vehicles on European long-haul transport applications. In each phase of the assessment, different simulations are performed with different routes, vehicles and payloads (or cargo). The total of routes, vehicles and payloads are referred to as the assessment matrix which is described in this chapter.

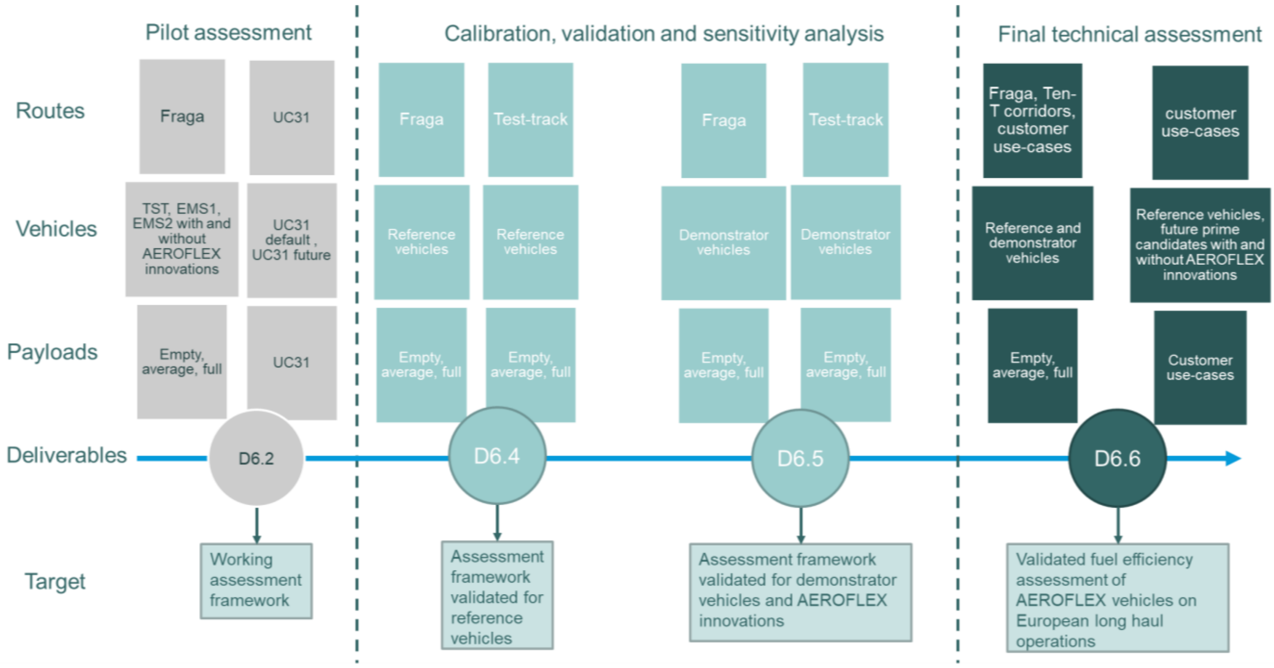


Figure 5-1 Phases in the technical assessment

5.1 Pilot assessment

The pilot assessment, which is described in detail in chapter 6, consists of two separate assessments. The first assessment focuses on the Fraga route and is used to show the effect of different sized vehicles and payloads on the simulation results. The assessment matrix consists of all possible combinations of the following inputs:

- Route: Fraga route
- Vehicles: tractor semitrailer, EMS1 (Rigid truck – dolly – semi-trailer), EMS2 (Tractor – semi-trailer – dolly – semi-trailer)
- Payloads: empty, average, full
- Innovations (scenarios): Default, AeroLoad, AEMPT, SLU, AEROFLEX.

In total, the Fraga pilot assessment matrix consists of 45 simulation runs.

The second pilot assessment focusses on the simulation of a customer use-case. The payload is fixed by the use-case and the assessment matrix consists of combinations of:

- Route: Leg 1, 3, 4, 5, 6, 8
- Vehicles: tractor semi-trailer, EMS2
- Scenario's: Default, AEROFLEX, default heavy, AEROFLEX heavy.

Since the tractor-semitrailer is only simulated with the default scenarios, the UC31 assessment matrix consists of 30 simulation runs (6 legs * 1 scenario for tractor -semitrailer and 6 legs * 4 scenarios for EMS2).

5.2 Calibration, validation and sensitivity analysis

Before the final technical assessment can take place, the models need to be calibrated to the vehicles and innovations of the AEROFLEX project. The calibration will be done with the measurement data from the reference and demonstrator tests. The following parameters need to be calibrated based on the reference tests:

- C_d*A for each vehicle combination/prime candidate
- η_{tm} for each pulling vehicle
- η_{engine} for each pulling vehicle

Based on the demonstrator tests, the following parameters need to be calibrated:

- η_{Regen} for each hybrid system
- $\eta_{battery}$ and battery loss factor for each battery
- η_{motor} for each hybrid system
- $\eta_{generator}$ for each hybrid system
- $\triangle C_d$*A for each (combination of) aerodynamic innovations.

Once the models are calibrated, they will be validated to test how well they compare to the measured vehicles. The assessment framework consists of different sub-models and calculation methods, as described in chapter 4. Some of these models include trivial conversions or calculations that have been used multiple times and are well documented. But some of the models are also developed specifically for the purpose of this task and need to be validated against real measurement results. For all the models the foreseen validation and calibration activities are described in this chapter. The tests performed by IDIADA are the main source for validation of the assessment framework. The results of these tests will be reported in the following deliverables (due dates in parenthesis):

- D6.4 (2020-03-31): Reference testing results
- D6.5 (2021-01-31): Demonstration testing results

Since the calibration and validation of the assessment framework will be performed directly following the testing of the vehicles, it is included in these deliverables.

In the route profile generator routes are generated from origin to destination. The route profiles consist of distance, elevation and speed limit:

- The distance calculation is based on the Open Street Map (OpenStreetMap, sd). This map is assumed to be well-defined as calculation of distances from coordinates is a trivial task. Common sense is used to check the trip distances, but no formal validation is performed
- The elevation profile is based on a filtered version of the elevation data from the Shuttle Radar Topography Mission (SRTM). This is an elevation map of the world based on radar measurements from a space shuttle. Many countries have more elevation maps, measured with LIDAR (LIght Detection And Ranging of Laser Imaging Detection And Ranging) from helicopters. This data will be used together with measured GPS-profiles of driven routes in hilly environments. At least the Fraga-route will be used for this validation. Furthermore, the generated profiles will be cross-checked with design restrictions of the road authority that manages the road (e.g. maximum slope on highways).
- The speed limits, gathered from the open street map, will be sample-checked by looking at speed limit signs on google street-view or on the streets outside.

The mission profile generator generates mission profiles for vehicles, based on the road profile and vehicle characteristics. The mission profile generator adds vehicle speed to the route profile. The following validations are foreseen:

- The variation in actual speed profiles (given the route and vehicle) can be checked by comparing different runs of the same vehicle on the Fraga route from the IDIADA tests. The difference between the simulated mission profiles and the actual driven mission profiles needs to be explained by this variation.

- Different mission profiles need to be generated for different vehicles and different payloads. A decision needs to be made when a change in payload is large enough to urge for a new mission profile to be simulated.
- The same holds for the AEMPT vehicles. Analysis of the demonstrator tests should show if AEMPT vehicles are able to drive faster uphill and thus new mission profiles need to be simulated for AEMPT vehicles.

The vehicle road load model and the hybrid powertrain model are used to calculate the energy that is required to fulfil the mission profile with a certain vehicle. In the case of a hybrid powertrain part of this energy comes from brake energy recuperation and part comes from the fuel. Based on the fuel energy the fuel consumption is calculated with a simple conversion. This means that the following needs to be validated with the measurement data:

- Total fuel consumption for an entire route
- Fuel consumption per second
- Total energy recuperation per hybrid axle
- Energy recuperation per second

If the validation is successful, this means that the model can predict the fuel consumption for reference vehicles and vehicles with AEROFLEX innovations. However, this can only be validated for those situations that actually occur on the test sites. Therefore, sensitivity analyses need to be carried out. As mentioned in section 3.5 at least the following sensitivity analyses are required:

- Variation of traffic conditions
- Variations in weather conditions
- Variations in road conditions
- Variations in vehicle characteristics

5.3 Final technical assessment

The final technical assessment will consist of the following two parts:

- Demonstrator assessment
- Customer use-cases assessment

The demonstrator tests assess the AEROFLEX demonstrator vehicles on routes, other than just the routes on which they are tested on the road. They will be compared to the reference vehicles from the test matrix. This means that the demonstrator tests consist of the following vehicles:

- Reference tractor semi-trailer
- Reference EMS1
- Reference EMS2
- AEMPT advanced reference
- AeroLoad advanced reference
- Demonstrator AEMPT+ EMS1
- Demonstrator AEMPT++ EMS1
- Demonstrator AEMPT++ EMS2
- Demonstrator AeroLoad

They will be compared on the following routes:

- Fraga route
- All eight selected customer use-case routes
- three to be selected TEN-T corridors

Furthermore, the following payloads will be compared:

- Empty
- Average
- Full

All roads will be calculated in average traffic conditions but for one route the following scenarios will be compared:

- Free-flowing traffic
- Average traffic
- Rush-hour traffic
- Congestion

The second part of the final technical assessment consists of the analysis of the selected customer use-cases. For all these customer use cases, the customers have stated the currently used (default) vehicle and maximum 3 preferred future prime candidates. Each customer use-case has its own fixed route. For each customer use-case the following scenarios will be compared:

- Current (default) vehicle
- Future prime candidate without AEROFLEX innovations
- Future prime candidate with AEROFLEX innovations

Which AEROFLEX innovations could be installed on which vehicles depends on the specific conditions of the use-case and the characteristics of the innovations. For each of the use-cases a first proposal will be made based on the customer interviews and the specification of the innovations. This proposal will be shared with the respective work packages and with the customer for approval.

5.4 Conclusion

In this chapter, the different simulations that will be conducted with the assessment framework have been described. Figure 5-1 shows that before the final technical assessment will take place serval other phases are still planned. Below each phase is summarized:

- Pilot assessment: The pilot assessment is used to show what the possibilities of the assessment framework are and what the results look like;
- Calibration, validation and sensitivity analysis: This phase is used to tune the models to the reference and demonstrator tests. After this phase it is known how well the models are capable to predict fuel consumption for reference and demonstrator vehicles. Furthermore, the sensitivity analysis puts a band with around the results.
- Final technical assessment: Two types of assessments are performed. The first tests what the fuel efficiency gains of the demonstrator vehicles would be if they drove on other roads than the Fraga route and the high-speed test-track. The second tests what the fuel efficiency gain could be if AEROFLEX innovations would be applied to actual logistic use-cases.

6 Pilot assessment

6.1 Introduction

The final technical assessment depends on the inputs from other work packages. The final inputs are expected to be received only in the final few months of the project. This means that the bulk of the analyses need to be performed in a short time window under high time pressure. In order to prepare the final technical assessment as good as possible, the assessment approach should be finished and accepted by all project partners so that the final technical assessment only consists of performing the simulations and calculations and not of refining the assessment approach to the comments from other work packages. One way of doing this is the description of the assessment framework in the current deliverable. However, experience teaches that not the description of a model, but the results generated by the model will trigger the most comments. In order to capture some of these comments from the other work packages and be able to include these inputs to the assessment framework, a pilot assessment has been performed. This pilot assessment captures a set of full analyses with the assessment framework, based on the inputs that are currently available, supplemented by engineering judgement. The analyses that are performed are the following:

- Pilot assessment 1: The Fraga route
- Pilot assessment 2: Customer use-case 31

All inputs and intermediate and end results of the analyses are presented in this chapter.

PLEASE NOTE: as should be clear from the introduction above, the results shown below are only meant for discussion purposes and give by no means an indication of the end results of the project. The aim of the pilot assessment is not to generate results but to show how results are calculated and presented.

6.2 Pilot assessment 1: Fraga route

6.2.1 Introduction

The ‘Fraga-route’ is a well-known route in the AEROFLEX project. It is used to perform the on-road fuel consumption tests for the reference and demonstrator vehicles. This means that for each tested vehicle combination, detailed measurement data will be available. This data can and will be used in the calibration and validation phase to tune and test the models. It makes sense to perform the pilot assessment on this route as well since it generates results that can be recognized by the project partners.

Figure 6-1 The Fraga route: from the IDIADA test site to Fraga and back through hilly terrain

The Fraga route is a route from the IDIADA proving ground to the inland city of Fraga and back, which is shown on Figure 6-1. The main characteristics of the route are summarized in Table 6-1. It shows that the route dominantly uses motorways and goes through hilly terrain. The length of the route is 242 km which means that it would take about 3 hours and 15 minutes to complete the trip with an average speed of 75 km/h. The route is usually not very busy which means that the traffic situation can be characterized as free flowing traffic.

Table 6-1 Characteristics of the Fraga route

Length	242.3 km
% motorway	97%
Total elevation change	+ - 2500 m
flat (<1%)	43%
hilly (1-<3%)	52%
% mountainous (>3%)	6%

6.2.2 Inputs

The vehicle combinations used for the pilot assessment are the same ones as are used in the reference and demonstrator tests. The main characteristics are summarized in Table 6-1. Note that none of these vehicles represents a specific brand.

Table 6-2 Default vehicle parameters used for the Fraga route

Parameter	Unit	TST	EMS1	EMS2
GCW	Kg	40000	60000	74000
NCW	Kg	15000	23500	27500
Payload average (156.3 kg/m^3)	Kg	13598	21422	27196
Payload full	Kg	25000	36500	46500
C_d*A	%	100	121	118
C_{RR}	-	0.006	0.006	0.006
Engine	kW	338	367	552
Vehicle combination	-			
Pulling unit	-	4*2 tractor	6*2 truck	6*4 tractor
Loading units	-	13.6 m semi-trailer	7.825 m swap-body 13.6 m semi-trailer	2*13.6m semi-trailer

The Gross Combination Weight (GCW) is the maximum allowed weight of the vehicle combination (empty vehicle and cargo). The values chosen are the same as are used in the test programme (Freixas & Mentink, 2019). The Net Combination Weight is the weight of the empty vehicle combination and is based on average values seen on the road:

- 4*2 tractor: 7500 kg;
- Semi-trailer: 7500 kg;
- 6*2 truck with swap body: 13500 kg;
- Dolly: 2500 kg;
- 6*4 truck: 10000 kg

The average payload is based on an analysis performed by the FALCON project (de Saxe, et al., 2018). Here, the EU average cargo density is estimated to be 156.3 kg/m^3. The average volume of a 13.6 m trailer is estimated at 87 m^3 and the average volume of a 7.825 m swap body at 50.06 m^3. The full or maximum payload is calculated by subtracting the NCW from the GCW.

The coefficient of drag and the frontal area (C_d*A) value for the tractor semitrailer is estimated, based on the air drag tests performed on the MAN reference vehicle by IDIADA. Since this value is classified, only the difference between the tractor semi-trailer and the EMS vehicles is given in this table. The values for the EMS vehicles are based on a small literature study on air drag for long and heavy vehicles (Martini, 2016) (Mihelic, Smith, & Matthew, 2018).

The coefficient of rolling resistance (C_{RR}) is an average value that is used for dry asphalt situations. The engine sizes are based on common values used for these types of vehicles.

The AEROFLEX innovations in the pilot assessment are based on what is currently known about the innovations on the demonstrator vehicles. The different options are summarized in Figure 6-2.

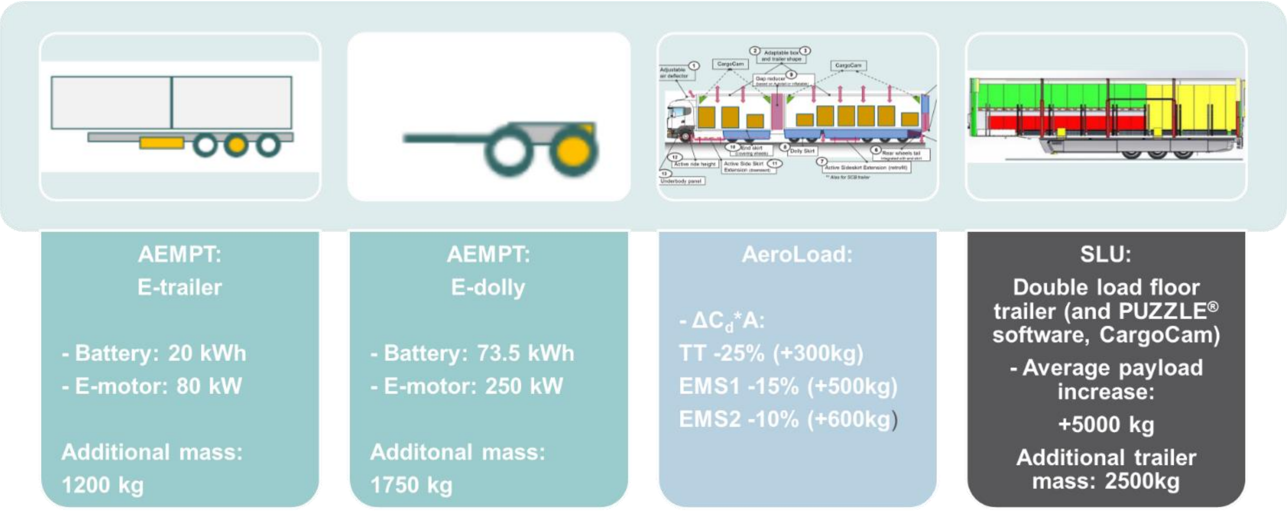


Figure 6-2 Possible AEROFLEX innovations considered in the pilot assessment

The specifications for the e-trailer are based on the TRANSFORMERS SCB trailer that will be used on the AEMPT demonstrator vehicle. The e-dolly specifications are based on the e-dolly that will be developed for the same demonstrator vehicle. Both specifications are checked with WP2.

The drag reduction factors for the AeroLoad tractor semi-trailer and the AeroLoad EMS1 are based on the targets specified in (Elofsson, 2018). The drag reduction factor for EMS2 and the weight penalties are based on discussions with WP2.

The concepts developed in WP4 are clear-cut solutions for specific logistic use-cases. The used technology and the potential fuel reduction strongly depend on the vehicle operation and the cargo of the vehicle. For demonstrative purposes a fictional use-case is created. The use-case entails that the combination of a double load floor, CargoCam® and PUZZLE® software can increase the payload on a trailer with 5000 kg by using the trailer volume more efficiently. The double load floor does add 2500 kg to the empty weight of the trailer.

Finally, four scenarios are given for each vehicle in Table 6-3. The reference scenario is the default vehicle without any AEROFLEX innovations. The AeroLoad, AEMPT and SLU scenarios include innovations from the three WPs and the AEROFLEX scenario includes a combination of all possible innovations.

Table 6-3 Scenarios considered for the Fraga pilot assessment

Scenario name	TST	EMS1	EMS2
Reference	-	-	-
AeroLoad	AeroLoad trailer	AeroLoad truck AeroLoad trailer	AeroLoad trailer 1 AeroLoad trailer 2
AEMPT	E-trailer	E-trailer E-dolly	E-trailer E-dolly
SLU	Double load floor trailer	Double load floor trailer	Double load floor trailer 1 Double load floor trailer 2
AEROFLEX	AeroLoad trailer E-trailer Double load floor trailer	AeroLoad truck AeroLoad trailer E-trailer	AeroLoad trailer 1 AeroLoad trailer 2 E-trailer

		E-dolly Double load floor trailer	E-dolly Double load floor trailer 1 Double load floor trailer 2

6.2.3 Results

In Figure 4-1 the steps performed in the assessment are shown. The results presented here include all the intermediate steps taken. The first step is the creation of a route profile, consisting of elevation and speed limit versus distance. Figure 6-3 shows the speed limits on the Fraga route. As mentioned, the route mainly consists of motorway with a speed limit of 100 km/h. Only the short distance from the test centre to the motorway has a speed limit of 50 km/h. In the middle the truck leaves the motorway for a short period, drives around a roundabout and returns to the motorway to start the return trip.

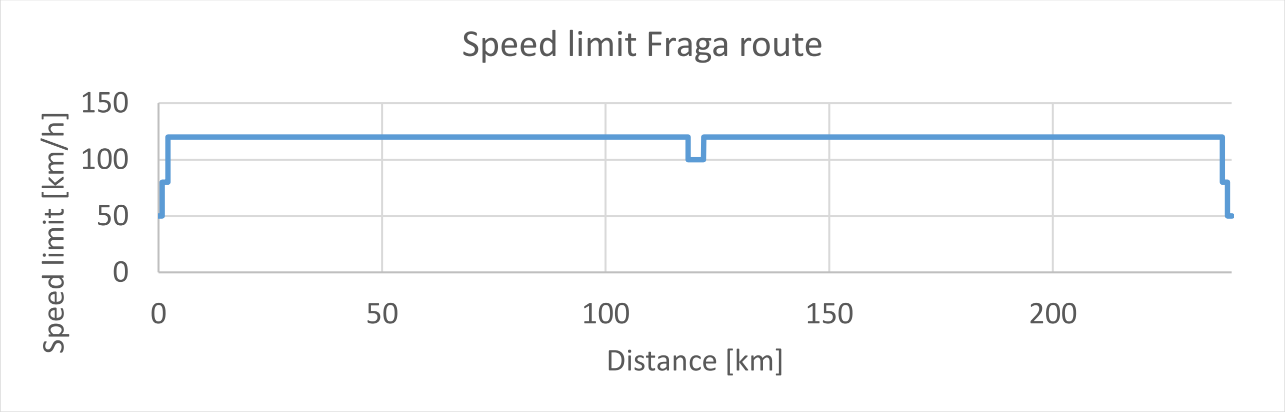


Figure 6-3 Speed limit Fraga route. Note that this is the speed limit of the road. The speed limit for trucks is the minimum of this speed limit and 80 km/h.

Figure 6-4 shows the filtered and unfiltered slope profiles. The filtered slope profile shows that extreme slopes of >7% are filtered out, as well as high frequency oscillations.

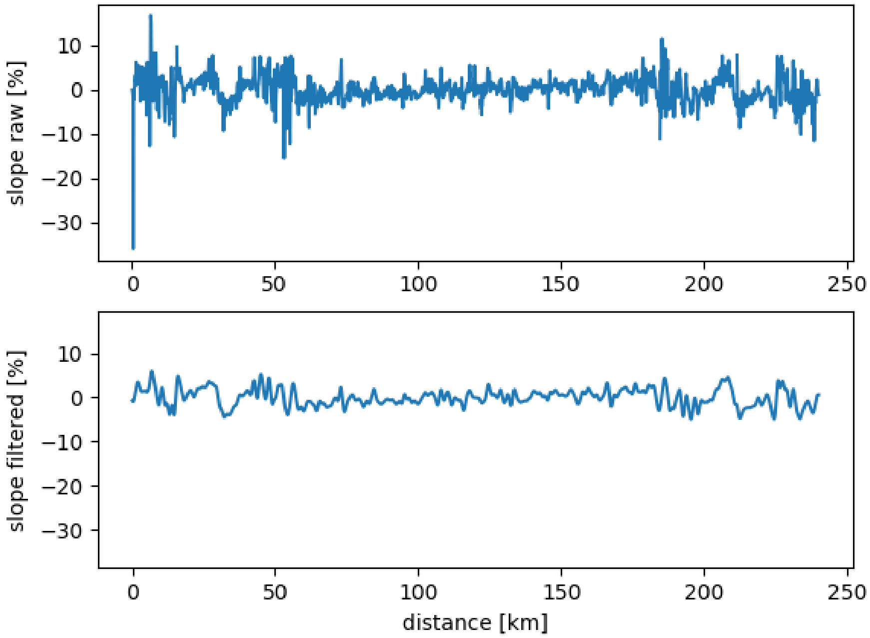


Figure 6-4 Raw and filtered road slope profile of the Fraga route

Figure 6-5 shows the filtered and unfiltered elevation profiles for the Fraga route. The pictures show that the filtering of the slope profile does not alter the elevation profile or the distance travelled.

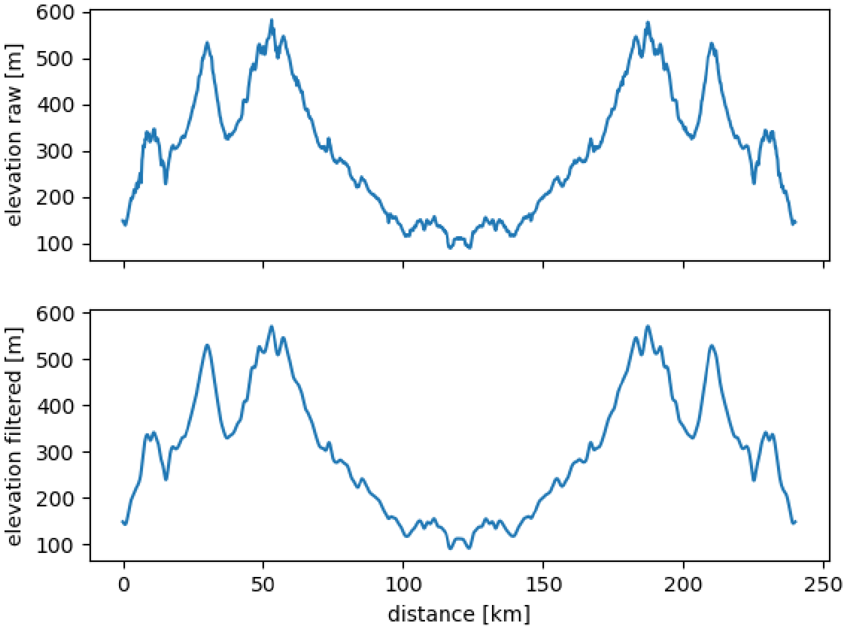


Figure 6-5 Raw and filtered elevation profile for the Fraga route

The same pictures have been made for a single hill in the elevation profile (between 20 and 37.5 kilometres). Figure 6-6 shows that the elevation profile has been changed from a bumpy climb to a more smooth hill. Figure 6-7 shows the slope profile for the same segment.

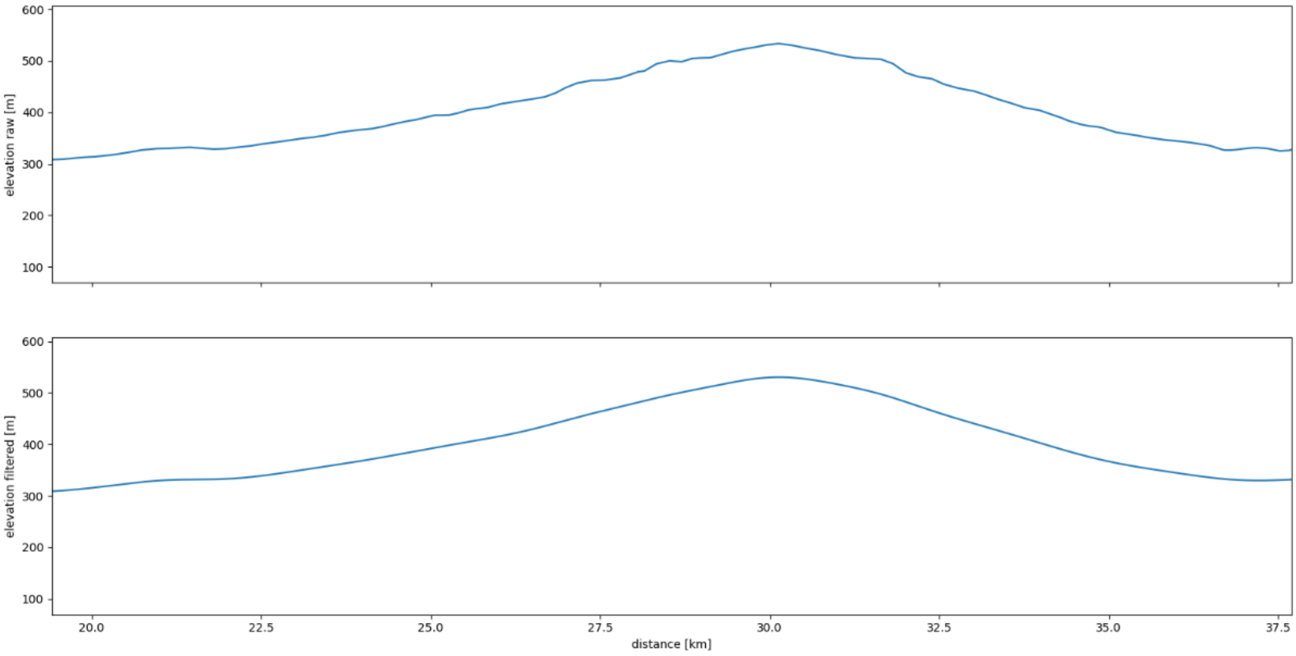


Figure 6-6 Subsection of the raw and filtered elevation profiles between 20 and 37.5 kilometres of the Fraga route

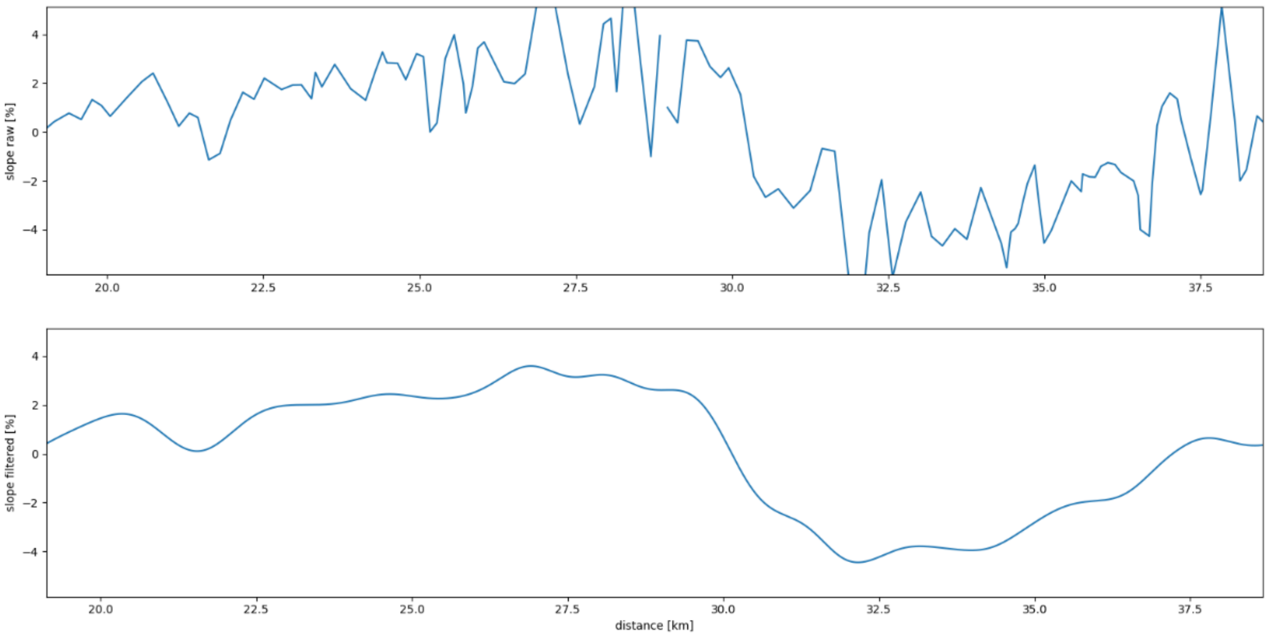


Figure 6-7 Subsection of the slope profile of the Fraga route between 20 and 37.5 kilometres

Based on the route profile of the Fraga route, mission profiles have been generated for a tractor semitrailer, an EMS1 vehicle and an EMS2 vehicle with different payloads. Figure 6-8 shows the generated mission profiles for the different vehicles. The figure shows that the weight of the different vehicle combinations determines how fast the vehicles can drive the hilly route. The total time spent for the vehicles to cover the 242 km route is summarized in Table 6-4. The table shows that the empty vehicles can drive the mission profile in the same time and speed, but the full EMS vehicles are a bit slower than the full tractor semi-trailer.

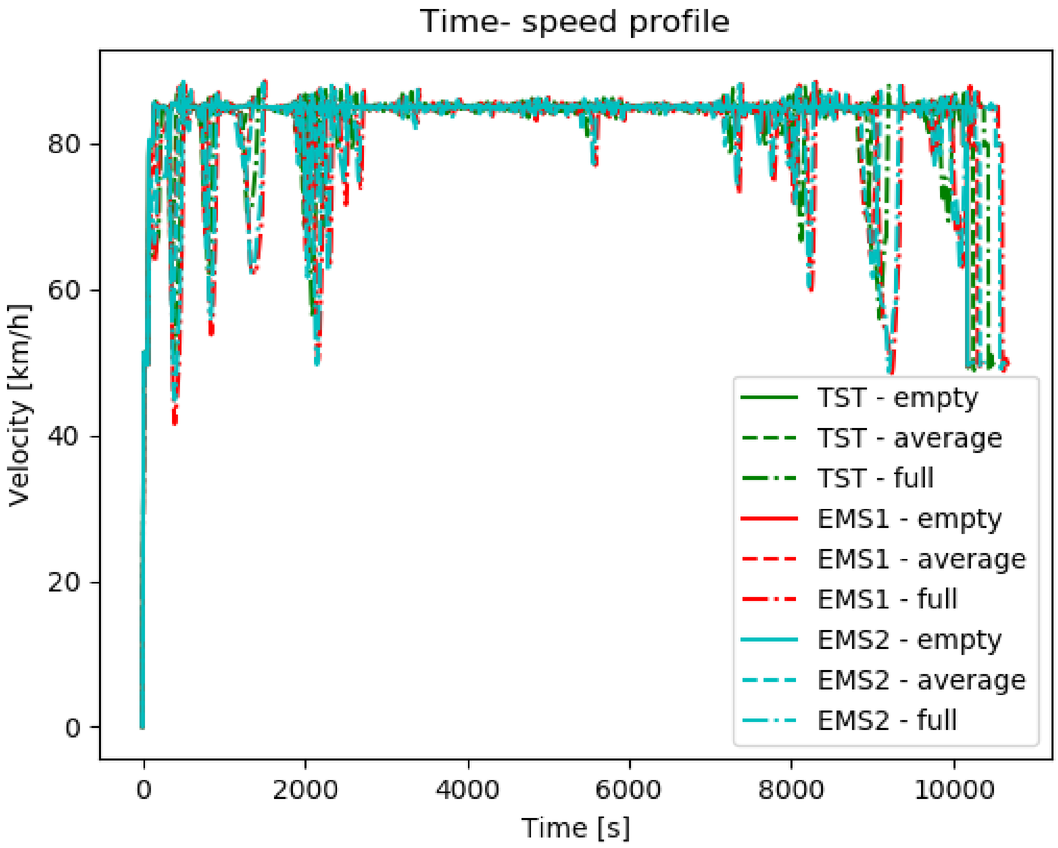


Figure 6-8 Time-speed profiles for the Fraga route

Table 6-4 Time spent and average speed for the mission profiles of the Fraga route

Vehicle -payload	Time spent [hh:mm]	Average speed [km/h]
TST – empty	02:51	84.4
TST – average	02:52	83.8
TST – full	02:55	82.3
EMS1 – empty	02:51	84.4
EMS1 – average	02:53	83.4
EMS1 - full	02:58	81.0
EMS2 – empty	02:51	84.4
EMS2 – average	02:53	83.1
EMS2 - full	02:57	81.2

In order to compare the behaviour of the different vehicles on a hilly segment, a distance-speed profile has been generated from the mission profile. Figure 6-9 shows a segment of this profile, going up and down a hill. The figure shows that the empty vehicles can all drive at the target speed, even in this hilly section. The average and fully loaded vehicles need to slow down and overshoot the target speed when they have reached the top. The loaded EMS vehicles slow down more than the tractor semitrailer to a minimum of 62 km/h in the fully loaded case.

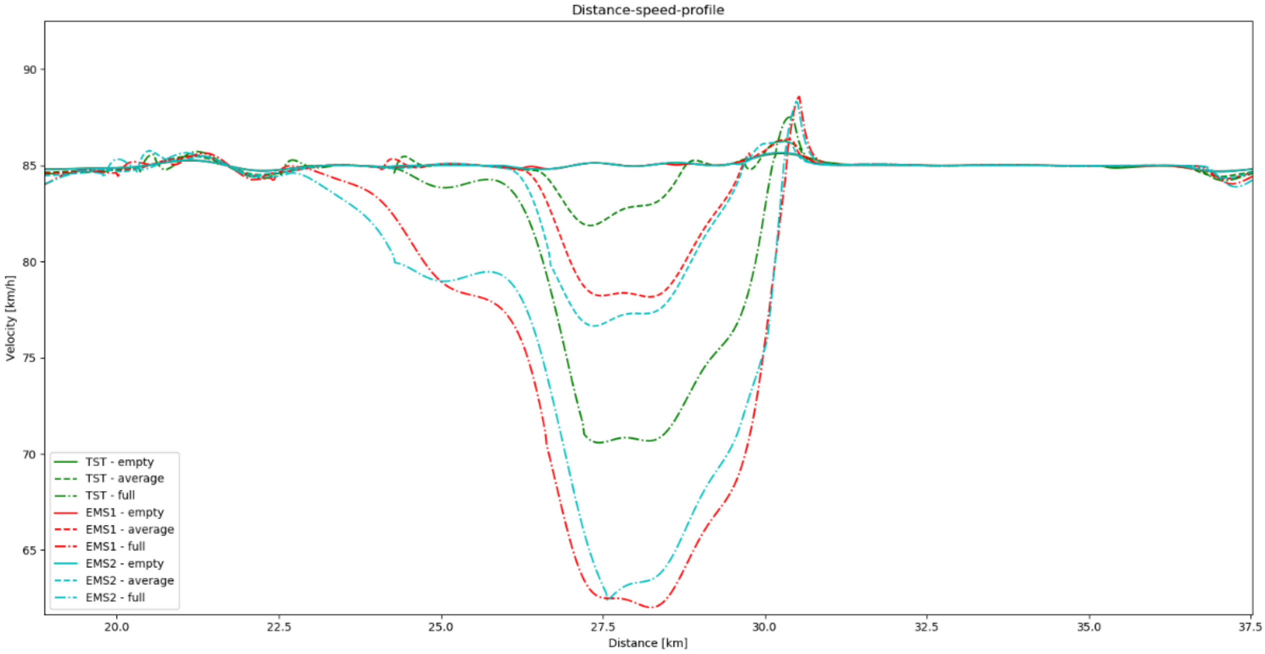


Figure 6-9 Distance-speed profile for a segment of the Fraga route between 20 and 37.5 kilometres

The mission profiles are used to simulate the vehicles with different scenarios in order to analyse the fuel efficiency of the different innovations on this route. Figure 6-10 shows the fuel consumption (l/km) and the fuel efficiency for the average payload and for the default and AEROFLEX scenarios. All results are indexed, the default tractor semi-trailer being 100. The top figure shows that the increased total weight of the vehicle combination (2.5 ton double load floor and 5 ton payload) causes that the AEROFLEX vehicles perform only slightly better (EMS1) or even worse than the default vehicles (EMS2 and Tractor semi-trailer). The figure also shows the increasing fuel consumption for heavier vehicles.. The bottom figure shows that the higher payload compensates for this increased fuel consumption, leading to a fuel reduction of 14 and 23% for the EMS1 EMS2 vehicle respectively. The AEROFLEX features reduce the fuel consumption further leading to a total reduction of 25, 31 and 34% for tractor-semitrailer, EMS1 and EMS2 respectively.

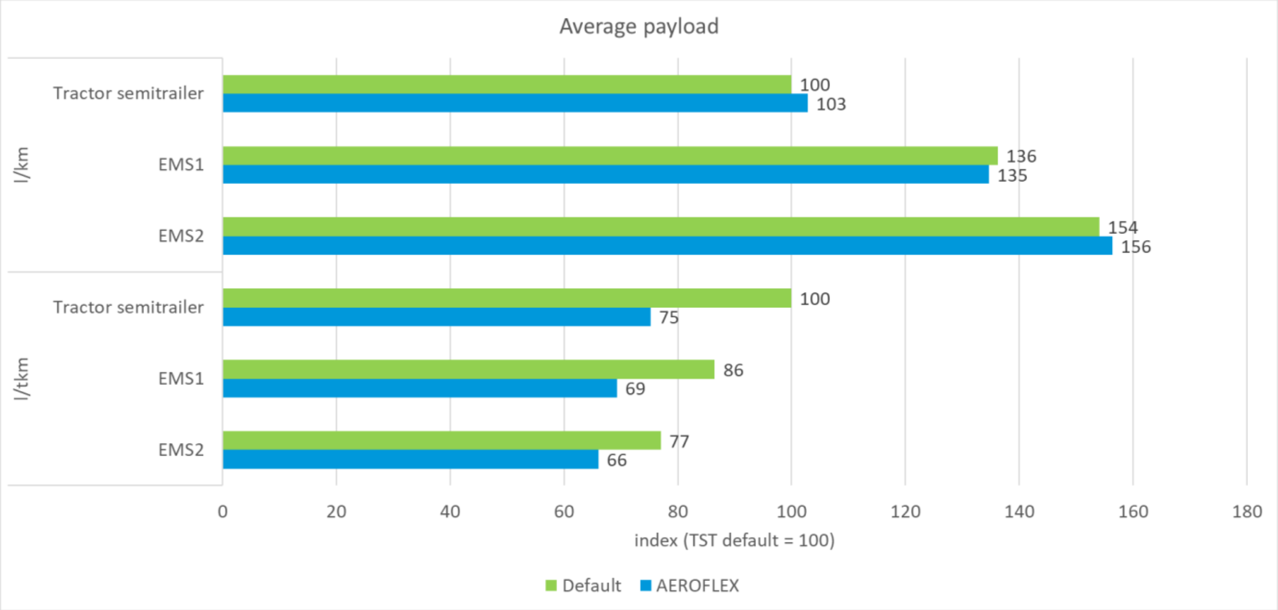


Figure 6-10 Fuel efficiency average payload (156.3 kg/m³), default and AEROFLEX innovations

Figure 6-11 shows the fuel efficiency for all scenarios on the tractor semitrailer with average payload. It shows that the double load floor is the most fuel efficient if applied individually. The total fuel efficiency gain for the combination innovations is, as mentioned 25%.

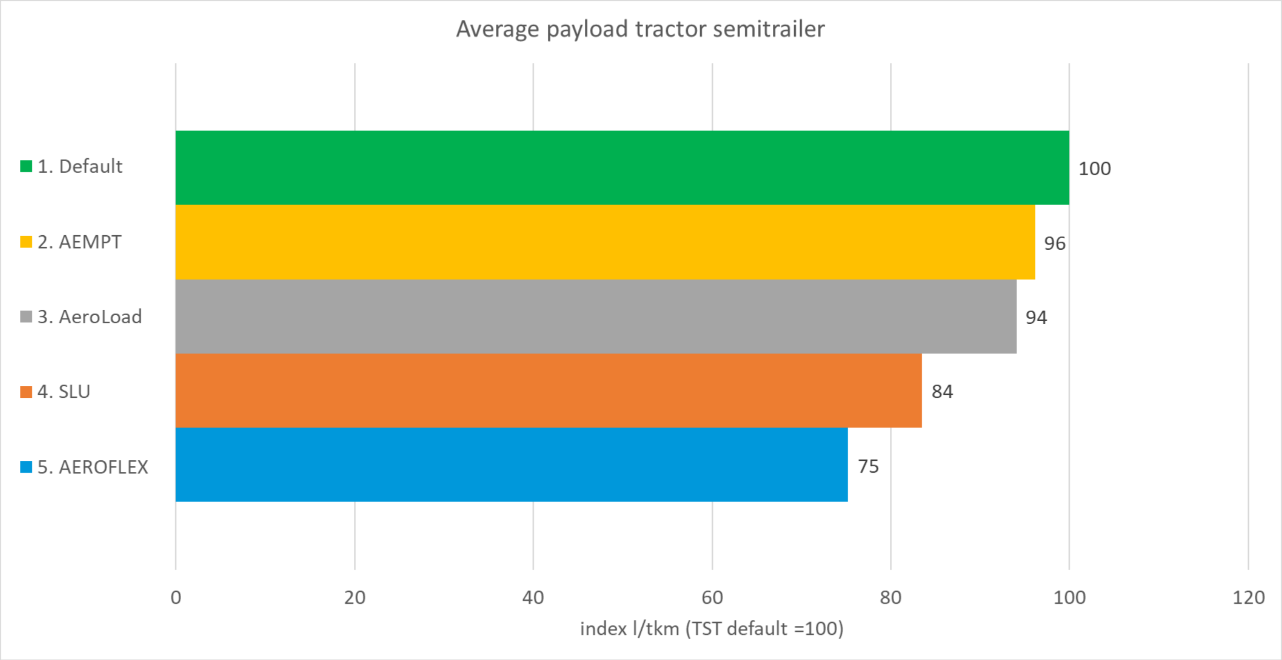


Figure 6-11 Fuel efficiency for different scenarios on a tractor semi-trailer with average payload

Figure 6-12 shows that AEMPT leads to a higher fuel reduction than AeroLoad on the EMS1 vehicle. This can be explained by the higher mass of the vehicle combination; drag represents a smaller proportion of the power balance of the vehicle. The total fuel efficiency gain for the combined AEROFLEX innovations is 20% compared to a default EMS1 vehicle.

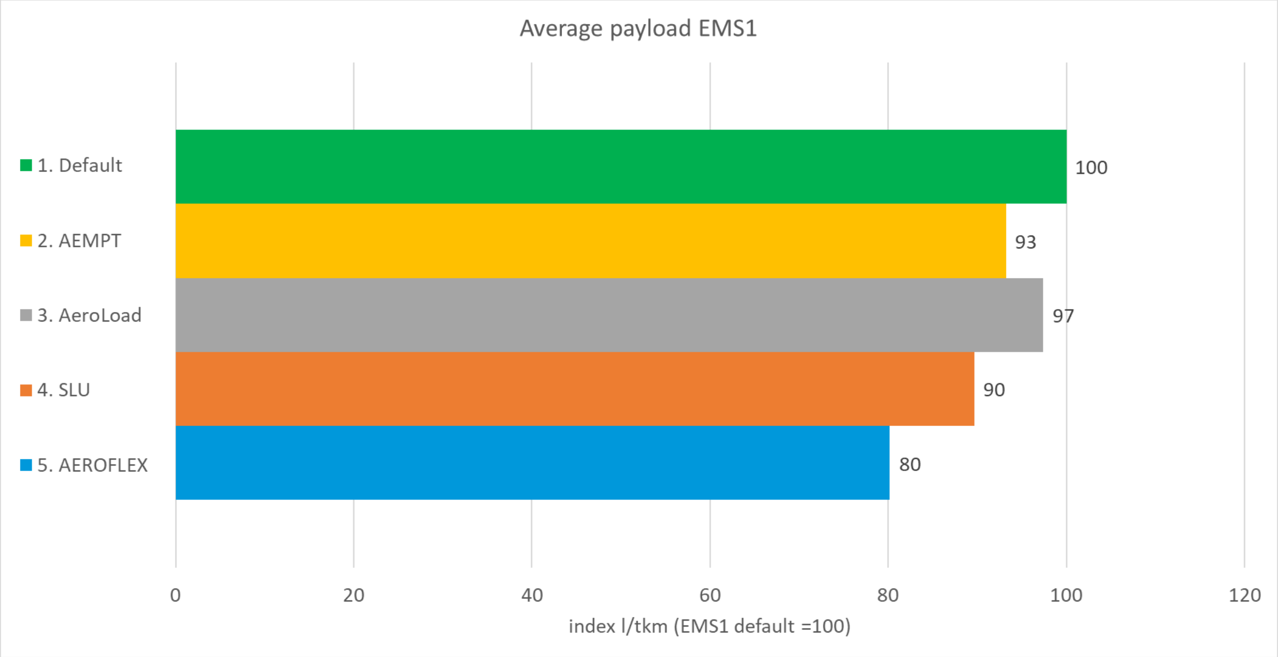


Figure 6-12: Fuel efficiency for different scenarios on an EMS1 with average payload

Figure 6-13 shows that AEMPT is the most important contributor to the fuel efficiency reduction for the EMS2, being the heaviest of the vehicles. The total combination fuel efficiency gain is 14%, compared to a default EMS2 vehicle.

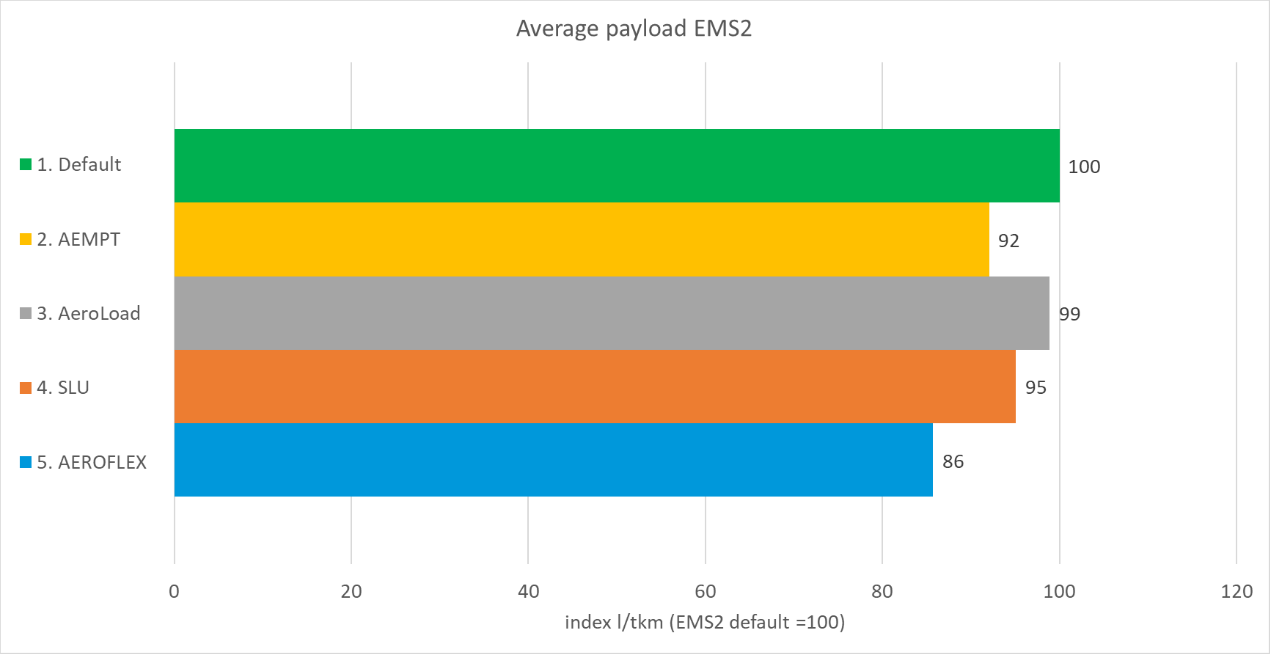


Figure 6-13 Fuel efficiency for different scenarios on an EMS2 with average payload

Figure 6-14 shows the fuel consumption result for the empty vehicles. Since the payload on the vehicles is 0 ton, the fuel efficiency cannot be calculated. In this case the double load floor only adds weight to the vehicle combination. Therefore, a second AEROFLEX combination is analysed where the SLU innovation is not included. The figure shows that the empty EMS1 and EMS2 vehicles respectively use 20 and 29% more fuel than an empty tractor semitrailer. That is if AEMPT and AeroLoad innovations are applied to the vehicles.

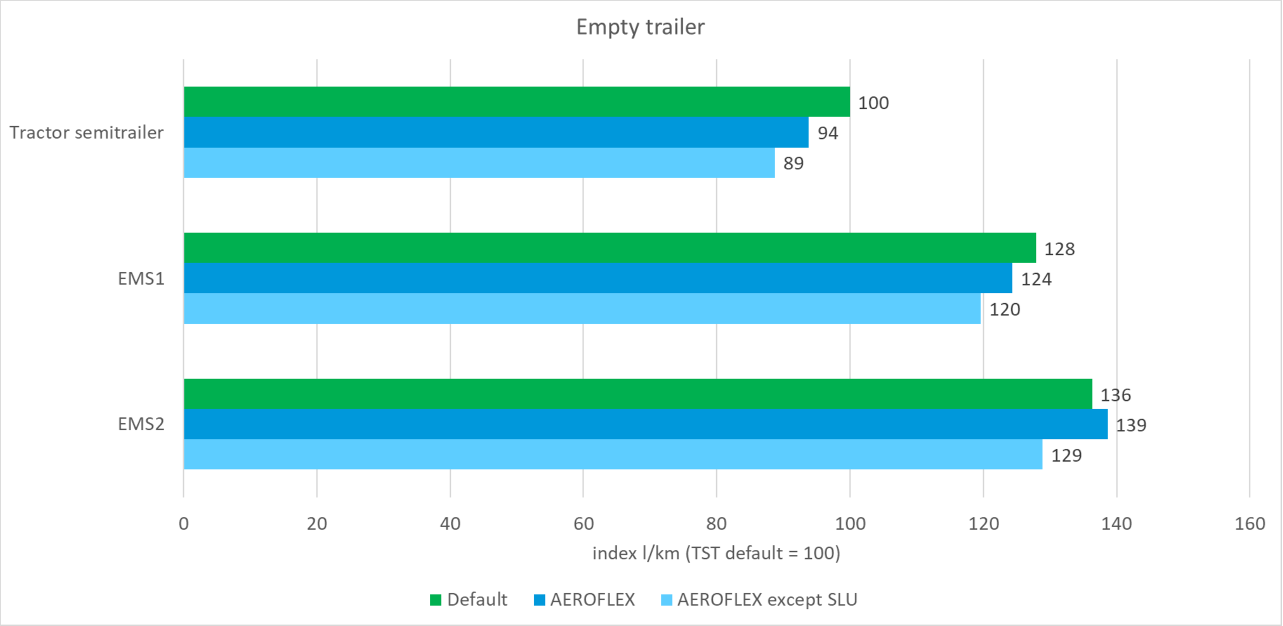


Figure 6-14 Fuel efficiency empty vehicle, default and AEROFLEX innovations

Figure 6-15 shows the results for the empty tractor semi-trailer. It shows that the effect added weight on the empty (light) tractor semi-trailer is only just compensated by the brake energy recuperation. The SLU only adds weight to the combination and is therefore excluded from the AEROFLEX scenario which saves 11% compared to the default vehicle.

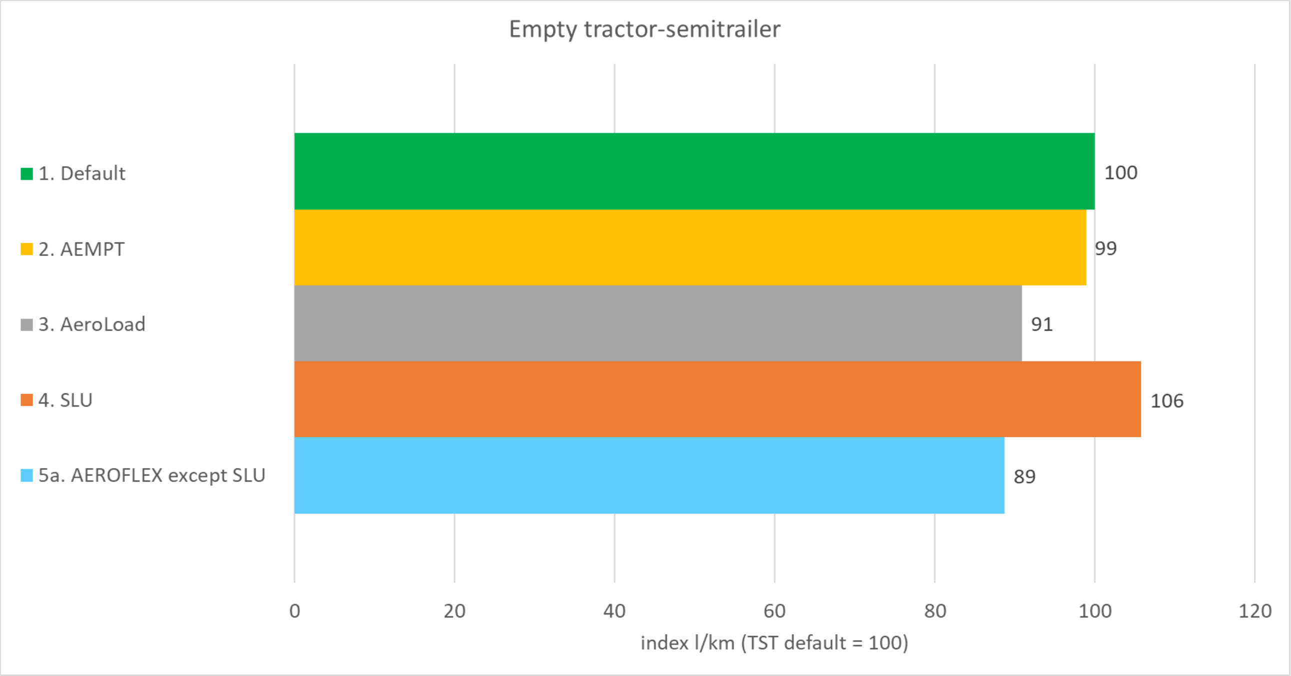


Figure 6-15 Fuel efficiency for different scenarios on an empty tractor semi-trailer

Figure 6-16 shows similar results for the EMS1 vehicle. Only the AeroLoad shows lower reduction (caused by lesser drag reduction and higher weight of the vehicle) totalling the AEROFLEX fuel efficiency gain at 6% compared to the default vehicle.

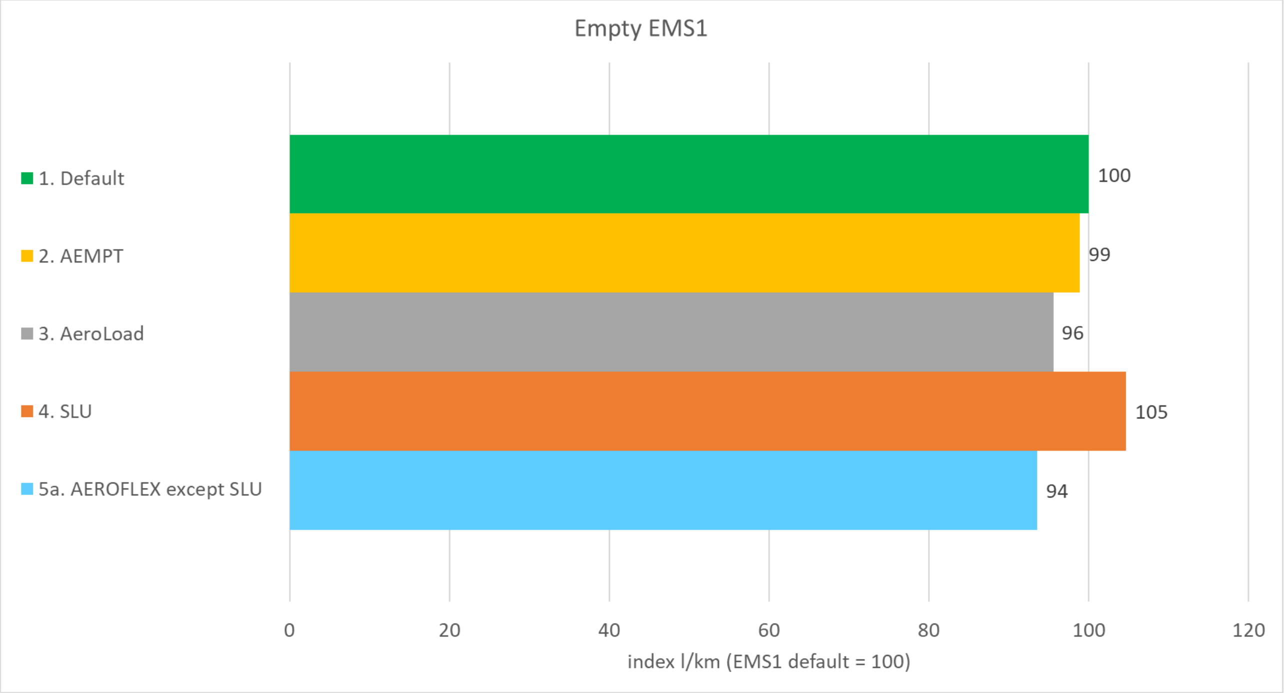


Figure 6-16 Fuel efficiency for different scenarios on an empty EMS1 vehicle

Figure 6-17 shows that the weight of the AEMPT systems has a smaller effect on the heavy EMS2 vehicle, making the AEMPT perform slightly better than the AeroLoad system. In total, the AEROFLEX scenario reduces fuel consumption with 5% compared to the default EMS2 vehicle.

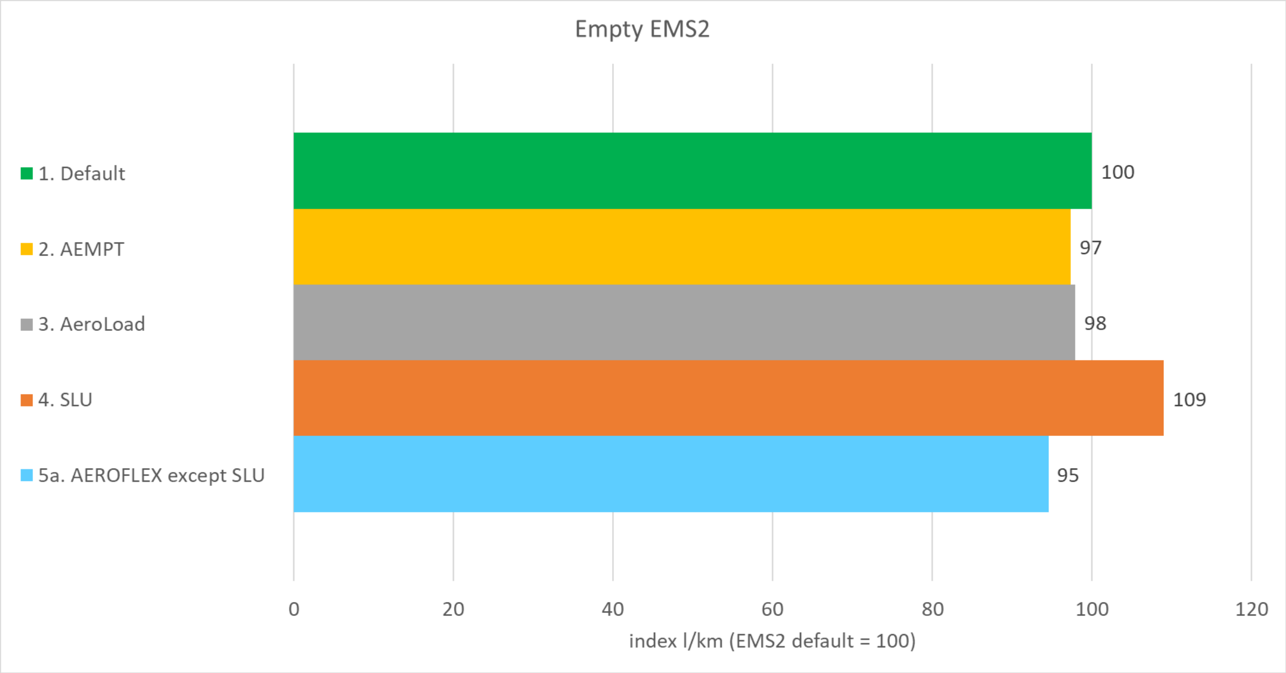


Figure 6-17 Fuel efficiency for different scenarios on an empty EMS2 vehicle

Figure 6-18 shows the fuel consumption and fuel efficiency of the fully loaded vehicles with and without AEROFLEX innovations applied. Like in the empty situation, the double load floor only adds weight to the vehicle combination. To compensate for the added weight less payload can be loaded to the vehicle. The figure shows that although the fuel consumption is the same for the scenario with and without a double load floor, the fuel efficiency is a lot worse due to the reduction in payload. The fuel efficiency gains for the fully loaded tractor semi-trailer, EMS1 and EMS2 is 6, 12 and 20 % compared to the default tractor semi-trailer.

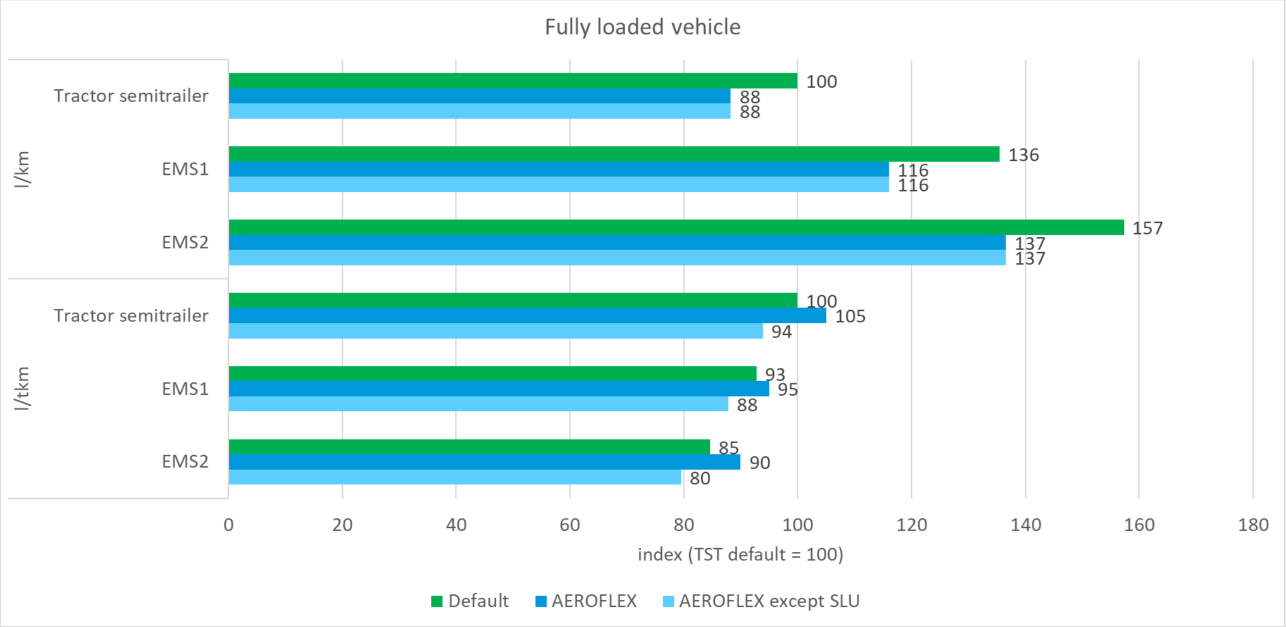


Figure 6-18 Fuel efficiency fully loaded vehicle, default and AEROFLEX innovations

Figure 6-19 shows that the effect of the AEROFLEX innovations is not that big on the fully loaded tractor semi-trailer, totalling at 6% reduction. Note that the weight of the innovations needs to be compensated with a reduction in payload equal to the weight of the installed systems (see Figure 6-2).

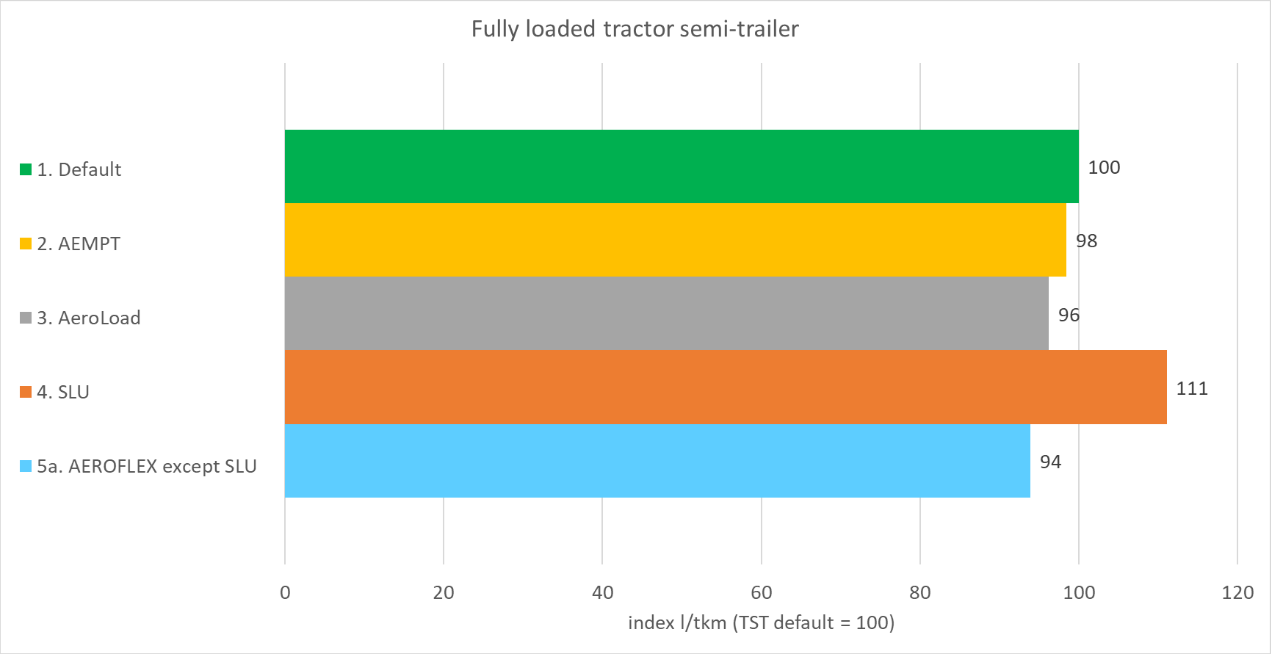


Figure 6-19 Fuel efficiency for different scenarios on a fully loaded tractor semi-trailer

Figure 6-20 shows that the weight of the AeroLoad system can only just be compensated by the drag reduction on the fully loaded EMS1. The AEMPT systems perform slightly better on the heavier combination.

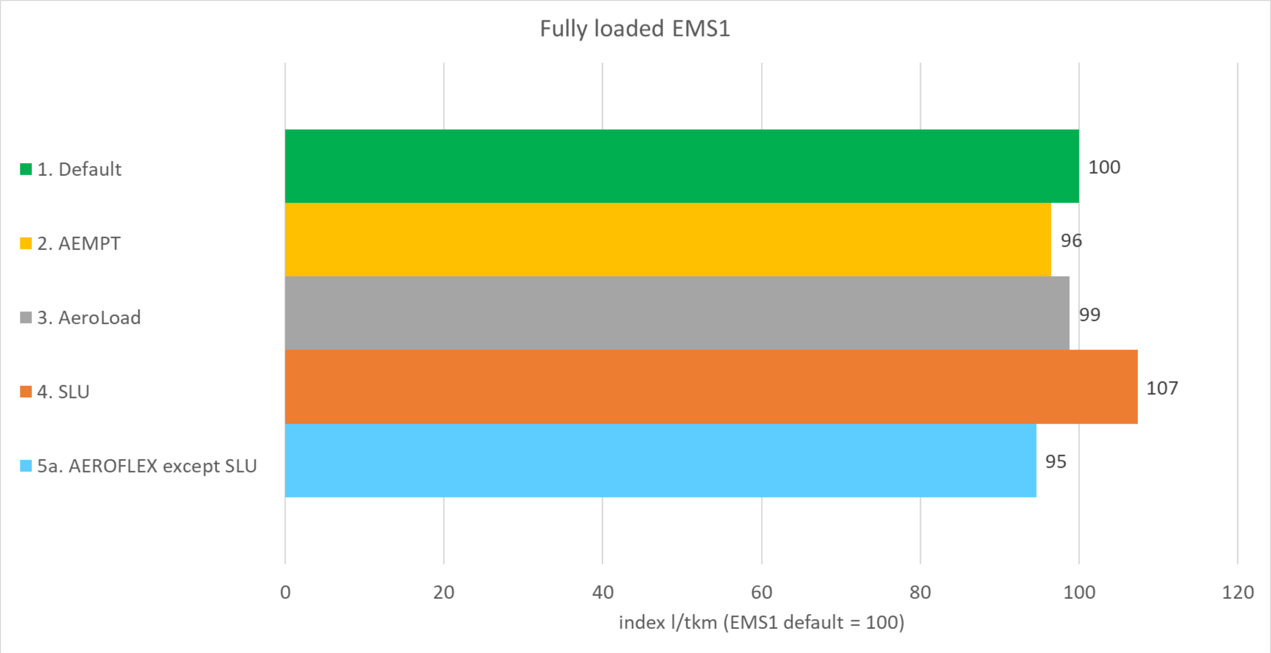


Figure 6-20 Fuel efficiency for different scenarios on a fully loaded EMS1 vehicle

Figure 6-21 shows that the net effect of the AeroLoad systems equals zero on the fully loaded EMS2. The AEMPT accounts for the total fuel efficiency gain of 6% in the AEROFLEX scenario.

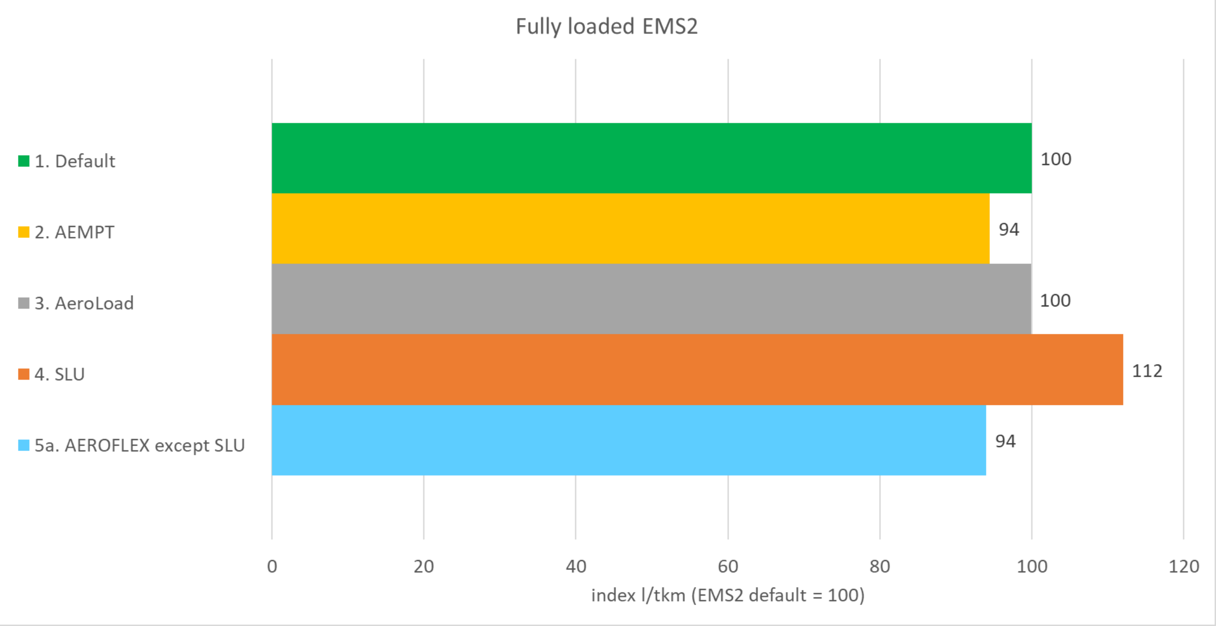


Figure 6-21 Fuel efficiency for different scenarios on a fully loaded EMS2 vehicle

6.3 Pilot assessment 2: Customer use-case 31

6.3.1 Introduction

In (Eijk, Mentink, & Freixas, 2019) 8 customer use-cases have been selected for further analysis in the technical assessment. For this pilot assessment customer use-case 31 is selected for the following reasons:

- It includes cross-border transport, testing this functionality in the route profile generator;
- It includes intermodal transport, setting limits on the usage of AEROFLEX innovations;
- It includes different payloads;
- The default and the future prime-candidate are also used in the Fraga-assessment.

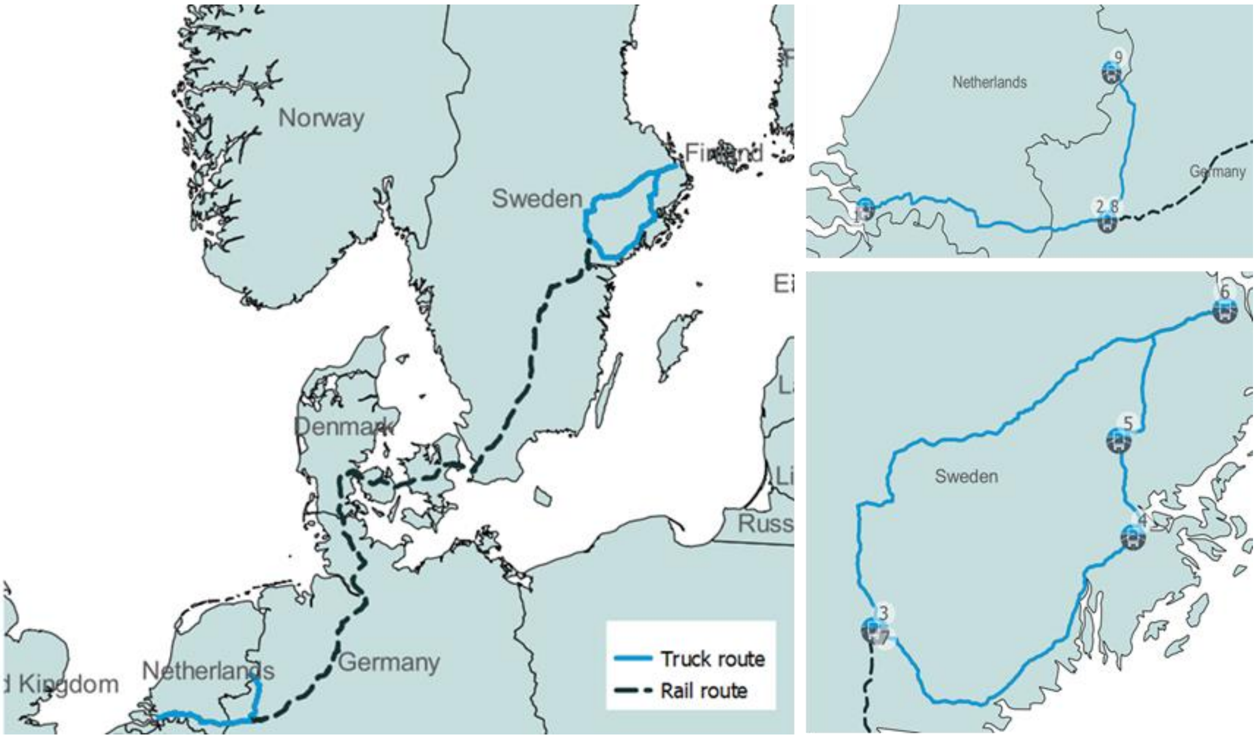


Figure 6-22 Overview of customer use-case 31 (left), Detail of Netherlands-Germany truck route (top right), detail of Sweden truck route (bottom right).

The route of the use-case is displayed in Figure 6-22. In the reference case a fully loaded tractor semitrailer drives from the southwest of the Netherlands to a train station in western Germany. There, the trailer is hauled by a train and driven to a train station in Sweden. There, the semi-trailer is loaded to a second tractor, which transports it to the first unload location where half of the payload is delivered. The combination continues to the second unload location where the rest of the cargo is delivered. The fifth leg of the use-case is driven with an empty trailer to the pickup location in the East of Sweden. There, the trailer is once again fully loaded and the combination returns to the Swedish train station. The trailer is loaded to the train and returns to Germany where the third and last tractor picks it up and delivers the load to the East of the Netherlands.

Table 6-5 Characteristics of the different legs of customer use-case 31

Leg	Description	Length [km]	% motorway	Total elevation change	flat (<1%)	Hilly (1-<3%)	Mountains (>3%)	Payload
1	FTL from Netherlands to Germany	200	97%	548 m up, 511 m down	99%	1%	0%	25 ton
2	Train Germany- Sweden							
3	Sweden: FTL	156	82%	1300 m up, 1400 m down	87%	12%	1%	25 ton
4	Sweden: LTL	48	90%	418m up, 405 m down	80%	20%	0%	12.5 ton
5	Sweden: empty	79	98%	523m up, 544 m down	91%	9%	0%	0
6	Sweden: FTL	233	64%	1500 m up, 1500 m down	90%	10%	0%	25 ton

7	Train Sweden-Germany							
8	FTL from Germany to the Netherlands	113	78%	486 m up, 494 m down	97%	3%	0%	25 ton

Table 6-5 shows the characteristics of the different legs of the use-case. Most of the distance is covered on motorways. The first and final leg are almost only on flat terrain. On the Swedish legs some hilly sections are travelled but compared to the Fraga use-case also these roads are predominantly flat.

6.3.2 Inputs

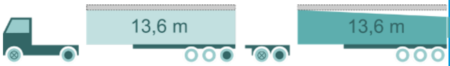
In the interview with the logistic service provider (LSP) that brought up this use-case, the current and future prime candidate have also been discussed. The currently used vehicle is Prime Candidate 1.3, a 4*2 tractor with a 13.6 meter semi-trailer. The preferred future prime candidate is prime candidate 6.1 an EMS2 combination consisting of a 6*4 tractor, a semi-trailer, a dolly and another semi-trailer. For these vehicles the same parameters are used as for the Fraga assessment (see Table 6-2). The available innovations are also the same (and shown in Figure 6-2).

Since a large part of the use-case consists of a fully loaded (25 ton payload) vehicle, no SLU innovations can be applied so the AEROFLEX scenario consists of only AeroLoad and AEMPT innovations. Since the trailer needs to be transported by train, less AeroLoad innovations can be applied. Therefore, the drag reduction potential is reduced to 5%. It is assumed that the use of AEMPT allows for the use of a 4*2 tractor on the AEROFLEX scenario. This compensates for the weight increase of the AEMPT and AeroLoad innovations.

In the interview the wish of the LSP for the future prime candidate was not just to use an EMS2 vehicle but to drive with one pulling vehicle and two of the same size semi-trailers behind. This would have the least impact on the operation and the highest efficiency gain. Since this is not possible with a GCW of 74 tons, this is considered as a separate scenario. Important to note here is that the 74 ton maximum is not a fixed maximum but an assumption on what the limit could be if these vehicles will be allowed on the road.

Table 6-6 shows all scenarios considered for the use-case. The table shows that the average axle load for the EMS2 vehicle, even for the heavy scenario is less than for the default tractor semi-trailer. The last column shows the number of vehicles per week. This is an important number in the calculation of the total fuel consumption for the use-case. It is assumed that the number of cargo loads delivered per day may vary but that the LSP is required to deliver the same amount of cargo per week in the future situation.

Table 6-6 Considered vehicle combinations for customer use-case 31

Scenario name	Icon	NCW [ton]	GCW [ton]	Average axle load [ton/axle]	Maximum payload	Number of vehicles/ week
Reference		15	40	8	25	10
EMS2		27.5	74	6.7	46.5	6
EMS2 AEROFLEX		28.25	74	6.7	45.75	6
EMS2 heavy		27.5	77.5	7	50	5
EMS2 AEROFLEX heavy		28.25	78.25	7.1	50	5

6.3.3 Results

Figure 6-23 shows the fuel consumption (l/km) and fuel efficiency (l/tkm) results for the different scenarios. The figure shows that the default EMS2 vehicles use 41% more fuel to perform the use-case than the default tractor semi-trailers. However, since only 6 vehicles are required to deliver the same cargo, the fuel efficiency is increased with 15%. The use of AEROFLEX innovations increases this gain to 19%. When the GCW of the vehicles is increased slightly to allow for two 25 ton semi-trailers behind one vehicle the fuel efficiency gain is increased to 25% or 28% with AEROFLEX innovations applied.

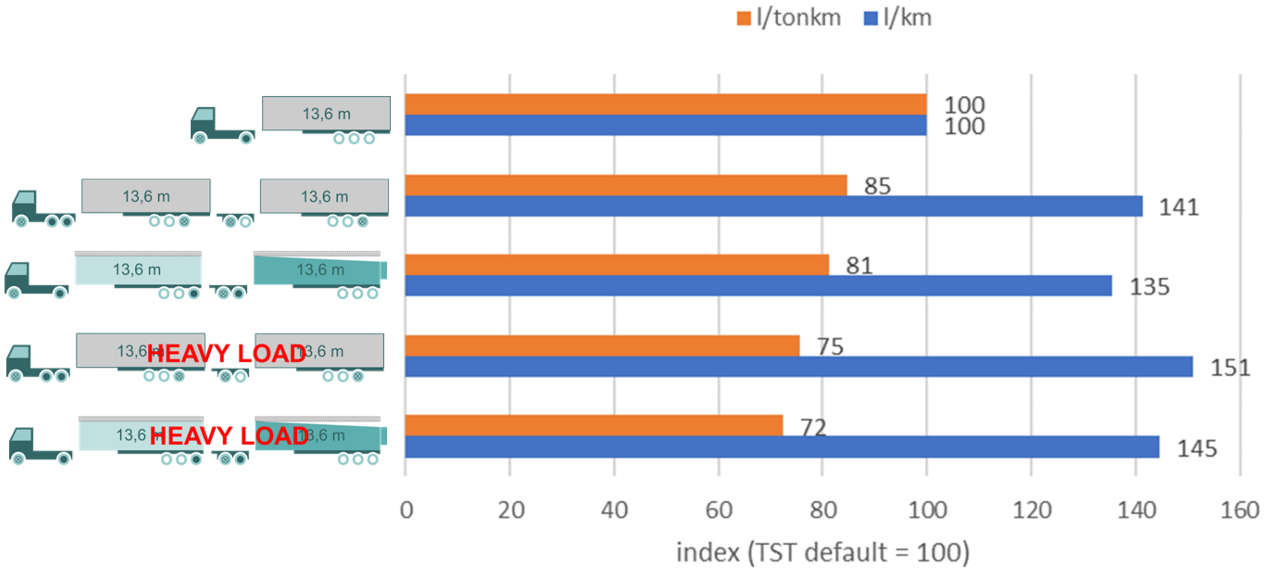


Figure 6-23 Fuel consumption results on vehicle level (l/km) and on fleet level (l/tkm)

Table 6-7 shows how well each of the scenarios performs on each of the different legs. The table clearly shows that the fuel reduction is the largest in leg 5, followed by leg 4. This makes sense since the vehicle is empty (leg 5) or half empty (leg4) in these legs. The weight difference and therefore the fuel consumption increase between the reference and future situation is less and therefore the efficiency gained from reducing the number of vehicles is larger.

Table 6-7 Total fuel consumption (l) per leg compared to reference case, the colours indicate on which leg each scenario shows the largest reduction.

Scenario	Leg 1	Leg 3	Leg 4	Leg 5	Leg 6	Leg 8
Reference	0%	0%	0%	0%	0%	0%
EMS2	-16%	-13%	-17%	-23%	-14%	-15%
EMS2 AEROFLEX	-18%	-20%	-20%	-25%	-18%	-18%
EMS2 heavy	-25%	-22%	-27%	-36%	-23%	-24%
EMS2 heavy AEROFLEX	-27%	-28%	-30%	-37%	-27%	-26%

However, leg 4 and 5 provide only a very small proportion of the total fuel consumption for the use-case, which is shown in Figure 6-24. It is therefore much more interesting to look at the other 4 legs. This shows that the default vehicles score better on leg 1 and the AEROFLEX vehicles score better on leg 3. This can be explained by the fact that leg 1 consists of flat terrain while leg 2 includes some elevation changes, providing possibilities for brake recuperation by the AEMPT system.

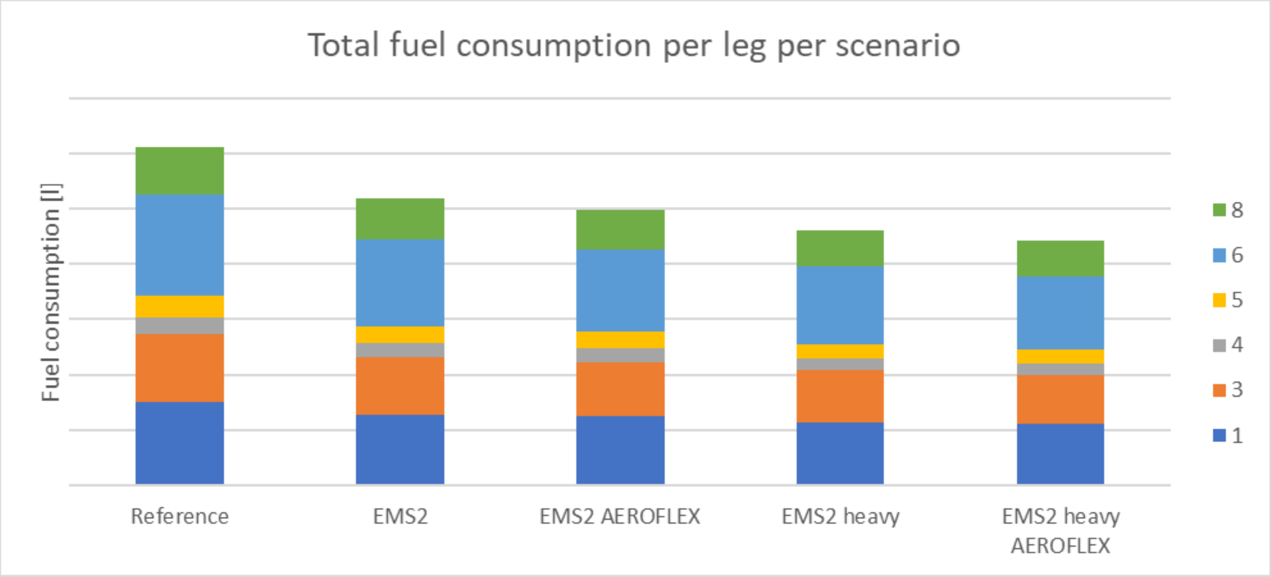


Figure 6-24 Total fuel consumption per scenario per leg

Finally, the AEROFLEX vehicles are compared to the default vehicles on each leg in Table 6-8. This table shows again that the AEROFLEX innovations (predominantly AEMPT) perform best on fully loaded vehicles and hilly terrain (legs 3 and 6).

Table 6-8 Fuel efficiency (l/tkm) gain of AEROFLEX innovations (AEMPT and AeroLoad) compared to the same vehicle without AEROFLEX innovations.

Scenario	Leg 1	Leg 3	Leg 4	Leg 5	Leg 6	Leg 8
EMS2	0%	0%	0%	0%	0%	0%
EMS2 AEROFLEX	-2%	-7%	-4%	-3%	-5%	-3%
EMS2 heavy	0%	0%	0%	0%	0%	0%
EMS2 heavy AEROFLEX	-2%	-8%	-4%	-3%	-5%	-3%

6.4 Conclusion

In the pilot assessment the assessment framework is tested on the Fraga route and a customer use-case. The Fraga-route is used, since it is a well-known route within the project and it plays an important role in the reference and demonstrator tests as well. The Fraga-assessment shows that the assessment framework can produce sensible results when comparing different vehicles with different payloads and innovations on a single route. Calibration and validation of the models is required to show how well the absolute fuel consumption results meet the measured values. The customer use-case assessment shows that it is possible to compare the currently used vehicle with a future vehicle. However, the result strongly depends on the assumptions made about the applicability of AEROFLEX innovations and (future) regulations. In the final technical assessment multiple scenarios should be defined in close cooperation with project partners and customers.

7 Conclusions and recommendations

In this report the framework for the final technical assessment has been described. The main purpose of the final technical assessment is summarized in the following sentence:

To assess the efficiency improvement potential of AEROFLEX innovations in typical European long-haul road transport operations, building on the reference and demonstrator test results, using realistic simulations and providing input to the impact assessment of the EU freight transport and book of recommendations.

From this sentence follows a long list of requirements to the assessment framework and the simulations that will be performed with this assessment framework. These requirements are given in Table 7-1.

Table 7-1 Requirements to the final technical assessment

Group	Requirements	Chapter /reference
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;	4.5
AEROFLEX innovations	• The assessment framework should allow for the simulation of hybrid drivetrains; • The assessment framework should allow for the simulation of torque management systems; • The assessment framework should be able to simulate passive flow control systems; • The assessment framework should be able to simulate active flow control systems, where the aerodynamics of the vehicle depend on speed or direction of the vehicle; • The assessment framework should allow for fleet level simulations. • The assessment matrix should include simulations of trucks and tractors with extended fronts.	4.4
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.	(Eijk, Mentink, & Freixas, 2019)
Test results	• The assessment framework should be calibrated with reference and demonstrator test results; • The assessment framework should be validated with reference and demonstrator test results.	5
Realistic simulations	• The sensitivity analysis should include variation of traffic conditions • The sensitivity analysis should include variations in weather conditions • The sensitivity analysis should include variations in road conditions • The sensitivity analysis should include variations in vehicle characteristics	5

In the previous chapters has been discussed how this proposed assessment framework makes sure that all requirements are met. This does not mean that the final technical assessment can already be performed now. In chapter 5 is shown that still several tasks need to be performed before the final technical assessment can take place. The most important steps still to be taken are the following:

- Test results will be shared within a week after completion of the reference and demonstrator tests;
- The hybrid powertrain mode needs to be adapted to simulate multiple hybrid systems working in parallel;
- Inclusion of the VECTO model to calculate wind-averaged C_d*A values;
- Calibration of the models with the test results;
- Validation of the models with the test results;
- Sensitivity analysis on the representativeness of the Fraga route for the customer use-cases;
- Innovations and parameters for the innovations will be shared before the reference tests are finished;
- Before the General Assembly in May 2020, a decision should be made on the innovations applied on the future prime candidates for the customer use-cases.

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Project partners:

#	Partner	Partner Full Name
1	MAN	MAN TRUCK & BUS AG
2	DAF	DAF Trucks NV
3	IVECO	IVECO S.p.A
4	SCANIA	SCANIA CV AB
5	VOLVO	VOLVO TECHNOLOGY AB
6	CRF	CENTRO RICERCHE FIAT SCPA
7	UNR	UNIRESEARCH BV
8	SCB	SCHMITZ CARGOBULL AG
9	VEG	VAN ECK BEESD BV
10	TIRSAN	TIRSAN TREYLER SANAYI VE TICARET A.S.
11	CREO	CREO DYNAMICS AB
12	MICH	MANUFACTURE FRANCAISE DES PNEUMATIQUES MICHELIN
13	WABCO	WABCO Europe BVBA-SPRL
14	CHALM	CHALMERS TEKNISKA HOEGSKOLA AB
15	DLR	DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV
16	FHG	FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.
17	HAN	STICHTING HOGESCHOOL VAN ARNHEM ENNIJMEGEN HAN
18	IDIADA	IDIADA AUTOMOTIVE TECHNOLOGY SA
19	NLR	STICHTING NATIONAAL LUCHT- EN RUIMTEVAARTLABORATORIUM
20	TML	TRANSPORT & MOBILITY LEUVEN NV
21	TNO	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO
22	MHH	MEDIZINISCHE HOCHSCHULE HANNOVER
23	UIRR	UNION INTERNATIONALE DES SOCIETES DE TRANSPORT COMBINE RAIL-ROUTE SCRL
24	WABCO-NL	WABCO AUTOMOTIVE BV
25	WABCO-DE	WABCO GMBH

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10 Appendix A – Risk table

Risk number	Description of risk	WP Number	Proposed risk-mitigation measures
1	External / Legislation] Major change in legislation regarding vehicle dimensions, emissions and fuel efficiency reducing the impact of AEROFLEX targeted outcomes.	WP1, WP2, WP3, WP4, WP5	Major activities in WP7 on mapping current and future regulations and interaction via Sounding Board
2	Internal / Management] Partner not performing as expected in the technical annex.	WP9	Regular synchronization and appropriate project monitoring and governance structure (See Section 3.2).
3	[Internal / Management] Confidentiality issues between the AEROFLEX partners or towards external partners.	WP1, WP2, WP3, WP4, WP5, WP6	Appropriate data and confidentiality management. Deployment of appropriate framework, e.g. data exchange platform with different access rights. Possibility to escalate at project management level (WP9) in case an issue is detected.
	[Technical] Accident data does not reveal sufficient level of information or access is not possible. Weighting		Check to ensure sufficient data is available and whether alternative datasources are needed.
4	of detailed data databases from national to European level difficult to achieve for benefit analysis.	WP5	Although the databases have been selected carefully, if needed, alternative data sources can be accessed. Data sources may not allow full scaling to European level. Partner experience will be used to create alternative analysis methods
5	[Technical] No authorization received from local authorities to perform tests with demonstrator vehicles on real roads	WP6	IDIADA maintains a strong link with public authorities and has often conduct similar tests with prior authorisation from both regional and national traffic authorities
6	[Technical] Changing environmental conditions during tests of reference and demonstrator vehicles can, which can influence comparability of testing results	WP6	Reference and demo tests are scheduled at the same season of the year. In the case the tests were moved in time, IDIADA has flexibility and experience to move the tests another time (e.g. at night temperatures are lower) in order to similar conditions among the different tests. IDIADA is
7	[Management] Lack of contributions and expertise from Sounding Board members and lack of attendants to Sounding Board meetings	WP7	All SB members have signed a Letter of Support and they will receive travel compensation as an incentive to attend the meeting
8	[Management] No coherent Interest of the Sounding Board members in the outcome (results and recommendations) of the AEROFLEX project.	WP7	The governance of the Sounding Board is setup in a way that all results and recommendations will be discussed with the technical members (TAA) and the policy/regulatory members (PRCG) separately. The finalization of all results, reporting and Book of Recommendations will be mutually agreed with the complete Sounding Board (CSG). See Task 7.1
9	[Technical] Simulations are too complex or not consistent with the background crash analysis based on the accidentology data	WP5	Simulations must be done using representative and simplified crash scenarios. They must represent adequately accident events avoiding variables that may increase the complexity of the simulations without additional value.

Risk number	Description of risk	WP Number	Proposed risk-mitigation measures
10	[Technical] Crash simulation state-of-the-art is mature and the main issue is the availability of open-source models.	WP5	The consortium has partners with experience with open-source models from NCAC in the US
11	[Technical] Interface problems when installing the scale model in the wind tunnel (either static connection to the wind tunnel balance or non-optimum dynamic behaviour between the moving belts and the wheels of the model).	WP3	CRF will share to NLR the geometry of wind tunnel ground and support system, to be included into the design of the model from the beginning. Periodic update of the progress to WP lead and partners. If relevant issues will persist that can not be addressed by modification to the design of the scale model , the possibility to perform tests in another wind tunnel will be explored.
12	[Technical] Transient flow phenomena (related to blockage or Reynolds number) in the wind tunnel tests that prevent the identification of the most effective concepts.	WP3	Use CFD to compare drag benefit ofselected concepts model in open-air and wind tunnel conditions (i.e. including wind tunnel geometry as boundaries in CFD simulations for verification)
13	[Technical] Difficult to interpret the results from the concept development due to differences in the methods used by the individual partners.		Agree on a common CFD strategy, including (but not being limited to) requirements on CAD input, boundary conditions and data output before the concept development simulations commences. Generic cases will be perfomed by multiple partners to converge to highest possible similarity in solutions. Limit the number of different CFD tools as much as possible (ideally to one or two CFD tools).
14	Poor convergence of the transient simulations, and as a consequence non-reliable time averaged results and/or too expensive simulations.	WP3	Run longer time-histories for verification (may require a big increase in the amount of computational resources required). Reduce the number of steady CFD simulations to release cpu hours for the transient runs
15	Wrong performance predictions due to over- simplified geometries in the CFD models.	WP3	Do not introduce simplifications of the geometries in the models. Verify that the simplifications do not influence the CdxA values.
16	Interface problems for the demonstrator related to shared responsibilities, potentially giving poor performance and increased risk for not meeting cost and time targets.	WP3	Define clear interfaces for the different parts of the demonstrator. Work with 3D CAD tools and make use of available tools for data exchange. Manufacturing of demonstration vehicles with its aerodynamic features should be based on final drawings (design freeze) to as large extent as possible, in order to avoid large deviations and thus assembling issues.
17	Deviation between results from on-road measurements compared to simulation results & wind tunnel measurements	WP3	Verify the fidelity of CFD models after the first wind tunnel campaign. Use the experience of the partners from on-road measurements, to identify critical components and reduce the risks. Co- operate closely with WP6.