AEROFLEX

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

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Written By	À. Freixas (IDIADA) and P. Mentink (TNO)	2019-04-01
Checked by	J. Engasser (MAN), P. Elofsson [Scania], M. Olbäck (Volvo) and G. Cordua (CNH)	2019-05-15
Approved by	B. Kraaijenhagen (MAN) - Coordinator	2019-05-15
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Publishable Executive Summary

As overall objective, AEROFLEX WP6 aims to define a suitable physical test protocol that concludes in energy efficiency and energy consumption results and a wide assessment framework which provides impact results of the developed technologies against the various logistic applications.

To accurately determine the improvement in fuel economy for the aerodynamic and distributed powertrain technological innovations and more effective loading space utilization, a test matrix and a test protocol have been defined to consider all of these innovations in a structured manner for different vehicle configurations and types of test. This test protocol for vehicles fuel consumption measurements is based on the SAE J1526-III protocol with some minor additions and is confirmed by the SAE Charmain, B. McAuliffe as suitable approach for evaluating the performance of the distributed powertrain and aerodynamic innovations. The air drag test protocol is an extension of the Commission Regulation (EU) 2017/2400.

The test program defined, include five different test use-cases being:

1. Fuel consumption tests at steady-state speed on test track
2. Fuel consumption tests on the public road
3. Air drag on test track
4. Vehicle dynamic measurement on test track and
5. Terminal loading tests at a customer's depot.

All these test use cases are included in a test matrix (Figure 1) that includes nine different vehicle configurations including tractor semi-trailers (16,5m) and European Modular System (EMS) configurations (both EMS1 of 25,25m and EMS2 of 32m).

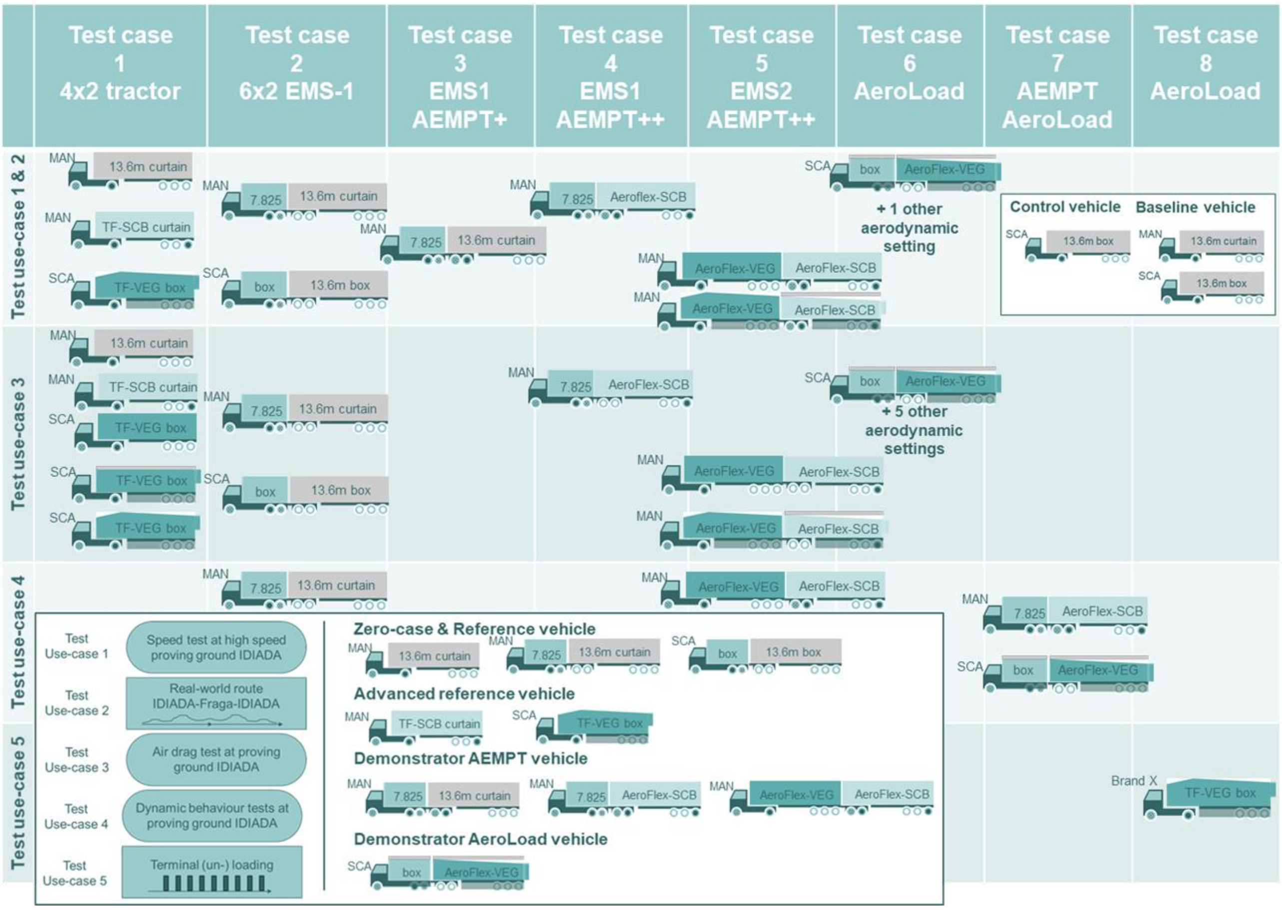

Figure 1. WP6 Test matrix with 8 test cases and 5 test use-cases. Four classes of vehicles are separated: 1) Reference vehicles including zero-case, 2) Advanced reference vehicles, 3) Demonstrator AEMPT vehicles and 4) Demonstrator AeroLoad vehicle

The smart selection of test cases and test use-cases has been made to deal with the trade-off between number of possible vehicle variations and number of repetitions for accurate and significant measurement results versus available test time, budget, equipment and resources. The objective is to evaluate the newly developed technologies, concepts, and architectures within WP2, WP3 and WP4 and to demonstrate their impact under real conditions followed by a validation and an assessment of the application potential for these concepts in Europe.

Parts of this test protocol are the necessary vehicle preparations, the characteristics of the measurement equipment for each test use case, vehicle loading conditions for the three vehicle configurations, test tracks and specific external location to carry on the tests as real route and loading terminal.

Based on the results of this test program, the aim of WP6 is to execute a technical impact assessments by simulation to quantify the impact of the AEROFLEX innovations for various relevant logistic applications (as part of D6.6).

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List of Abbreviations

AEMPT: Advanced Energy Management Power Train
KPI: Key Performance Indicator
WP: Work Package
EMS: European Modular System
GCW: Gross Combination Weight
NCW: Net Combination Weight
HOD: Hybrid on Demand
CFD: Computational Fluid Dynamics
SOC: State Of Charge
CV: Control Vehicle
TF: Transformers
GETMS: Global Energy and Torque Management
EMG: Electric Motor Generator
GPS: Global Positioning System
DPF: Diesel Particulate Filter
ECU: Engine Control Unit
OBD: On Board Diagnosis
SCR: Selective Catalytic Reduction
PEMS: Portable Emissions Measurement System
VECTO: Vehicle Energy Consumption Calculation Tool
GRC: General Road circuit
HST: High Speed Track
DPA: Dynamic Platform
P&G: Procter & Gamble
WP: Work Package
NET: Net Energy Change

1 Purpose of the document

The overall objective of the 6.3 Test program and protocol deliverable is to evaluate the benefits of the different technologies developed in the WP 2, 3 and 4. To achieve this objective, first a list of assessment and measurement Key Performance Indicators (KPI's) are identified together with the different Work Packages (WP's).
This initial evaluation has allowed to clearly identify the objectives to evaluate each new technology and how to define the test matrix. These KPI's include fuel consumption, aerodynamics, performance based safety standards, and loading efficiency.

Once, the KPI's have been defined, preparations started for defining the final test matrix. The test matrix includes test-cases, which are groups of vehicles that consider the same innovations(s) for a given vehicle type. On the other hand, the test matrix contains test use-cases, which are the different type of tests. The test cases contain nine vehicle configurations which are classified as follows:

- Zero-case;
- Reference vehicles;
- Advanced reference vehicles
- Demonstrator vehicle of the AEMPT type
- Demonstrator vehicles of the AeroLoad type

The test use-cases contain:

- Fuel consumption tests at steady-state speed at proving ground;
- Fuel consumption test at a real world route;
- Vehicles air drag measurements at proving ground
- Dynamic vehicle behaviour tests at proving ground
- Terminal (un-) loading tests at a customer's depot.

The definition of this test matrix allows us to determine an overview of vehicle comparisons necessary to understand for each vehicle category and KPI. This comparison focusses on the defined KPI's, e.g. fuel consumption, fuel efficiency, air drag reduction, loading and unloading performance as well as performance based safety standards.

The definition of the test protocol deals with the difficulty to evaluate the different vehicle configurations during a long period of two test years. For this reason, the test protocol includes the necessary tools to control the results obtained and evaluate the benefits of each technology without interferences of external influences, like ambient conditions.
The testing activities will be carried out in IDIADA's test track (fuel consumption test at steady-state speed, air drag and dynamic tests) and surroundings for the fuel consumption on public roadway.
The terminal (un-) loading evaluations will be carried out at P&G facilities.

The data will be provided in a standardized format that can be easily used by each partner to do its own calculations and data post processing.

2 Introduction

A specific test matrix and test programme has been defined to align the interests of each WP and the budget allocated to the testing activities. The WP needs has been identified and explained in the deliverable 6.1 Definition of use cases/test cases and the overall KPIs and the information extracted from that deliverable has been essential for the development of to the test programme and protocol.

The KPI's defined in the deliverable 6.1 used to determine the test matrix and test programme are the following:

Fuel consumption efficiency

- Fuel consumption [l/km] (Energy consumption)
- Fuel consumption [l/tonne-km] (Energy efficiency)
- Average vehicle speed [km/h]

Aerodynamic efficiency

- Air drag reduction factor [-]

Loading efficiency

- Fill speed [minutes]
- Payload capacity [tonnes]
- Load factor [Volume-%]

Safety standards

- Startability
- Gradeability
- Acceleration capability
- Low speed swept path width
- Tail swing
- Static rollover threshold
- Rearward amplification
- Directional stability under braking
- High speed transient offtracking (HSTO)
- Yaw damping
- 360º Circle

3 Test matrix

Important part of the test program is the test matrix. This chapter describes in detail the combinations of test cases (containing different vehicle configurations) and test use-cases (types of tests), as main dimensions of the test matrix, supplemented with the specifications of these so-called third dimensions, like payload and aerodynamic settings. The Chapter starts with an introduction to the test matrix (Section 3.1) explaining the different dimensions of the test matrix, followed by the test-cases in Section 3.2 and the test use-cases in Section 3.3. Moreover, this Chapter provides an overview of the comparisons to be made, which besides others are applied in the final assessment D6.6 (Section 3.4). Finally, deviations from the initial test matrix as part of the Grant Agreement are listed in Section 3.5, including its reasoning behind.

3.1 Introduction to the test matrix

It is important to determine accurately the improvement on fuel economy for the different technological innovations towards improved aerodynamics, distributed powertrains and more effective loading space utilization. So, the test matrix considers all of these innovations in a structured manner for different vehicle types and types of tests.

The test matrix contains three vehicle types:

Tractor semi-trailer (16.5m)

EMS1 (25.25m)
(European Modular System)

EMS2 (32m)
(European Modular System)

For each vehicle type, different topologies are possible that demonstrate the innovations. The different vehicles that consider the same innovation(s) for a given vehicle type, are grouped in a so-called test-case. Within a test-case, more than one demonstrator could be tested. That is why the actual number of vehicles tested exceeds the number of test-cases. Additionally each vehicle configuration will need specific type of tests (test use-case).
To limit the number of tests however, usually one vehicle is tested per test use-case. Also to limit the size of the test matrix, not all vehicles are subject to the same number of tests. A smart selection of test-cases and test use-cases is made to deal with the trade-off between number of possible vehicle variations and number of repetitions for accurate and significant measurement results versus available test time, budget, equipment and resources.

The complete test matrix is given in Figure 3 at the end of this Section on page 16 and is explained in detail in the successive Sections. It contains of eight test-cases using nine different vehicle configurations and five test use-cases. The test use-cases are listed in Table 1 and each links to a particular KPI category. The test use-cases 1 and 2, which relates to the fuel consumption efficiency KPI category, are executed both on test track and public road. Only test use-case 5 will not be tested at IDIADA premises, but will be executed at the premises of a client of Van Eck Group.

Test use-case	Focus of test	Location	KPI
1.	Fuel consumption and emissions	Proving ground of IDIADA	Fuel consumption efficiency
2.		Public road close to IDIADA	
3.	Air drag	Proving ground of IDIADA	Aerodynamic efficiency
4.	Dynamic vehicle behaviour	Proving ground of IDIADA	Safety standards
5.	Loading and unloading of cargo	Loading dock	Loading efficiency

Table 1. Overview of the test use-cases as part of the test matrix and connected to a particular KPI

The test-cases are listed in Table 2 and are classified as:

- Zero-case vehicle;
- Reference vehicles;
- Advanced reference vehicles;
- Demonstrator vehicles.

For simplicity, this table does not include all different topology and innovation settings. These are covered in the successive sections as well as the complete test matrix (Figure 3).

	Vehicle classification	Configuration	Name	Part of test-case
0.	Zero-case vehicle	MAN 	MAN zero-case	1
1.	Reference vehicles	MAN 	MAN EMS1 reference	2
2.		SCA 	SCANIA EMS1 reference	2
3.	Advanced reference vehicles	MAN 	Advanced reference AEMPT	1
4.		SCA 	Advanced reference AeroLoad	1
5.	AEMPT demonstrator vehicles	MAN 	AEMPT+ EMS1	3
6.		MAN 	AEMPT++ EMS1	4 and 7
7.		MAN 	AEMPT++ EMS2	5
8.	AeroLoad demonstrator vehicle	SCA 	AeroLoad EMS1	6, 7 and 8

Table 2. Overview of the test-cases as part of the test matrix

The zero-case classification represents the current on-road state-of-the-art with high market sales volume in the EU of the tractor semi-trailer configuration. The reference vehicles are the 25.25m combinations (EMS1) treated as references for the Advanced Energy Management PowerTrain (AEMPT) and AeroLoad demonstrator vehicles. These demonstrators are also of the EMS1 type (except for the additional EMS2 AEMPT demonstrator). The advanced reference vehicles contain of tractor semi-trailer vehicles using the following EU TRANSFORMERS demonstrator trailers:

- Schmitz Cargo Bull (SCB) TRANSFORMERS (TF) Hybrid-on-Demand trailer (HOD)
- Van Eck Group (VEG) TF trailer.

Both semi-trailers have advanced aerodynamics and are visible in Figure 2.
Detailed specifications of the semi-trailers is given in Appendix B.

Figure 2. EU Transformers vehicle on the Swedish public road, left Schmitz Cargo Bull semi-trailer, right Van Eck Group semi-trailer [Source: TRANSFORMERS-D6.4-Final report and Conclusions-PU-FINAL-2017.09.28]

The AEROFLEX demonstrator vehicles are logically grouped in the demonstrator vehicles classification and contain of EMS1 and EMS2 configurations. The AEMPT demonstrator is always configured with a MAN pulling unit, whereas the AeroLoad demonstrator is pulled with a SCANIA unit. This is done, since MAN is involved in the AEMPT developments and SCANIA in the AeroLoad developments. To avoid influences of differences in powertrain controls between brands on the results, the advanced reference pulling units are aligned accordingly. This means that the TF-SCB with HOD is pulled by a MAN tractor unit and the TF-VEG trailer by a SCANIA tractor. Consequence is, that these advanced reference vehicles actually are not the TF demonstrators anymore, because back than DAF and VOLVO pulling units were involved (see Figure 2). Though, for accurate comparisons of the AEROFLEX demonstrators with the advanced references, exclusion of difference between brands is decided to be much more important. Additionally, no concessions are necessary on the tractor semi-trailer interaction, because the AEROFLEX pulling units are equipped with similar aerodynamic devices like in Transformers and the same HOD control functionality is present in the MAN tractor driving with the TF-SCB trailer. Detailed descriptions of both these vehicle configurations are given in Section 3.2.

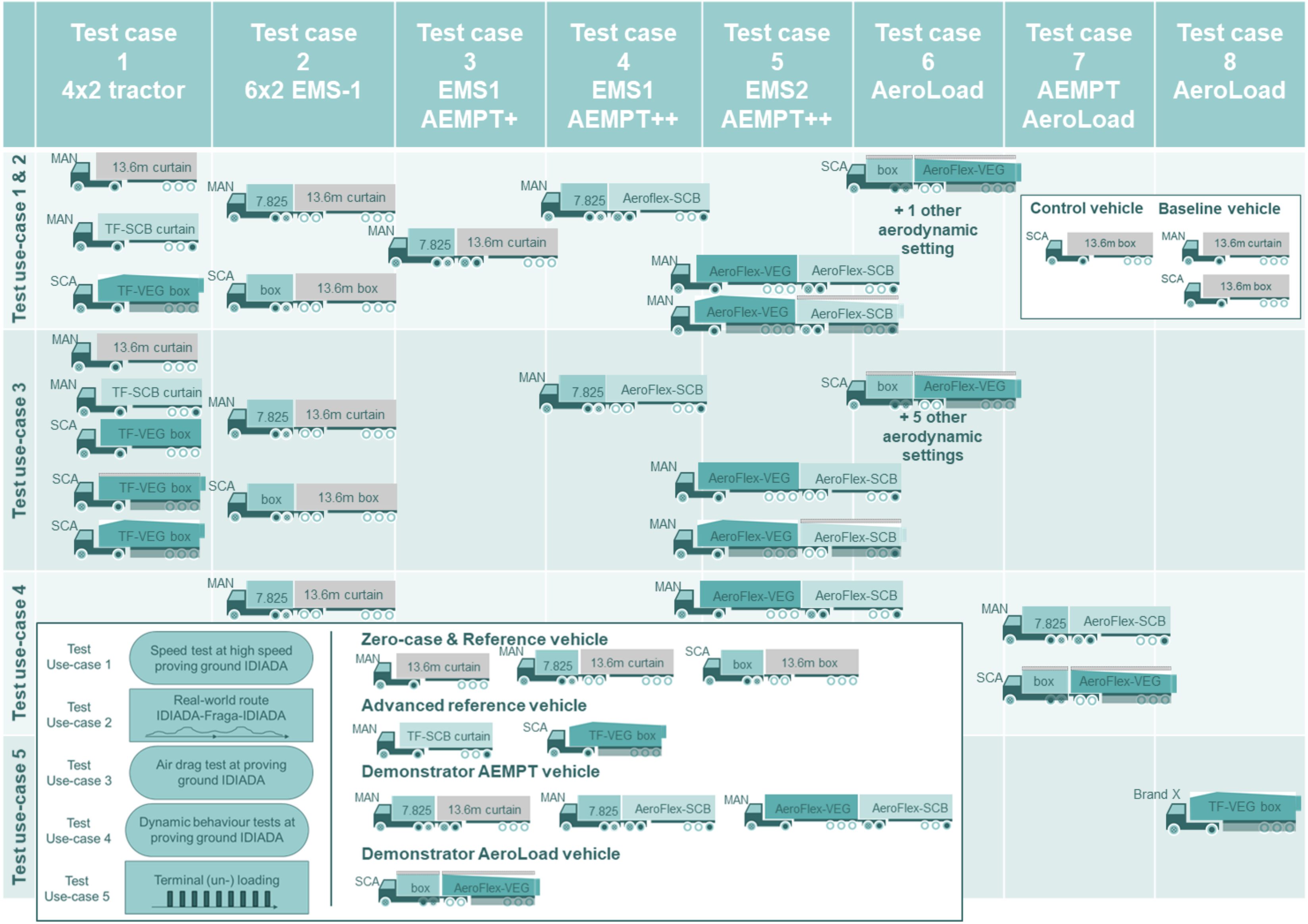
Beside the type of tests and vehicle configurations, other properties (“third dimensions”) have to be specified like payload and aerodynamic settings. Additionally in case of distributed powertrains also State Of Charge (SOC) related settings have to be specified. Since in particular this topic is linked to the fuel consumption measurement protocol it is described in Chapter 4.Payloads and aerodynamic settings are described in detail in the next Section. Chapter 4 Measurement equipment and protocols, describes in detail the applied methodology to conduct representative and accurate measurements for the individual test use-cases.

The test-case categorization is made to distinguish between tractor semi-trailers at one and the EMS1/EMS2 vehicles at the other end. The latter is splitted further into EMS1 reference vehicles, containing of current on-road rigid trucks, dollies and semi-trailers and the demonstrators, each in its own test-case. Only, test-cases 7 and 8 contain of vehicle configurations originating from test-case 3 (AEMPT) and test-case 6 (AeroLoad). The three AEMPT test-cases (3-5) contain two levels of rated electric propulsion power (test-cases 3 and 4), indicated with the + and ++ signs in Table 2 originating from either the E-dolly (+) supplemented with E-trailer (++) and EMS2 in test-case 5 only with E- dolly and single E-trailer (++).

By conducting the tests according to the test matrix, the following goals are served:

- Quantification of the KPI’s for the different test-cases at the corresponding test use-cases, allowing for the comparison with the set KPI targets;
- Providing input for the WP6 final technical assessment to validate the models:
    - Vehicles air drag.
    - Vehicles rolling resistance.
    - Fuel consumption.
- Demonstrate that 4x2 tractors or 6x2 trucks with 13l engines can deal with a broader vehicle portfolio, like EMS1 (European Modular System, configuration 1 containing of 25.25m vehicle with a 6x2 rigid truck – dolly – semi-trailer) and EMS2 (32m vehicle with a 4x2 tractor – semi-trailer – dolly – semi-trailer), if equipped with distributed powertrain and advanced aerodynamics, compared to current situation.

Figure 3. WP6 Test matrix with 8 test cases and 5 test use-cases. Four classes of vehicles are separated: 1) Reference vehicles including zero-case, 2) Advanced reference vehicles, 3) Demonstrator AEMPT vehicles and 4) Demonstrator AeroLoad vehicle



3.2 Test-cases (vehicle configurations)

As addressed in the previous Section, the vehicle configurations are classified by:

1. Zero-case vehicle (Section 3.2.1)
2. Reference vehicles (Section 3.2.2)
3. Advanced reference vehicles (Section 3.2.3)
4. Demonstrator vehicles (Section 3.2.4 and 3.2.5)

The AEROFLEX demonstrator vehicles contain both the AEMPT vehicles of MAN developed in WP2 and the AeroLoad vehicle of SCANIA developed in WP3 and WP4 with respect to the loading unit. Each configuration is described in detail in the successive subsections. Additionally, control and baseline vehicles are described in Section 3.2.6, as being used in test use-cases 1 and 2 for accurate fuel consumption testing.

3.2.1 Zero-case vehicle

Tractor semi-trailer axle configurations are by far the most used configuration in Europe for road freight transport, e.g. >76% of the total on-road freight transport in the 28 European countries in tonne-kilometres in 2016 is shipped with tractor semi-trailers[1]. Therefore, this vehicle is included in the test matrix as reference for the current on-road situation with which the AEROFLEX innovations can be compared too. So, the specification of the tractor semi-trailer vehicle should represent the high market share configuration in Europe. Currently, for EU >16t long haul applications, a DAF XF 4x2 tractor is mostly sold. However, potential comparisons of vehicles fuel consumption containing different brands is a sensible topic, especially if a control vehicle is necessary to obtain accurate fuel consumption values from the tests. Although brand comparisons are fully out of scope for this project, a DAF tractor unit could not be selected here and an alternative was required. Both MAN and SCANIA tractor options were available, where finally the MAN tractor is selected for the zero-case, because a SCANIA type Control Vehicle (CV) is selected. The CV vehicle and its need is described in detail Subsection 3.2.6. This choice also provides benefits when AEMPT and AeroLoad innovations need to be compared with the same brand pulling units to avoid differences in powertrain controls, e.g. MAN for AEMPT and SCANIA for the AeroLoad.

The MAN tractor is equipped with an adjustable roof spoiler, side air deflectors and tractor side skirts. This choice is made, because adjustable roof spoilers for long haul transport are in most cases selected from the catalogue and strongly advised together with the side air deflectors and side skirts, as a long haul aerodynamic package. Moreover, the combination serves as a state-of-the-art aerodynamic package.

The selected powertrain also needs to cover the high sales volumes and based on DAF, MAN and SCANIA data an engine with 450-500hp is chosen as typical for these EU long haul applications. Therefore, the MAN with a 12.4l 500hp suits this purpose. It is connected to an automatic 12-speed gearbox. In addition, state-of-the-art predictive cruise-control is present at the truck (MAN EfficientCruise®), enabling efficient use of kinetic energy by using trucks actual GPS position and route information in hilly environments. The applied settings for this cruise-control are described in Chapter 4.

Tractors cabin type is selected for long haul usage too. This means a medium height sleeper cabin, which for the MAN TGX line tractor is the XLX cabin type. Detailed specifications of this tractor unit can be found in Appendix B

To complete the zero-case tractor semi-trailer vehicle, the MAN tractor is coupled with a 3-axle curtain sider trailer. Curtain siders have over 60% market share in EU[2] and therefore provides a valuable EU market driven zero-case for the AEROFLEX innovations, both AEMPT and AeroLoad. The three axles are all non-steered and the trailer is equipped with side underrun protection only (no trailer side skirts), which is also mostly sold in EU. The combination of the MAN tractor and curtain sider semi-trailer is referenced to as the MAN zero-case.

The same MAN tractor unit is also being used in the advanced reference vehicle configuration for AEMPT and AEMPT EMS2 demonstrator, as is described in the next subsection.

[1] EUROSTAT 2016, Road freight transport by vehicle characteristics

[2] According to internal Schmitz CargoBull information

	Vehicle configuration	Main tractor specifications	Main trailer specifications
0.	**MAN zero-case**  • 16,5 m combination • GVW: 40 tonne • EU directive 96/53 compliant	• MAN TGX500 • XLX sleep cab (mid-size) • 4x2 tractor • 12.4l 368 kW Euro-VI (500hp) • With adjustable roof spoiler, side air deflectors and side skirts • Predictive cruise-control	• Guillen-group GSRE3, 2014 • 3 axles (non-steered) • Curtain sider • Side underrun protection (no side skirts) • Length: 13.6m • Tare weight: 6,500 kg

Table 3. Overview of main tractor/semi-trailer reference vehicle specifications

The vehicle specifications with respect to payload and test use-cases are given in **Error! Reference source not found.**. The zero-case vehicle is tested for two different payloads taken from the FALCON[3] project. The first payload is a fixed payload weight independent of the Nett Combination Weight (NCW) of the vehicle and approximately coincides with 50% payload and equals the EU average payload. The second payload is limited by the Gross Combination Weight (GCW), where the actual payload is dependent on the NCW. A vehicle with higher NCW carries less payload, if loaded to GCW. For the tractor semi-trailer configuration a GCW of 40t is applied. The conversion of the FALCON payloads to the absolute Aeroflex payloads is given in Appendix C – FALCON payload conversions. No variations in aerodynamic settings are necessary, because the tractor's adjustable roof spoiler and side air deflectors are set such that they best aligned with the semi-trailer for all test use-cases.

The zero-case vehicle is also tested in test use-case 3, but since these tests are air drag tests, payload variations are not necessary and empty vehicles are applied only. For more details on the test protocols and equipment, see Chapter 4.

Number	Reference name	Vehicle setting	GEM logic	Aerodynamic trailer settings	Payload [kg]	Test use-case
0	MAN zero-case	 	NA	• Side underrun protection (no side skirts)	13,598	1&2
					Up to GCW 40t	1&2

Table 4. Overview of aerodynamic settings, Global Energy Management (GEM) logic type and payloads for the tractor/semi-trailer zero-case vehicle

3.2.2 Reference vehicles

Besides the tractor semi-trailer zero-case as reference of current on-road state-of-the-art, also EMS1 configurations are allowed nowadays in parts of Europe. EMS1 vehicle configurations offer increased loading area, additional flexibility in the logistic operations and are already allowed in several EU countries under specific conditions and therefore another very important reference vehicle to include in the comparisons.

Two different EMS1 reference vehicles are incorporated. One as reference for the AEMPT demonstrators and another one for the AeroLoad demonstrator. These two are by purpose chosen to avoid multi-brand pulling units affecting the contributions of either the AEMPT or AeroLoad in the test results due to different powertrain control between brands. Furthermore, the SCANIA Aeroload demonstrator and SCANIA EMS1 reference use the same type of box to align both configurations.

For the MAN EMS1 reference, a curtain sider semi-trailer is selected to align with the TF-SCB trailer is also a curtain sider type. Both EMS1 reference vehicles make use of the same dolly, but differ in the rigid truck and semi-trailer type. Table 5 lists the main features of the two EMS1 reference vehicles. Details of the tractors and semi-trailers are listed in Appendix B**Error! Reference source not found.**.

[3] FALCON: Freight And Logistics in a Multimodal Context, research project funded under the CEDR Transnational Road Research Programme, http://www.cedr.eu/wpfb-file/cedr-call-2015_summaries-falcon-pdf/

MAN EMS1 reference
The MAN TGX 6x2-2 rigid truck (with liftable trailing axle) is selected to secure qualitative comparison of the MAN AEMPT demonstrator vehicles of which EMS1 type is the major part of it. Moreover, this MAN rigid truck is in essence the same unit for the AEMPT EMS1 demonstrator vehicles, which avoids the necessity of another vehicle in the test matrix.

The powertrain consists of a 15.2l engine with a 580hp rated power. This is more than sufficient for the EMS1 reference vehicle, keeping in mind the Dutch and Finland requirement for these vehicles of 5kW/ton of the GCW (60 ton – 300kW). Also this engine is coupled with an automatic 12-speed transmission. Like the zero-case tractor, this truck is also equipped with predictive cruise-control.

The aerodynamics on the rigid truck contains of adjustable roof spoiler and side air deflectors, but no side skirts. Instead, side underrun protection is installed. This because of the swap body type. The cabin type is also a mid-size sleeper cabin, applicable for long haul usage. The trucks body is a 7.825m length swap body to apply it also in the intermodal transport context.

The selected semi-trailer type is a curtain sider and the same unit as used for the MAN zero-case. This semi-trailer is selected here to align with the TF-SCB HOD trailer, which also is a curtain sider. This vehicle configuration is referenced to as MAN EMS1 reference.

SCANIA EMS1 reference
The SCANIA R-line 6x2-2 rigid truck is selected to secure qualitative comparison with the SCANIA AeroLoad demonstrator, which is also an EMS1 type configuration. As much as possible alignment with the MAN rigid is tried to obtain. This holds for the aerodynamics, powertrain and cruise control. The truck body is by purpose different from the MAN rigid truck, because it is a closed box type. This box has to be adjusted later on for the AeroLoad demonstrator (adjustable box height), since this rigid truck is in essence the same unit to avoid an unnecessary additional truck. A swap body with adjustable rood height is out-of-scope for the project and therefore not selected nor considered.

The selected semi-trailer is a box trailer, because the TF-VEG trailer is a box type trailer too. By this the AeroLoad reference and demonstrator vehicles all have a box type semi-trailer securing qualitative comparisons of the innovations. This vehicle configuration is referenced to as SCANIA EMS1 reference.

Since it is not the purpose to select vehicle configurations compliant to nowadays national and European legislations, a non-steered dolly is selected, simply because of the availability of these dollies at partners and/or rental companies.

	Vehicle configuration	Main tractor specifications	Main trailer & dolly specifications
1	**MAN EMS1 reference**  • 25.25 m combination • GVW: 60 tonne • EU directive 96/53 compliant with exception for length and weight, allowed in several EU countries under specific conditions	• MAN TGX580, XLX • 6x2-2 rigid truck • Steered trailing axle • 15.2l – 427 kW Euro-VI • Swap body 7.825m • With adjustable roof spoiler and side air deflectors • Without side skirts • Predictive cruise-control	Trailer: • Guillen-group GSRE3, 2014 • 3 axles (non-steered) • Curtain sider • Side underrun protection (no side skirts) • Length: 13.630m • Max payload: 27,000 kg • • Tare weight: 6,500 kg Dolly: • Schmitz Cargobull – Dolly DO 18/L-2", 2018 • 2 axles (non-steered)Tare weight: 2.55 tonne

2	**SCANIA EMS1 reference**  • 25.25 m combination • GVW: 60 tonne • EU directive 96/53 compliant with exception for length and weight, allowed in several EU countries under specific conditions	• CR20N sleep cab • 6x2-2 rigid truck • Steered trailing axle • 16.4l – 427 kW Euro-VI • Closed/rigid body ~7.825m • Curtain-sider or dry-box, possibly in a swap-body configuration • With adjustable roof spoiler and side air deflectors • With side skirts • Predictive cruise-control	Trailer: • SCB S.KO EXPRESS, 2005 • 3 axles (non-steered) • Box type • Side underrun protection (no side skirts) • Length: 13.685m • Max. payload: 32,018 kg • Tare weight: 7,613 kg Dolly: • Schmitz Cargobull – Dolly DO 18/L-2", 2018 • 2 axles (non-steered) • Tare weight: 2.55 tonne

Table 5. Overview of main EMS1 reference vehicle specifications

The specific settings of the EMS1 reference vehicles are given in Table 6 for the test use-cases 1 and 2. Since no dedicated aerodynamic settings are available, only variations in payload are applied of which the values are taken from the FALCON project. The truck's adjustable roof spoiler and side air deflectors are set such that they best align with the body for all test use-cases. For test use-case 3, both configurations are tested with a zero payload.

Number	Reference name	Vehicle setting	GEM logic	Aerodynamic trailer settings	Payload [kg]	Test use-case
1	MAN EMS1 reference	 	NA	• Side underrun protection (no side skirts)	21,422	1&2
					Up to GCW 60t	1&2
2	SCANIA EMS1 reference	 	NA	• Side underrun protection (no side skirts)	21,422	1&2
					Up to GCW 60t	1&2

Table 6. Overview of aerodynamic settings, Grobal Energy Management (GEM) logic type and payloads for the EMS1 reference vehicles.

3.2.3 Advanced reference vehicles

The most important reference vehicles for the project are the advanced reference vehicles using the Transformers (TF) semi-trailers. This is because the target energy efficiency improvements are relative to these innovative vehicle concepts. The first Transformers trailer is from Schmitz Cargo Bull and referenced to as TF-SCB. The second semi-trailer is manufactured by Van Eck Group and referenced to as TF-VEG. The main specifications of these two Transformers semi-trailers are given Table 7.

Manufacturer	Loading space	Aerodynamics	HOD
SCB	• Single floor	• Adjustable roof height: high/low flat/tapered with boat tail • Side skirts • Bulkhead cover	Yes
VEG	• Double floor, second floor contains of flexible floor segments (height adjustment)	• Adjustable roof height and shape of 4 trailer body segments with boat tail • Side skirts • Bulkhead cover	No

Table 7. Overview Main features of the Transformers trailers

Since, the TF-SCB trailer is equipped with the Hybrid-on-Demand (HoD) system, it is the main reference vehicle for the MAN AEMPT. The tractor/TF-SCB semi-trailer vehicle is referenced to as advanced reference AEMPT. In the test matrix, a MAN tractor is selected (same unit as in MAN zero-case) together with this TF-SCB trailer, because MAN is developing the Global Energy and Torque Management (GETMS) of the AEMPT vehicle. Moreover, a MAN unit is selected to minimize differences in aerodynamics and vehicle/engine performance between brands. Of course, aerodynamic differences between tractor and rigid truck cannot be eliminated, because of the different vehicle types, but is minimized because of the same brand and cabin type selected. Although, this combination of MAN tractor and TF-SCB trailer was not part of the Transformers project, still the Transformers hybrid-on-Demand control logic – implemented by Fraunhofer IVI – between tractor and trailer is compatible by using TNO's gateway interface. The TF-HoD software used for this advanced reference vehicle is the same as was used in TF for the majority of testing – especially the DAF-testing. In the TF project the strategy was referred to as "Case 4". It provides features as:

- Regenerative braking;
- Combined driving (ICE + EMG);
- Usable SOC-window: approximately 30 to 80 %.

The TF-VEG trailer is not equipped with a HOD system and has even more advanced aerodynamics compared to the TF-SCB trailer (roof height adjustment in 4 segments). Therefore, it is the main reference for the AeroLoad vehicle. As the AeroLoad vehicle is a SCANIA brand truck, a same brand tractor is selected with this TF-VEG trailer. This vehicle is referenced to as advanced reference AeroLoad.

Table 8 shows the main tractor and trailer specifications for the advanced reference vehicles. Exact settings of aerodynamic devices, payload and energy management control logic type are specified for these vehicles in Table 9.

Number	Vehicle configuration	Main tractor specifications	Main trailer specifications
3	<u>**Advanced reference AEMPT**</u>  • 16.5 m combination • GVW: 40 tonne • EU directive 96/53 compliant	• MAN TGX500 • XLX sleep cab • 4x2 tractor • 12.4l 368 kW Euro-VI (500hp) • With adjustable roof spoiler, side air deflectors and side skirts • Predictive cruise-control	• SCB Hybrid-on-Demand trailer from Transformers • 3 axles, third axle driven • Curtain sider • Length: 13.8m • Max. payload: 27,700 kg • Tare weight: 8,300 kg • Movable roof and boat tail • Peak power EMG: 105kW • Battery capacity: 23 kWh • Overall reduction: 1:11.72 • With clutch

4	**<u>Advanced reference AeroLoad</u>**  • 16.5 m combination • GVW: 40 tonne • EU directive 96/53 compliant	• SCANIA 4x2 R-line with CR20N sleep cab • 13l, 368kW Euro-VI engine (500hp) • With adjustable roof spoiler, side air deflectors and side skirts • Predictive cruise-control	• VEG trailer from Transformers • 3 axles • Covered semi-trailer with adjustable roof height/ shape and boat tail • Length: 13.8m • Max. payload: 27,000 kg • Tare weight: 10,000 kg

Table 8. Overview of main advanced reference vehicle specifications

The advanced reference AEMPT vehicle will only be tested using a single aerodynamic semi-trailer setting, because for pure AEMTP comparison, the influence of different aerodynamic settings needs to be minimized. Moreover, in Transformers other aerodynamic settings have been tested and are out-of-scope for this project. The trailer setting selected is called high flat without boat tail folded off and without trailer side skirts (replaced by side underrun protection during the test). These settings are specified in detail in Table 9.

The aerodynamic performance of the TF-VEG trailer is not tested in the Transformers project, so performance numbers on air drag reduction or fuel improvements are unknown. To obtain a good advanced reference for the AeroLoad demonstrator this vehicle need to be tested. However, to avoid significant reference vehicle testing (focus should be on the demonstrators), WP3 will investigate whether by CFD simulations the best aero dynamic settings can be determined to limit the number of configurations to be tested for this vehicle to 2 in the air drag tests (test use-case 3). In case this is not possible, three different aerodynamic settings will be tested for this vehicle in test use-case 3. Table 9 is set-up assuming three different aerodynamic settings to be tested at test use-case 3. At the moment of writing, it is unknown whether these CDF simulations can be performed to reduce the test. Potential candidates for the best performing aerodynamic setting and its relation to different kind of cargo are listed:

- 5a. <u>Nominal settings</u>: maximum roof height, flat roof position, boat tail folded in and no side skirts;
- 5b. <u>High volume</u>: maximize cargo volume (maximum roof height) while still have reduced air drag by boat tail folded out and side skirts;
- 5c. <u>High mass</u>: Lowest flat roof height with boat tail folded out and side skirts to get maximum air drag reduction, since trailer is limited by mass and not by volume;
- 5d. <u>Teardrop:</u> settings with lowest air drag assumed that cargo will fit the internal trailer shape. Exact settings of the trailer wall/roof segments will follow from WP3 CFD simulations.

The fuel consumption performance for this advanced reference vehicle is limited to only the best performing aerodynamic setting from the air drag tests (test use-case 3). This vehicle will be tested with two different payloads as is indicated in Table 9.The choice is made to again get more time for the demonstrator tests and improve significance of test results by allowing more repetitions. The selected payloads applied in test use-cases 1 and 2 originate from the FALCON project, applied to the advanced reference vehicle configurations.

Number	Reference name	Vehicle setting	GEM logic	Aerodynamic trailer settings	Payload [kg]	Test use-case
3	Advanced reference AEMPT		TF-HOD	• High flat • No boat tail • No side skirts (underrun protection instead)	13,598 Up to GCW 40t	1&2 1&2
4a	*Best aerodynamic setting applied from Test use-case 3 results*		NA	• High flat • With boat tail • With side skirts		
				Optimal VEG trailer shape found from test-use case 3	13,589 Up to GCW 40t	1&2 1&2
4b	Advanced reference AeroLoad			• Full height configuration • With boat tail • With side skirts		
4c				• Sloped roof • With boat tail • Air deflector in low positions • With side skirts		

Table 9. Overview of aerodynamic settings, Global Energy Management (GEM) logic type and payloads for the advanced reference vehicles. All specified configurations are tested at test use-case 3 (air drag), but only one is evaluated on fuel consumption as specified in the table

3.2.4 Demonstrator AEMPT vehicles

The distributed powertrain technology developed in WP2 is demonstrated at two different vehicle categories, being EMS1 and EMS2. For EMS1, it is considered by taking a steered E-dolly, with the TF-SCB HOD trailer and conventional curtain semi-trailer. The + sign in the reference name, indicates the total electric peak power, where + relates to the conventional dolly with E-trailer and ++ to the E-dolly and E-trailer. The main vehicle specifications are given in Table 10. Both AEMPT EMS1 configurations use the same truck as used in the MAN EMS1 reference.

The AEMPT+ EMS1 demonstrator (5) configuration is obtained by replacing the conventional dolly from the MAN EMS1 reference by the E-dolly developed in the project and obviously add the GETMS control logic to the truck. In this way, a pure comparison with the EMS1 reference is obtained.

The AEMPT++ EMS1 demonstrator (6) is obtained by replacing the conventional trailer from the AEMPT+ EMS1 demonstrator with the TF-SCB trailer with minimized aerodynamic difference compared to the conventional semi-trailer to get the purest AEMPT comparison possible.

Table 10. Overview of main AEMPT demonstrator vehicle specifications

Number	Vehicle configuration	Main tractor specifications	Main trailer and dolly specifications	
5	**AEMPT+ EMS1**  • 25.25 m combination • GVW: 60 tonne	• MAN 6x2-2 TGX580 XLX cab • 15.2l, 427kW Euro-VI engine (580hp) • With adjustable roof spoiler and side air deflectors • Without side skirts • C782 swap body • Predictive cruise-control	Trailer: • Guillen-group GSRE3, 2014 • 3 axles (non-steered) • Curtain sider • Side underrun protection (no side skirts) • Length: 13.630m • Max payload: 27,000 kg • Tare weight: 6,500 kg	E-Dolly: 2 axle, steered 1st axle, electrically driven 2nd axle Peak power EMG: 2x125kW (2x60kW cont.) • Battery capacity: 48-80 kWh • Overall reduction: 1:17.8 without clutch
6	**AEMPT++ EMS1**  • 25.25 m combination • GVW: 60 tonne	• MAN 6x2-2 TGX580 XLX cab • 15.2l, 427kW Euro-VI engine (580hp) • With adjustable roof spoiler and side air deflectors • Without side skirts • C782 swap body • Predictive cruise-control	Trailer • SCB Hybrid-on-Demand trailer from Transformers, curtain sider • 3 axles, third axle driven • Length: 13.8m • Max. payload: 27,700 kg • Tare weight: 8,300 kg • Movable roof and boat tail • Peak power EMG: 105kW • Battery capacity: 23 kWh • Overall reduction: 1:11.72 with clutch	E-Dolly: 2 axle, steered 1st axle, electrically driven 2nd axle Peak power EMG: 2x125kW (2x60kW cont.) • Battery capacity: 48-80 kWh • Overall reduction: 1:17.8 without clutch
7	**AEMPT++ EMS2**  • 32 m combination • GVW: 74 tonne	• MAN 4x2 TGX500 XLX cab • 12.4l, 368kW Euro-VI engine (500hp) • With adjustable roof spoiler side air deflectors and side skirts • Predictive cruise-control	Trailer 1 (left): • VEG trailer from Transformers, 3 axles • Covered semi-trailer with adjustable roof height/ shape and boat tail • Length: 13.8m • Max. pay load: 27,000 kg • Tare weight: 10,000 kg E-Dolly: 2 axle, steered 1st axle, electrically driven 2nd axle Peak power EMG: 2x125kW (2x60kW cont.) • Battery capacity: 48-80 kWh • Overall reduction: 1:17.8 without clutch	Trailer 2 (right): • SCB Hybrid-on-Demand trailer from Transformers • 3 axles, third axle driven • Curtain sider • Length: 13.8m • Max. payload: 27,700 kg • Tare weight: 8,300 kg • Movable roof and boat tail • Peak power EMG: 105kW • Battery capacity: 23 kWh • Overall reduction: 1:11.72 • With clutch

Besides EMS1 configurations, AEROFLEX also treats vehicle concepts beyond todays state-of-the-art, so an EMS2 configuration is included with distributed powertrain technology. The vehicle concept is especially of interest to see whether a current 4x2 tractor with 13l engine is able to deal with this longer and heavier configuration when air drag is reduced and the powertrain is assisted by an E-dolly and E-trailer. In addition, this EMS2 configuration demonstrates the transfer of the GETMS logic to another pulling unit. Whereas, the GETMS logic is developed for multi-brand purposes, demonstrating this within the project is decided to be out-of-scope, because of the additional effort and limited budget.

The AEMPT EMS2 demonstrator uses a MAN 4x2 tractor and both Transformers trailers, with the TF-SCB trailer as latest. Since the TF-VEG trailer is more advanced on aerodynamic features, having this semi-trailer at the back is most favourable. However, insufficient space to mount a coupling at the TF-SCB trailer is reason to put this trailer at the back instead.

The MAN tractor is identical to the advanced reference AEMPT MAN tractor, but now making use of the GETMS logic. A 4x2 tractor is selected, because compared to a tractor semi-trailer combination, no difference in axle loads occurs. Moreover, a 6x4 is not necessary here to comply to the rule of 25% of vehicles laden weight need to be applied to the driven axles, because of several reasons:

- One might assume E-axles to be considered as drive torque axles, then the requirement is met;
- EMS2 is generally not allowed (except for Finland) and complying to current EU legislation is not the purpose of the project.

Additionally, since the MAN 4x2 tractor unit can be re-used here, it saves additional costs.

The specific aerodynamic settings and payloads for the AEMPT EMS1 and EMS2 demonstrators are given in Table 4.11. Basically, the aerodynamic features are as much as possible disabled for pure AEMPT comparisons. Moreover, it supports the model parameterization for the final technical assessment to simulate such vehicle configurations. This implies, no trailer side skirts (side underrun protection instead), high trailer roof height and boat tail folded in. Other aerodynamics settings are not chosen due to limited test budget and the AeroLoad demonstrator already focusses on the aerodynamics more than the AEMPT.

For EMS2 (7) another decision is made, because this is an extreme heavy configuration and a high potential configuration in terms of fuel energy savings. Therefore, two aerodynamic settings (7a and 7b) are tested both in test use-case 1 and 2. One only showing the pure AEMPT contribution (7a) and the other one with combined AEMPT and best aerodynamic settings possible (7b). The latter also quantifies the statement whether 4x2 tractors with 13l engines can deal with this EMS2 configuration while supported by lower air drag and assisted by the distributed powertrain.

During the air drag tests of all these AEMPT related demonstrator vehicles, the E-dolly will be replaced by the conventional dolly which is also used in the EMS1 reference vehicles, because the E-dolly is not equipped with a clutch. This is required to not affect the tractor/truck wheel torque measurements. Furthermore, it avoids deviations from the air drag test protocol followed and described in Chapter 4.

In case the TF-SCB trailer is involved, the clutch in the trailer will be opened, such that no wheel torque can be applied by the Electric Motor Generator (EMG).

Number	Reference name	Vehicle setting	GEM logic	Aerodynamic trailer settings	Payload [kg]	Test use-case
5	AEMPT+ EMS1		GETMS	• NA	21,422	1&2
					Up to GCW 60t	1&2
6	AEMPT++ EMS1		GETMS	• High flat • No boat tail • No side skirts (side underrun protection)	21,422	1&2
					Up to GCW 60t	1&2
7a	AEMPT++ EMS2		GETMS	VEG: • High flat • No boat tail • No side skirts (side underrun protection) SCB: • High flat • No boat tail • No side skirts (side underrun protection)	27,196	1&2
					Up to GCW 74t	1&2
7b				VEG: • Tear drop shape • No boat tail • With side skirts SCB: • Low tapered • With boat tail • With side skirts	27,196	1&2
					Up to GCW 74t	1&2

Table 11. Overview of aerodynamic settings, Global Energy Management (GEM) logic type and payloads for the AEMPT demonstrator vehicles. All specified configurations are tested at test use-case 3 (air drag).

3.2.5 Demonstrator AeroLoad vehicle

The SCANIA AeroLoad demonstrator vehicle is an EMS1 configuration. It consists of a non-steered dolly developed by VEG in WP3 together with the TF-VEG trailer all pulled by a SCANIA rigid 6x2-2 rigid truck. The main specifications of this vehicle are given in Table 12. The aerodynamic features of this demonstrator are at this stage unknown, because the aerodynamic concepts are under development in WP3. Two best performing aerodynamic setting are used for fuel consumption evaluation in test use-cases 1 and 2. Again two different payloads are applied with equally to the other EMS1 vehicles, so 21,422 kg and GCW up to 60t taken from the FALCON project.

From D3.1[4], in total 25 aerodynamic concepts are under evaluation of which in total 10 concepts are at this stage already assigned not to be evaluated on the demonstrator vehicle, either because the concept better suits a tractor semi-trailer configuration or the expected performance is limited. Additionally, at this stage at least three different concepts are selected to be part of this AeroLoad demonstrator, being:

- Retractable trailer via the dolly;
- Adaptable trailer and box shape;
- Movable boat tail.

Other concepts to be part of the demonstrator will follow after these are evaluated by CFD simulations as part of WP3. This information is expected in project month 30 after task 3.3 is completed. Consequently, the applied AeroLoad icons are indicative.

Number	Vehicle configuration	Main tractor specifications	Main trailer and dolly specifications
8	**AeroLoad EMS1**  • 25.25 m combination • GVW: 60 tonne	• SCANIA 6x2-2 R-line CR20N cab (sleeper) • 16.4l, 427kW Euro-VI engine • Steered trailing axle • Closed/rigid body 7.825m • Several aerodynamic features (unknown at this stage)	Trailer: • VEG trailer from Transformers, 3 axles • Covered semi-trailer with adjustable roof height/ shape and boat tail • Length: 13.8m • Pay load: 27,000 kg • Tare weight: 10,000 kg Dolly: • Schmitz Cargobull dolly • 2 axle, non-steered • Tare weight: 2,501 kg

Table 12. Overview of main AeroLoad demonstrator vehicle specifications

Table 13 provides an overview of the different aerodynamic settings and its selection towards test use-cases 1 and 2. Six different aerodynamic settings are evaluated for air drag in test use-case 3. From these 6 air drag results, the best two settings are selected to be tested in test use-case 1 and 2 for fuel consumption.

[4] "AEROFLEX-D3.1-Seection on concepts-CO-FINAL-2018.04.27", Elofsson P. et. al., 2018

Number	Reference name	Vehicle setting	GEM logic	Aerodynamic trailer settings	Payload [kg]	Test use-case
8a			NA	• All aero systems activated • Lowest drag position • With standard boat-tail		
	The best 2 aerodynamic settings applied from Test use-case 3 results			1st Optimal aerodynamics found from test-use case 3 results	21,422	1&2
					Up to GCW 60t	1&2
				2nd Optimal aerodynamics found from test-use case 3 results	21,422	1&2
					Up to GCW 60t	1&2
8d	AeroLoad EMS1			• Configuration to be determined		
8e				• Configuration to be determined		
8f				• Configuration to be determined		
8g				• Configuration to be determined		
8h				• Configuration to be determined		

Table 13. Overview of aerodynamic settings, Global Energy Management (GEM) logic type and payloads for the AeroLoad demonstrator vehicle. All six specified configurations are tested at test use-case 3 (air drag).

The number of configurations may be reduced for the benefit of increased number of repetitions in each configuration to improve the data quality. This final decision will be agreed between WP3 and WP6.

3.2.6 Control and baseline vehicles

3.2.6.1 Control vehicle

Accurate fuel consumption measurements for heavy-duty vehicles to compare different innovations with each other on test track and public road are described in several protocols, like SAE J1526 (type III), SAE J1321-II (type II), SAE J2711. In both type II and III procedures, the use of a control vehicle (CV) is highly recommended in case there is no simultaneous testing of the different test vehicles (TV). The latter is the case in this project, because the testing period covers approximately 2-2.5 years. The CV enables the compensation of fuel consumption measurements of TV's for different external conditions like ambient pressure and temperature. This safeguards correct comparisons of different TV performances with each other.

Both protocols prefer that CV and TV are as close as possible to each other (e.g. brand, configuration, powertrain, etc.) securing that the effect of different ambient conditions towards fuel consumption are equal as possible for both CV and TV. Additionally, the differences between the TV's should only be the innovation(s) to be quantified by the tests to quantify its performance.

The test matrix in this project goes far beyond this type of testing due to the broad range of innovations, different vehicle configurations and brands. Therefore, the test matrix is set-up in such a way that within the project constraints, the maximum amount of information is obtained to quantify and fairly compare the innovations with each other. The comparisons are described in Section 3.4.

Although three different vehicle configurations are part of the test matrix, a single tractor trailer CV is chosen for all fuel consumption testing to secure that over the complete test period, the same CV is used to correct the TV's fuel consumptions with. Since both SCANIA and MAN TV's are part of the test matrix, either a MAN or SCANIA CV is chosen. The decision is made to select a SCANIA control vehicle, because the MAN is already embedded as zero-case in the test matrix.

To minimize expenditures and not have a too advanced CV, a tractor semi-trailer configuration is selected. The trailer is chosen to be a 3-axle, like all other semi-trailers in the test matrix and of the box type. This because it nicely aligns with the AeroLoad TV's (all box types) and for the AEMPT related test vehicles the differences between them are already much larger compared to the AeroLoad related TV's (like an EMS2). Figure 4 depicts the different AEMPT and AeroLoad related TV's for the fuel consumption testing in test use-cases 1 and2 together with the CV being identical for both AEMPT and AeroLoad related testing. The so-called baseline test for AEMPT and AeroLoad are explained in more detail in the next sub-section.

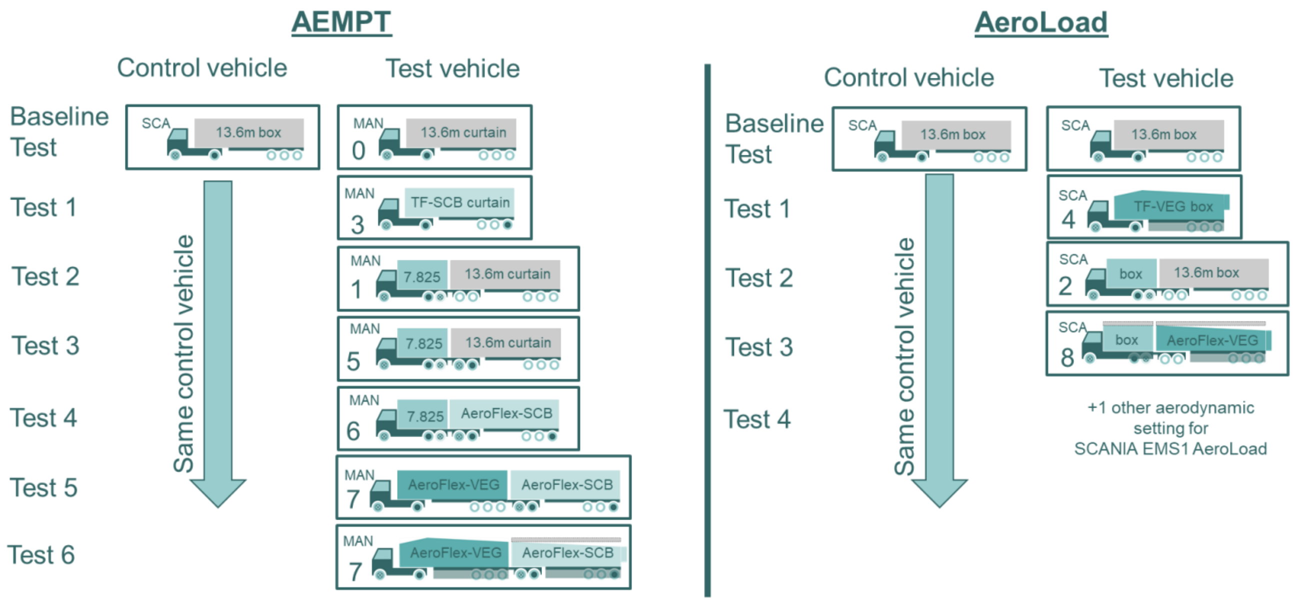


Figure 4. Overview of the different Test Vehicle (TV) configurations for AEMPT and AeroLoad both using the same Control Vehicle throughout the testing period.

Main specifications of the CV is given in Table 14. The selected vehicle is chosen to be as close as possible to the demonstrator tractors, meaning a 4x2 axle configuration, long haul cabin type, rated engine power 450hp and predictive cruise-control.

	Vehicle configuration	Main tractor specifications	Main trailer specifications
CV1	**Control Vehicle**  • 16,5 m combination • GVW: 40 tonne • EU directive 96/53 compliant	• SCANIA R450 A4x2NA • 4x2 tractor • CR20H (sleep cab high roof height) • DC13 148 Euro-VI (450 hp) • With adjustable roof spoiler and side air deflectors and side skirts • Predictive cruise-control • 2017 model year • Mileage at start 50,000 km	• SCB S.KO Express, 2016 • 3 axles (non-steered nor trailing) • Box type • Side underrun protection (no side skirts) • Length: 13.6m • Max. payload: 32,018 kg • Tare weight: 7,613 kg • 2016 model year • Mileage start: 273,500km • Bearing revision

Table 14. Overview of main tractor/semi-trailer control vehicle specifications

3.2.6.2 Baseline vehicles

A baseline vehicle, in principle is the TV without the innovations to be assessed and is typically part of test matrix. Its purpose is to monitor the performance over the testing period of the CV and baseline vehicle (e.g. wear). It allows normally to correct fuel consumption measurements with more accurate baseline values, but only makes sense if the TV's are always compared to the same baseline vehicle. In this project this is not the case as is explained in detail in Section 3.4. Also due to the large number of different vehicle configurations, ideally multiple baseline vehicles are required. This would lead to unrealistic testing expenditures.

Hence, 2 baseline vehicles are defined, one for the AEMPT and another one for the AeroLoad demonstrators and other tests being described in the test protocols to detect mechanical wear, like for instance static friction measurements. The AEMPT baseline vehicle is chosen to be identical to the MAN zero-case vehicle. The SCANIA baseline vehicle is close to the CV. The main specifications of both baseline vehicles are given in Table 15.

	Vehicle configuration	Main tractor specifications	Main trailer specifications
B1	**AEMPT Baseline**  • 16,5 m combination • GVW: 40 tonne • EU directive 96/53 compliant	• MAN TGX500 • XLX sleep cab • 4x2 tractor • 12.4l 368 kW Euro-VI (500hp) • With adjustable roof spoiler, side air deflectors and side skirts • Predictive cruise-control	• Guillen-group GSRE3, 2014 • 3 axles • Curtain sider • Side underrun protection (no side skirts) • Length: 13.630m • Max payload: 27,000 kg • Tare weight: 6,500 kg
B2	**AeroLoad Baseline** 	• SCANIA R500 A4x2NA • 4x2 tractor • CR20N (sleep cab normal roof height) • DC13 155/500 hp, Euro 6 • With adjustable roof spoiler and side air deflectors and side skirts • Predictive cruise-control • 2017 model year	• SCB S.KO EXPRESS, 2005 • 3 axles (non-steered nor trailing) • Box type • Side underrun protection (no side skirts) • Length: 13.685m • Max. payload: 32,018 kg • Tare weight: 7,342 kg • 2005 model year • Mileage at start: 273,500km • Bearing revision

Table 15. Overview of main tractor/semi-trailer baseline vehicle specifications

3.3 Test use-cases (type of tests)

There are 5 different test use-cases, being described in this Section.

3.3.1 Test use-case 1 – Steady-state speed test at proving ground

This test use-case contains of constant vehicle speed tests at the high speed test track of IDIADA measuring vehicles fuel consumption. The vehicles are prepared following the test protocol described in Chapter 4. The actual test covers a single constant vehicle speed at 85 km/h with two different payloads repeated for several rounds to guarantee a significant measured value of each test. The vehicle speed of 85 km/his selected, because it is the typical highway cruising speed of heavy-duty trucks. Although, constant vehicle speeds for hybrid vehicles does not make sense (hybrid system is not used or battery gets depleted), this test is still marked valuable to determine the systems functionality, quantify the vehicles power- and drivetrain efficiencies, behaviour on energy flows (fuel and electric) as well as providing details for model identification required for the final assessment activities.

3.3.2 Test use-case 2 – Real world Route Fraga

Quantification of the vehicles fuel consumption under real-world conditions with varying payloads is the purpose of this test use-case. Each vehicle configuration is tested at least three times at the public road from IDIADA to Fraga and back which is 240km in total. As example, the vehicle speed and road slope of the route for a 40t tractor semi-trailer vehicle with 440hp is given in Figure 5. The route characteristics are summarized in Table 16 and shows over 95% of the route is highway and takes around 3.5 hrs for the example vehicle. The route is mainly a two-lane highway with an additional lane when a significant incline is heading (see route impression in Figure 6). Traffic conditions are qualified by IDIADA as very light, so barely influence of other road users are expected during the tests. The hilliness route is a toll road, with maximum elevations of 6-7%, where the 40t tractor semi-trailer with rated power of 330hp reaches the lowest speeds of just above 40 km/h.

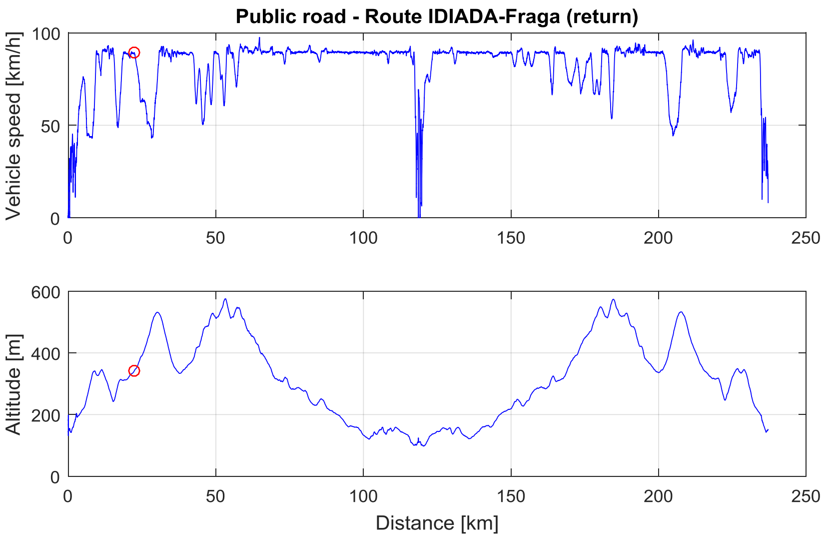


Figure 5. Example vehicle speed and slope profile of the IDIADA-Fraga route for a 40t tractor semi-trailer (GPS data). Red circle indicated the location of Google Street Maps view in Figure 6.

Trip duration [s]	12,000
Trip distance [km]	240
Average speed [km/h]	73.9 (>95% highway-distance based)
Min/max altitude [m]	87 / 573 m
Max up- and downhill slope [%]	6.6 / -6.8
Traffic conditions	Light (6 exits in between origin and destination)

Table 16. IDIADA-Fraga route characteristics for 40t tractor/semi-trailer

Figure 6. Impression of IDIADA-Fraga route (GPS data) taken from Google Street Maps at location indicated in Figure 5

3.3.3 Test use-case 3 – Air drag measurement at proving ground

The aim of this test use case is to measure the aerodynamic resistance of the vehicles by measuring the torque applied to the drive wheels at high and low speed and compare them. During the test, the air velocity, its yaw angle and the vehicle speed will also be measured and taken into account in order to obtain a result of the influence of the wind on the vehicle.

The air drag test will be performed as per Annex VIII of Commission Regulation (EU) 2017/2400 constant speed test procedure and will include the following phases:

- 1st warm-up
- Torque metres zeroing
- 2nd warm-up
- 1st low-speed test (14 km/h)
- 3rd warm up
- High-speed test / Anemometer misalignment (87 km/h)
- 2nd low-speed test
- Drift check of torque meters (14 km/h)

3.3.4 Test use-case 4 – Dynamic behaviour tests at proving ground

The aim of this test use case is to measure and compare the dynamic behaviour of the EMS1 and EMS2 vehicles. The test protocol is based on the PBS Scheme – The Standards and Vehicle Assessment Rules of the NTC (National Transport Commission) of Australia and adapted to IDIADA facilities with the support of HAN.
It is planned to carry out the following types of tests to evaluate the dynamic behaviour:

- Startability
- Gradeability
- Acceleration capability
- Low speed swept path width
- Tail swing
- Static rollover threshold
- Rearward amplification
- Directional stability under braking
- High speed transient offtracking (HSTO)
- Yaw damping
- 360º Circle

3.3.5 Test use-case 5 – Terminal (un-) loading tests

The objective of this test use-case is to measure the WP4 KPI's as described in D 4.1. The influence of the TF-VEG trailer innovations on payload capacity, fill speed and load factor for will be estimated. This is done by putting the trailer in operation in a line between two P&G warehouses. It is planned to use the daily roundtrip between Euskirchen and Crailsheim (see Figure 7). The trailer will be handed over to the haulier who is running the line now. The haulier is asked to adapt the truck so it can charge the batteries during driving and place a permanent driver on the truck that will be trained. P&G will need to arrange a forklift to raise the floors and lift the pallets to the second level. The forklift drivers need to be trained, to set the floors, at both warehouses. The planner must plan, with the new PUZZLE software the extra pallets that can be loaded in the VEG trailer and estimate their optimal positions and roof profiles. The trailer needs to be approved by the Safety Coordinator and undergo a Risk Assessment according the rules of P&G.
To make this test use-case successful, collaboration between WP4 (VEG, WABCO and FHG), WP6 (TNO and IDIADA) and the representatives of P&G (responsible person, driver, planner and maybe others) are required. TNO and VEG will coordinate this test use-case and the prerequisites are supplied by the others.

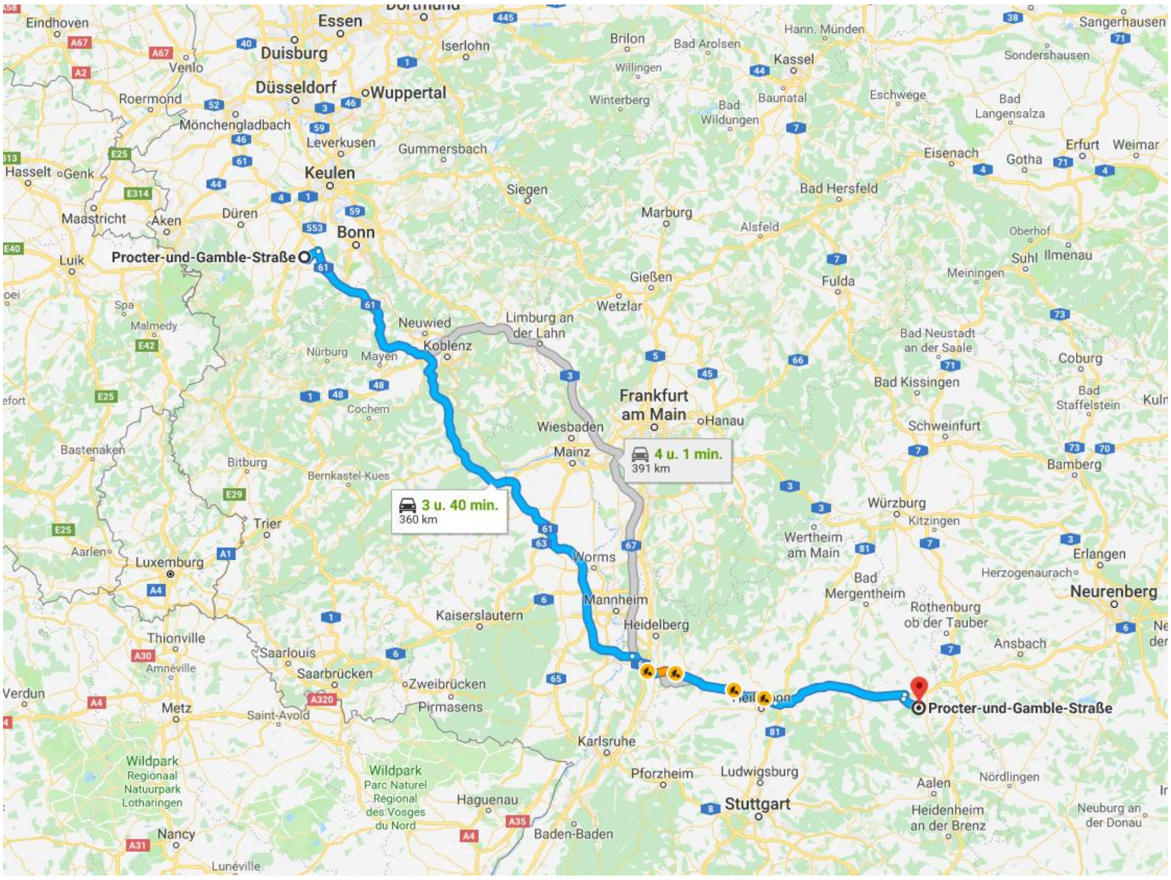


Figure 7. Foreseen route between the two P&G warehouses in Euskirchen and Crailsheim from Google Street Maps, distance of approx. 360 km single trip

Test description:

Phase 1 Baseline testing.
The first 3 weeks the trailer will be used as a standard trailer, no use of the flex floors, no use of the aerodynamic features such as movable roof and boat tail. The planner will plan 34 pallets so the first innovation, a bigger inner length will be tested and the goal of 3% efficiency improvement might be reached. The permanent driver is trained to note the times of setting the trailer on the dock, loading time and the time to prepare the trailer for taking off and collecting the freight letters. If the Cargo Cam, see D4.2, is installed the driver does not need to do these tasks, because the Cargo Cam will registrate and file it in the cloud. The haulier will calculate the fuel consumption in litres per km for the two weeks. The installed Cargo cam can also calculate from the GPS data the speed profiles.

Phase 2 Aerodynamic testing.
In this phase of also three weeks the influence of the aerodynamic features is tested. The influence of the extra time needed to set the roof and fold out and in the boat tail will be registered. The roof will be set at lowest possible position by the driver. The driver will note the times or the Cargo Cam will do the registration. The haulier will again calculate the fuel consumption and litres per km for the testing period. The installed Cargo Cam can also calculate from the GPS data the speed profiles.

Phase 3 Volume optimization testing
In this last phase the influence of the flex floor on pay load and load factor will be estimated. The planner now needs to prepare new shipments according to the opportunities the VEG trailer offers. The results strongly depend on the dimensions (heights) of the pallets and the possibility to find optimal load distribution and optimal roof shape. Again the PUZZLE software is a needed tool to get positive results and the Cargo Cam to registrate it.

3.4 Overview vehicle comparisons

The quantification of the impact of the AEROFLEX innovations is based on the different KPI's as described in Section 2**Error! Reference source not found.**. Each KPI category relates to a particular test use-case. Therefore, the comparisons are described per KPI category, being:

- Fuel consumption efficiency.
- Aerodynamic efficiency.
- Loading efficiency.
- Safety standards.

3.4.1 Vehicle comparisons for KPI – Fuel consumption efficiency

The assessment of the fuel consumption efficiency KPI's are obtained via test use-cases 1 and 2 from the test matrix. The comparisons contain of six different reference vehicles all with its own purpose, either overall project objective related or work package related. Table 17 lists the different vehicle configurations tested in these 2 test use-cases and the corresponding comparisons to be made with the different reference vehicles. These six different references are:

I. MAN zero-case (and simultaneously AEMPT baseline)
II. Advanced reference AEMPT
III. MAN EMS1 reference
IV. AeroLoad baseline
V. Advanced reference AeroLoad
VI. SCANIA EMS1 reference

Group	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				
AEMPT related vehicles	MAN 7.825 13.6m curtain	*(1) MAN EMS1 reference*	X		Reference			
AEMPT related vehicles	MAN 7.825 13.6m curtain	*(5) AEMPT+ EMS1*	X	X	X			
AEMPT related vehicles	MAN 7.825 AeroFlex-SCB	*(6) AEMPT++ EMS1*	X	X	X			
AEMPT related vehicles	MAN AeroFlex-VEG AeroFlex-SCB	*(7a) AEMPT++ EMS2*	X	X	X			
AEMPT related vehicles	MAN AeroFlex-VEG AeroFlex-SCB	*(7b) AEMPT++ EMS2 aero*	X	X	X			
AeroLoad related vehicles	SCA 13.6m box	*(B2) AeroLoad baseline*	X			Reference		
AeroLoad related vehicles	SCA TF-VEG box	*(4) Advanced reference (for AeroLoad)*	X			X	Reference	
AeroLoad related vehicles	SCA box 13.6m box	*(2) SCANIA EMS1 reference*	X			X		Reference
AeroLoad related vehicles	SCA box AeroFlex-VEG	*(8b) AeroLoad EMS1*	X			X	X	X
AeroLoad related vehicles	SCANIA EMS1 AeroLoad with different aerodynamic settings	*(8c) AeroLoad EMS1*	X			X	X	X

Table 17. Overview of the fuel consumption comparisons between the different vehicle configurations

3.4.1.1 Reference: MAN zero-case (& AEMPT baseline)

The MAN tractor semi-trailer represents the current, high sales volumes, EU averaged vehicle configuration. All other vehicle configurations, both other references and demonstrator vehicles can be compared to this vehicle. This leads to an overall lumped performance comparison for the different fuel consumption efficiency KPI's, because of the different vehicle configurations and innovations. The expectation is that using this reference, the highest relative savings are obtained by the AEROFLEX innovations, when using the [l/tonne-km] unit, because it benefits also due to the EMS configurations (making vehicles longer and heavier).

The advanced reference AEMPT performance benchmark with the MAN zero-case, using the TF-SCB HOD trailer is part of this comparison. The comparison of this advanced reference for AEMPT is a pure comparison of only the TF-SCB HOD trailer contribution, since the tractor in both configurations is identical, it only covers a replacement of the trailer. So, a qualitative number is obtained for the Transformers trailer here.

The advanced reference AeroLoad is also another important comparison with the MAN zero-case, because it will quantify the performance of the other Transformers trailer for advanced aerodynamics compared to the EU average vehicle. However, it does not provide a pure contribution of the TF-VEG trailer, expressed in fuel consumption numbers, because the tractor is also different. Nevertheless, the pure comparison of the TF-VEG trailer is obtained by taking comparison IV explained further on.

3.4.1.2 Reference: Advanced reference AEMPT

This reference vehicle is the comparison to quantify the AEROFLEX AEMPT innovations compared to the Transformers HOD trailer, especially of interest for WP2. This is the most important comparison to purely quantify the added-value of the AEMPT distributed powertrain for the EMS type demonstrators. Of course, this comparison is biased by both making the vehicle longer and heavier and making it an AEMPT, but therefore also comparison III is included to circumvent the effect of different vehicle configurations.

3.4.1.3 Reference: MAN EMS1 reference (AEMPT)

Taking this EMS1 vehicle which is equipped with a conventional powertrain, the EMS1 AEMPT demonstrators can be compared purely. This means that in two-steps the level of electrification of the EMS1 can be quantified, first with an E-dolly only (AEMPT+ EMS1) and secondly supplemented with an E-trailer too (AEMPT++ EMS1).

The EMS2 type AEMPT demonstrator, can also be compared to the MAN EMS1 reference, but also benefits from being longer and heavier. The EMS2 demonstrator does not have a pure baseline vehicles, but attempts are made to create a reference by simulation and/or using information from the conventional EMS2 configuration of Ewals Cargo Care used in Finland. If the available test time/budget is not limiting us during testing in 2020, a EMS2 reference is as first being considered as nice-to-have in addition. Then it will make use of existing tractor, dolly and semi-trailer units to set-up this vehicle configuration.

3.4.1.4 Reference: AeroLoad Baseline

The AeroLoad innovations all cover box type semi-trailers, so the baseline vehicle for test use-cases 1 and 2 is a box type too. By selecting this vehicle as reference, the fuel efficiency improvements of the AeroLoad demonstrator can be quantified without the influence of a non-box type trailer. Of course, the EMS1 vehicles benefits already from being longer and heavier, but will be eliminated when using comparison VI. Additionally, this reference purely quantifies the performance of the TF-VEG trailer for the same type of trailers (e.g. box) and without the bias of different pulling units (e.g. all SCANIA).

3.4.1.5 Reference: Advanced reference AeroLoad

Not only the AeroLoad demonstrators need to be compared to current state of the art on-road, but also towards the advanced aerodynamic Transformer trailer, e.g. TF-VEG. Therefore, taking this vehicle as reference quantifies the fuel consumption performance reductions established by the AEROFLEX demonstrators towards this advanced reference.

Like with the advanced reference AEMPT, this comparison is biased due to longer and heavier EMS1 configurations being the AeroLoad demonstrator configurations. Therefore, comparison VI is included to eliminate this bias.

3.4.1.6 Reference: SCANIA EMS1 reference (AeroLoad)

This comparison is the pure EMS1-based comparison of the AeroLoad innovations. The different aerodynamic settings of the AeroLoad demonstrator are quantified referenced to a conventional EMS1. All trucks in this comparison are identically powered, so a pure comparison remains.

At the moment of writing this deliverable, the final aerodynamic innovations brought to the EMS1 AeroLoad demonstrator are unknown and need to be determined. Two AeroLoad vehicle tests are incorporated allowing for the assessment of different aerodynamic settings/features.

3.4.2 Vehicle comparisons for KPI – Aerodynamic efficiency

The assessment of the aerodynamic efficiency performance is mainly important for the AeroLoad related vehicles. The AEMPT related vehicles are included in the comparison for this category in order to determine the rolling resistance and CdA values to be used in the final technical assessment (D6.6). Therefore, the description of the relevant comparisons are limited to the AeroLoad related vehicles. All potential comparisons in this category are given in Table 18.

Test vehicles	Comparison	I	II	III	IV	V
MAN 13.6m curtain	*MAN zero-case*	Reference				
MAN TF-SCB curtain	*Advanced reference (for AEMPT)*	X	Reference			
MAN 7.825 13.6m curtain	*MAN EMS1 reference*	X		Reference		
MAN 7.825 AeroFlex-SCB	*AEMPT EMS1*	X	X	X		
MAN AeroFlex-VEG AeroFlex-SCB	*AEMPT EMS2 (aero-1)*	X	X	X		
MAN AeroFlex-VEG AeroFlex-SCB	*AEMPT EMS2 (aero-2)*	X	X	X		
SCA TF-VEG box	*Advanced reference (for AeroLoad)*	X			Reference	
SCA TF-VEG box		X			X	
SCA TF-VEG box		X			X	
SCA box 13.6m box	*SCANIA EMS1 reference*	X			X	Reference
SCA box AeroFlex-VEG	*AeroLoad EMS1*	X			X	X
SCANIA EMS1 AeroLoad with 5 other aerodynamic settings		X			X	X

Table 18. Overview of the air drag comparisons between the different vehicle configurations

3.4.2.1 Reference: MAN zero-case

The MAN zero-case is the current EU averaged reference and its aerodynamic performance can be compared to the AeroLoad related vehicles. This comparison includes different vehicle configurations, but consequently also provides insight in the different CdA values between tractor semi-trailer, EMS1 and EM2 vehicles.

3.4.2.2 Reference: Advanced reference AeroLoad

This comparison covers 2 aspects. First, the aerodynamic performance of the TF-VEG trailer for different settings, since it was not part of the test matrix in Transformers and it provides the quantification of the improved aerodynamics of the AEROFLEX project compared to the Transformers project.

3.4.2.3 Reference: SCANIA EMS1 reference (AeroLoad)

This comparisons purely compares EMS1 vehicle configurations using box-type trailers all referenced towards the SCANIA EMS1 reference. With this, the AeroLoad innovations can be purely compared and in total 6 different aerodynamics settings/innovations are included here to be determined exactly when D3.3 becomes available. This occurs after this deliverable and therefore is not further specified here.

3.4.3 Vehicle comparisons for KPI – Loading efficiency

As described in Section 3.3.5 the TF-VEG trailer will be placed in operation at P&G. By comparing the TF-VEG trailer towards a conventional semi-trailer (e.g. no double floor, adjustable roof height, side skirts and boat tail) its performance on loading efficiency KPI's can be quantified as well as an average reduction in fuel consumption. Since these tests are not done at IDIADA, different vehicle units will be used. However, the same pulling unit will be used throughout this test use-case as well as the driver to exclude variations on these aspects. Table 19 provides the overview of the vehicle comparisons to be made in this test use-case.

Brand X 13.6m box		Reference
Brand X TF-VEG box	*Innovation: longer inner length (34 pallets)*	X
Brand X TF-VEG box	*Innovations: longer inner length and aerodynamics setting*	X
Brand X TF-VEG box	*Innovations: longer inner length, Aerodynamics setting and double floor (PUZZLE SW)*	X

Table 19. Overview of the loading efficiency comparisons between the different vehicle configurations

3.4.4 Vehicle comparisons for KPI – Safety standards

Performance based standards are highly important to quantify the safety of EMS vehicles. Since in this project two types of demonstrators are included, being and AEMTP and AeroLoad demonstrator, these are part of this comparison. Here the reference is a conventionally powered EMS1, being the MAN EMS1 reference vehicle (see Table 20). The AEMPT demonstrator also covers an EMS2 type and is for completeness incorporated in this test use-case. Due to limited test time and budget, an EMS2 reference is excluded. Nevertheless, this AEMPT EMS2 demonstrator provides insight in the safety performance of this particular vehicle.

Test vehicles	Comparison	I
MAN 7.825 13.6m curtain	*MAN EMS1 reference*	Reference
MAN 7.825 AeroFlex-SCB	*AEMPT++ EMS1*	X
SCA box AeroFlex-VEG	*AeroLoad EMS1*	X
MAN AeroFlex-VEG AeroFlex-SCB	*AEMPT++ EMS2*	X

Table 20. Overview of the dynamic vehicle behaviour comparisons between the different vehicle configurations

3.5 Deviations from initial test matrix

There are several adaptations made to the original test matrix as described in the project description. For completeness, the original test matrix is given in Figure 8.

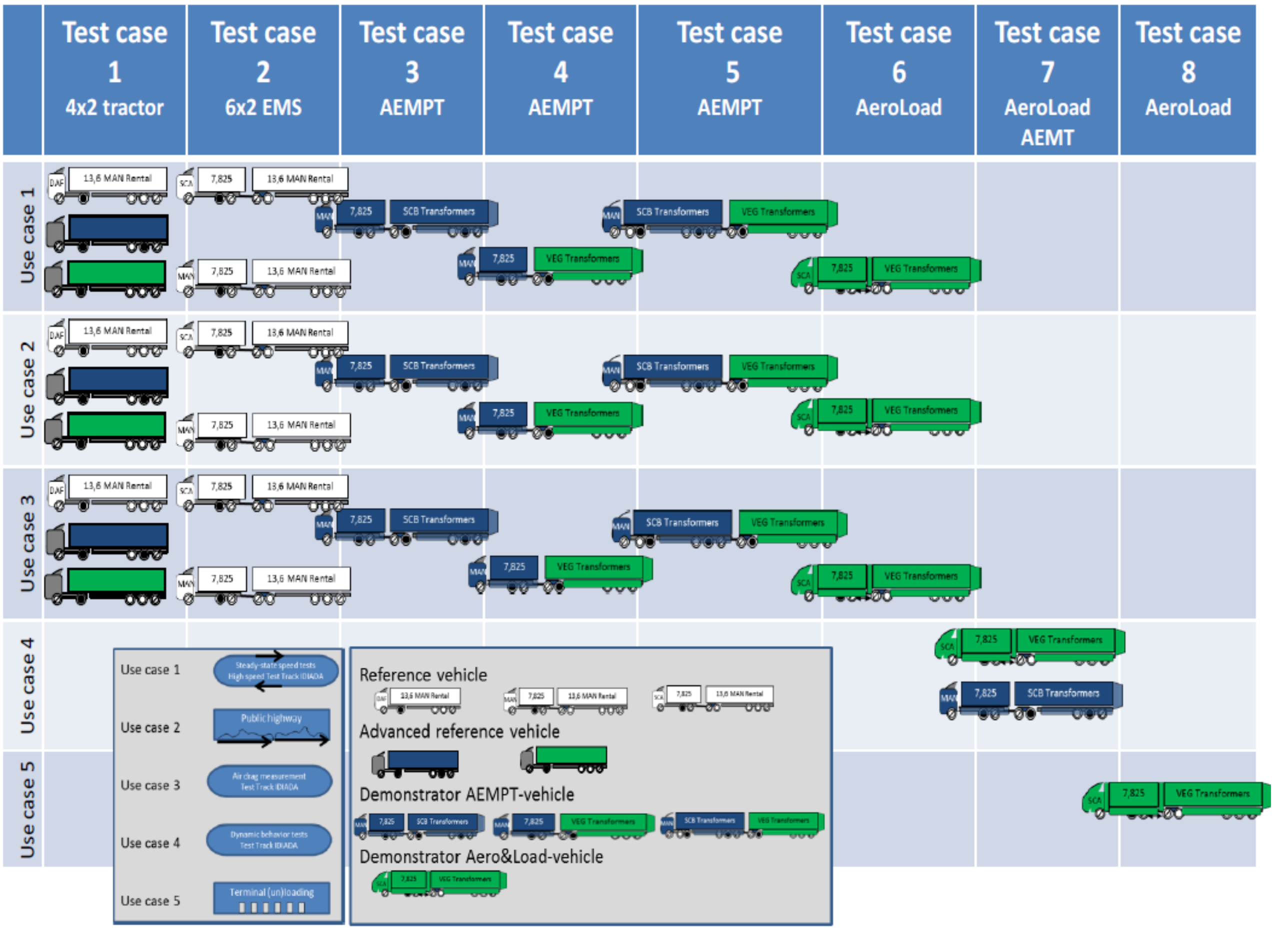


Figure 8. Original test matrix as part of the project description

These are listed and judged in this Section.

- Test use-case 1 only consists of a single constant vehicle speed test instead of 7 different speed levels as described in the Grant Agreement. Main reasons for this is the limited test time, minimum allowed vehicle speed of 50 km/h on the high speed test track at IDIADA and especially for distributed powertrains, constant speeds are not relevant because of battery depletion (in case of non-proper hybrid control) or battery energy is not being used at all.

- Additional vehicle configuration in test case 1, being a MAN tractor/semi-trailer configuration is added. It is included to better compare the AEMPT performance results with current state-of-the-art on-road.
- Specification of the so-called “third dimensions” (e.g. payload and aerodynamic settings) in the test matrix resulted in additional tests, compared to the number of icons depicted in the original test matrix. It is chosen to:
  - Align test use-cases 1 and 2 on all aspects, e.g. vehicle configurations, payloads and aerodynamic settings. Two different payloads for each vehicle configuration are included. A choice is made about the applied aerodynamic settings here (see Section 3.2);
    - It includes a single control vehicle for all testing in these 2 test use-case for accurate fuel consumption measurements and comparisons according to SAE J1526 protocol
    - A DAF tractor as being the EU averaged high sales volume-based vehicle, is removed from the test matrix, since fuel consumption comparison between brands is a very sensitive topic even though from the project point of view this is not the intention at all. It is replaced by a MAN tractor instead.

        - Alignment of single brand per innovation (e.g. AEMPT and AeroLoad). This means that AEMPT related vehicles are pulled by a MAN and the AeroLoad related vehicles by a SCANIA. This also avoids the difference in fuel consumption caused by different types of powertrain controls between brands.
    - conduct in test use-case 3:
        - advanced reference AEMPT vehicle in 2 aerodynamic settings;
        - advanced reference AeroLoad vehicle in 4 aerodynamic settings;
        - AEMPT demonstrators with 2 aerodynamic settings;
        - AeroLoad in 6 aerodynamic settings.
- Test use-case 4 is supplemented with an EMS1 reference besides the EMS1 type demonstrators (e.g. AEMPT and AeroLoad)
- In test use-case 3, test case 3 is removed, because of similar performance is expected compared to Test case 4, because for air drag tests, the E-dolly is replaced by a conventional dolly, because the E-dolly is not propelled and a clutch is not part of the E-dolly to decouple the EMG from the wheels.

4 Measurement equipment and protocol

To determine accurately the improvement on fuel economy for the different aerodynamic, distributed powertrain and effective loading space utilization solutions, it is necessary to elaborate a measurement protocol that guarantees the repeatability of the results obtained and allows these results to be compared with the different vehicle configurations defined in the test matrix.

The following test use cases are included in the measurement and test protocol:

- Test use-case 1 – Steady-state speed test at proving ground
- Test use-case 2 – Real-world Route Fraga
- Test use-case 3 – Air drag measurement at proving ground
- Test use-case 4 – Dynamic behaviour tests at proving ground
- Test use-case 5 – Terminal (un-) loading tests

4.1 Test use cases location

4.1.1 IDIADA facilities location for test use cases 1, 2, 3 and 4.

4.1.1.1 Test track overview

The IDIADA's facilities and test track are located at 70 km south-west of Barcelona, 10 km from the Mediterranean coast. Around IDIADA, there are a wide range of public roads, including coastal roads, mountainous areas and different kind of motorways.

The following picture (Figure 9) shows an aerial view of IDIADA's proving ground and a detailed map of the different test tracks are included in Figure 10 to Figure 14:

Figure 9. Aerial view of IDIADA's proving ground

The following tracks should be used to perform the different test use cases.

- Reference 0: General road circuit
- Reference 1: High-speed track
- Reference 4: Dynamic platform A
- Reference 6: Test hills track

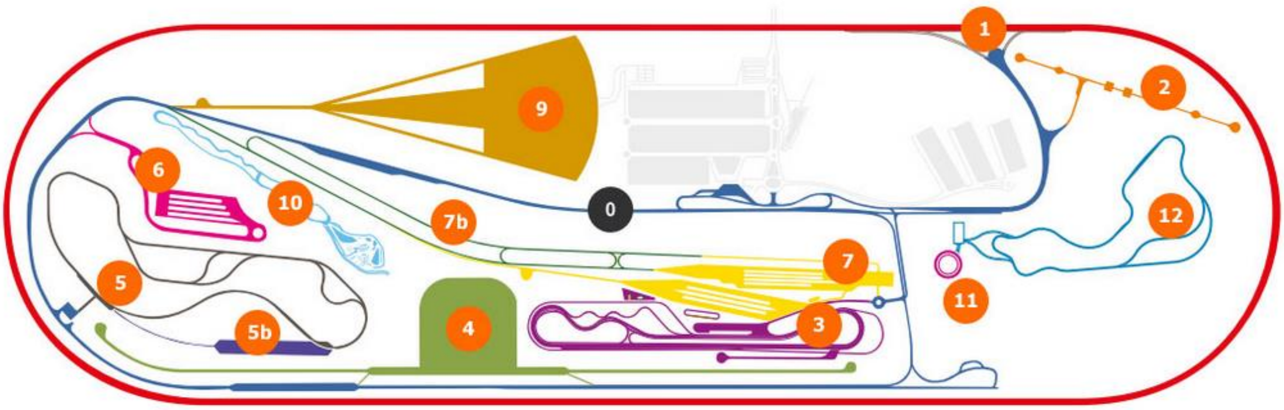


Figure 10. Proving ground map

4.1.1.2 General road circuit (GRC)

The following table shows the main characteristics of the general road circuit:

Concept	Remarks
Direction of travel	Clockwise
Total length	5,333 m
Length of south straight	1,620 m
Longitudinal gradient (south straight and braking area)	0 %
South straight wide area (length)	300 m
South straight wide area (width)	20 m
Braking area (length)	250 m
Braking area (width)	10 m
Braking area (approach lane)	100 m

Table 21. General road main characteristics

The following figure shows the general road circuit detailed map:

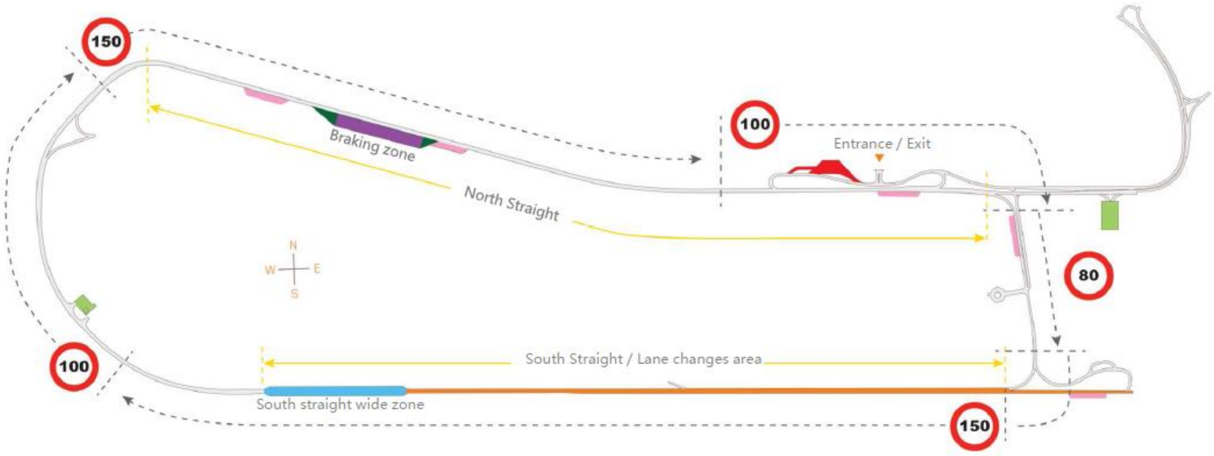


Figure 11. General road detailed plan

The general road circuit is used to perform:

- Dynamic safety check
- Shake down / vehicle signal verification
- Additional vehicle warm up
- Access to other test tracks

4.1.1.3 High-speed track (HST)

Its High-speed lane has a constant 0,3% slope in each direction, either uphill (south straight) or downhill (north straight) with a calibrated distance of 2.000 meters per straight, and a total distance of approximately of 7.500 metres (two straights and two curves).

The following table shows the main characteristics of the high-speed track:

Concept	Remarks
Direction of travel	Clockwise
Length Lane 1	7,493 m
Length Lane 2	7,513 m
Length Lane 3	7,546 m
Length Lane 4	7,579 m
Length of straights	2,000 m
Radius of the bends	471 m
Longitudinal gradient (North straight)	- 0.3 %
Longitudinal gradient (South straight)	+ 0.3 %
Transversal gradients (straights)	1.0 %

Table 22. High-speed track main characteristics

The following figure shows the high-speed track map:

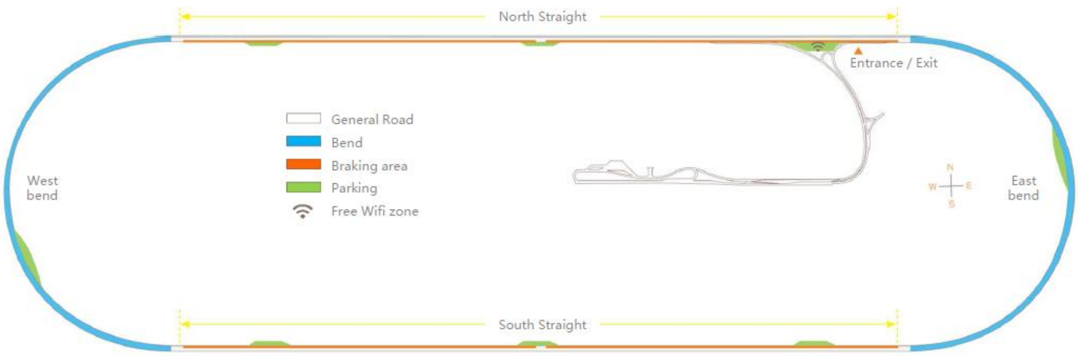


Figure 12. High-speed track map

The HST is used to perform:

- Vehicle warm up for test use-case 1 and 3
- Carry on test use case-1
- Carry on test use case-3 (vehicles EMS1 and EMS2)
- Part of the test use case-4

4.1.1.4 Dynamic platform A (DPA)

The following table shows the main characteristics of the dynamic platform

Concept	Remarks
Platform dimensions	250 m length x 250 width
Length of straights	1,800 m

Table 23. Dynamic platform main characteristics

The following figure shows the dynamic platform map:

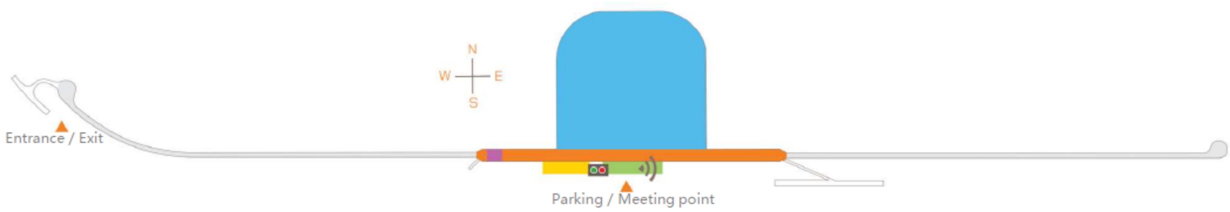


Figure 13. Dynamic platform map

The dynamic platform is used to perform

- Carry on test use-case 3 (tractor/semi-trailer)
- Additional correlation between tracks on test use-case 3
- As part of the test use-case 4

4.1.1.5 Test hills track

The following table shows the main characteristics of the test hill track:

Concept	Remarks
Length lane with constant gradient 8%	188 m
Length lane with constant gradient 12%	102 m

Table 24. Test hills main characteristics

The following figure shows the dynamic platform map:

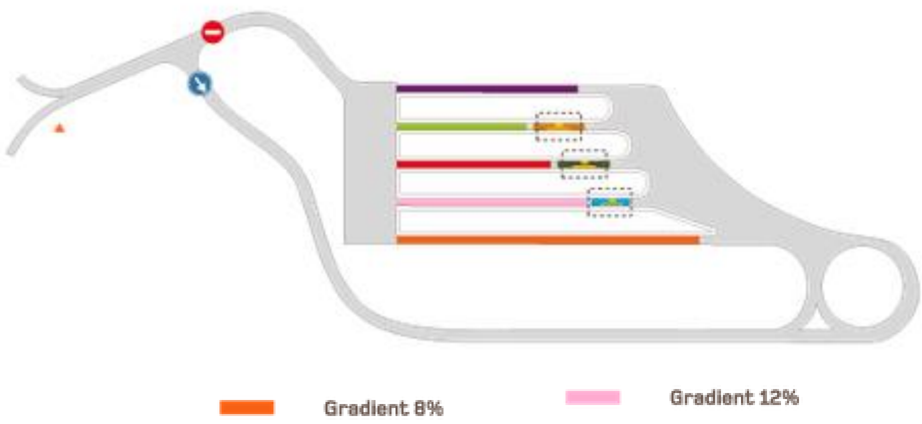


Figure 14. Test hill map

The test hills track is used to perform:

- Part of the test use-case 4

4.1.2 Real world route Fraga. Test use case 2.

The real world route starts and ends in the same point inside IDIADA facilities. The picture below shows the route IDIADA-Fraga-IDIADA by using Google Earth tools:

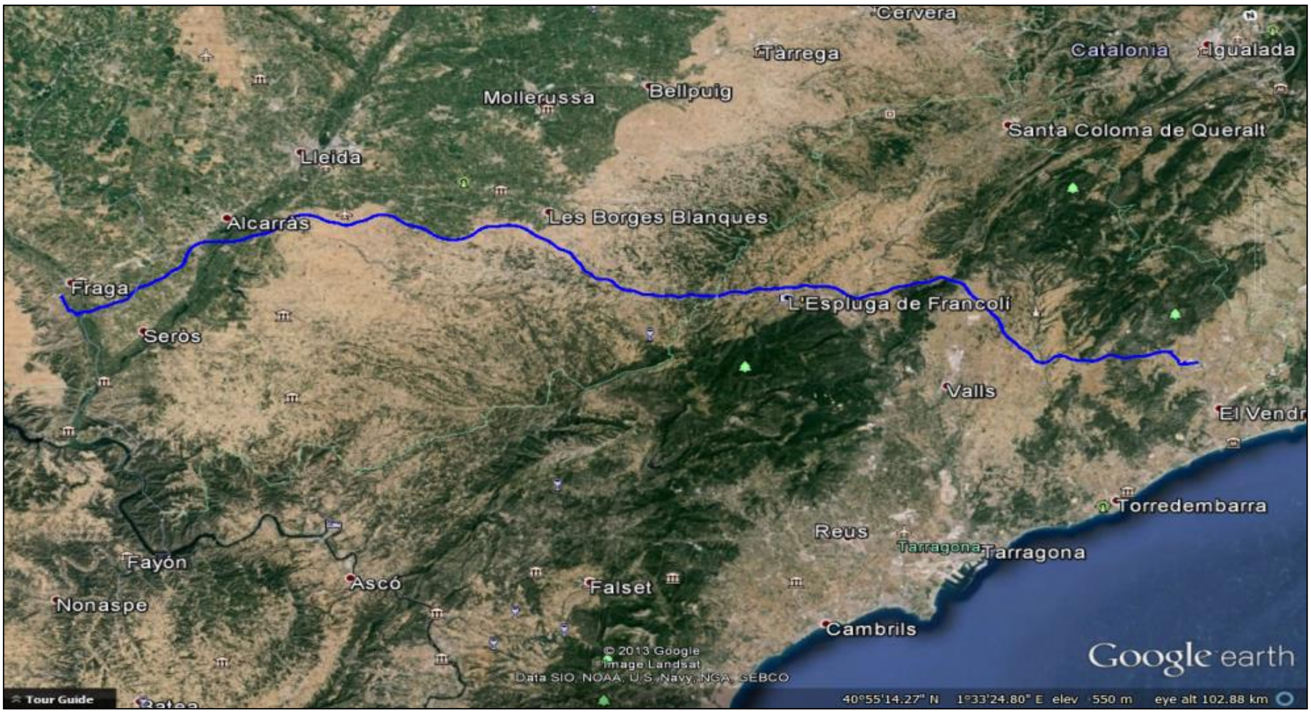


Figure 15. Route IDIADA-Fraga-IDIADA overview

The following table shows the main theoretical characteristics of the IDIADA-Fraga-IDIADA route:

Concept	Remarks
Trip duration	≈ 12,000 s
Trip distance	237.5 km
Average speed (>95% highway-distance based)	≈ 72.5 km/h
Min / max altitude	87 / 573 m
Max up- and downhill slope [%]	6.6 / -6.8 %
Traffic conditions	low

Table 25. IDIADA-Fraga route characteristics for 40t tractor/semi-trailer

Additional information is given in Section 4.3.6.5. Although this route performance will be adapted to the requirements of the test protocol summarized in Section 4.3.6.

4.1.3 Terminal (un)-loading for test use case 5

The objective of this test use-case is to measure the WP4 KPI's. The influence of the TF-VEG trailer innovations on payload capacity, fill speed and load factor will be estimated. This is done by putting the trailer in operation in a line between two P&G warehouses. It is planned to use the daily roundtrip between Euskirchen and Crailsheim. The trailer will be handed over to the haulier who is running the line now. The haulier is asked to adapt the truck so it can charge the batteries during driving and place a permanent driver on the truck that will be trained. P&G will need to arrange a forklift to raise the floors and lift the pallets to the second level. The forklift drivers need to be trained, to set the floors, at both warehouses. The planner must plan, with the new PUZZLE software, the extra pallets that can be loaded in the VEG trailer and estimate their optimal positions and roof profiles.

4.2 Vehicle preparation and checklist at IDIADA's facilities

4.2.1 Objective

To ensure the correct vehicle behaviour prior and during the tests different types of activity described in the following points are considered:

- Vehicle set up
- IDIADA's safety check
- Functional checklist
- Instrumentation
- Shake down
- Daily vehicle checking

Each items is described in more detail in the next subsections.

4.2.2 Vehicle set up

At the vehicle's arrival, an initial vehicle set up verification will be done according to the following points:

- Connect testing tractor, semi-trailer and dolly to verify that there is no alarm or not proper function system.
- Adjust the complete vehicle to test according to the specification provided by the OEM's involved in the project (side skirts, aerodynamic devices, etc…).
- For rental vehicles, in order to identify any possible non-original part that can have influence on the results obtained; a visual verification of the specific vehicle parts will be done. The OEM's should have to provide the information of the original vehicle checklist parts.
- Vehicle refuelling according chapter 4.2.8.1
- The vehicles shall have a minimum of 3,000 km of use. If the vehicles do not fulfil this requirement, IDIADA will carry out the internal safety check described in the following point and after validating the global vehicle status. IDIADA will run the vehicle until the target value of 3.000 km is reached.
- Due to the characteristics of the demo vehicles (included tractors and semi-trailers), It is not possible to stablish a minimum/maximum range of kilometres in each vehicle during the test period so for the rental vehicle defined in the test matrix, IDIADA will try to get these vehicles with less than 30.000 km but it will depend of the availability of this vehicle in the market.
- Tire adjustment according chapter 0
- Vehicle wheels alignment. The OEM's should provide the necessary information to fix the vehicle with the correct configuration.
- Vehicle weight in empty conditions.
-

4.2.3 IDIADA's safety check

IDIADA's internal safety check in static and dynamic mode is mandatory to be carried out at vehicles arrival. The safety check focuses on finding any possible malfunction of the vehicles, trailers and dollys.

The elements to verify in the static safety check are indicated in the following table:

Elements to be checked	Remarks
Exterior	
Windscreen and other windows	Visibility and absence of cracks in vision area
Rear-view mirrors	Cleaning, absence of cracks and possible adjustment
Wiper blades	Condition
Lighting and signalling devices:	Exterior condition, operation and correct adjustment
Opening and closing of doors	Correct operation
Fuel flap/cap	Condition and correct closing
Camouflage	Fastening, visibility, enabling lighting and signalling and opening and closing of doors
Engine compartment	
Engine oil	Level
Refrigerant	Level
Brake fluid	Level
Clutch fluid/clutch cable	Level / Condition of cable
Automatic transmission fluid	Level
Assisted steering fluid	Level
Windscreen wiper fluid	Level
SCR system fluid (urea)	Level
Low-voltage battery	Fastening of battery, fastening of cables, and no traces of acid
General inspection	No leaks, damage/cracks, deformation, loose elements in mechanical parts, pipes and wiring
Fuel	Level
Interior	
Condition of ABS and ESP	Verify that ABS or ESP are not inactive, failed or unknown
Condition of airbags	Verify that driver or occupant airbags are not inactive, disabled or unknown
Other tell-tales or indicators	Check that not showing fault
Guides, anchorages, seats, headrests and seat belts	Condition, fastening and possible adjustment (all seats)
Substitute seat belts (if fitted)	Check condition, correct fitting, fixing and possible adjustment for driver and passenger
Interior roll bars	Check status and fixing
Horn	Operation
Windscreen wipers	Operation and surface wiping
Interior mirror	Possible adjustment and fastening
Accelerator pedal	Condition, fastening, play, travel, return and stiffness
Service brake pedal	Condition including pedal rubber, fastening, play, travel, return and stiffness
Clutch pedal	Condition, fastening, play, travel, return and stiffness
Gear lever	Condition, fastening, play, travel and stiffness
Lever, parking brake pedal or electric or pneumatic parking brake	Condition, fastening, play, travel and stiffness. Operation OK if electric or pneumatic brake

Steering wheel and steering linkage	Condition, fastening, play, travel and stiffness
Opening and closing of doors	Operation
Service brake pedal	Condition including pedal rubber, fastening, play, travel, return and stiffness
Wheels and wheel arch (without dismounting wheels)	
Tyre condition	No cracks, punctures, leakages, or ageing. Uniform wear
Tread depth tyres (mm)	Write down the value for each tire
Tyre pressures in unloaded conditions	Write down the value for each tire
Wheel tightening torques	Check according to manufacturer specifications or instructions from the supervisor. Mark screws / nuts or place parts in "S"
Suspension	Visual check of condition and absence of leaks
Brake circuit pipes	Visual check of condition and absence of leaks
ABS sensor wiring	Visual check of condition and absence of leaks
Discs and pads	Visual check of wear condition and absence of cracks
Under vehicle	
Mudguards	Condition and fastening
Suspension system	Visual check of condition and fastening of components and joints (No cracks or other damage)
Exhaust system	Visual check of condition and fastening
Braking system	Visual check of condition fastening, no cracks, rubbing or leakages
Fuel system	Visual check of condition fastening, no cracks, rubbing or leakages
Engine and transmission line	Visual check of condition fastening, no cracks, rubbing or leakages
Undercover	Condition and fastening
Others, if installed when checking:	
Ballast	Condition, fastening, position
Measuring equipment, visual display	Condition, fastening, position

Table 26. Characteristics of safety check static

The elements to verify in the dynamic safety check are indicated in the following table:

Concept	Remarks
1. Speedometer	Performance
2. Driving in a straight line up to 50 km/h	No deviation, vibration, noises or other abnormalities
3. Exiting curve at 30 km/h	Correct self-return of the steering wheel and no vibration, noise or other abnormalities
4. Weaving within same lane with initial speeds up to 30 km/h	Stability, control and no vibration, noise or other abnormalities
5. Braking up to 0,5g with initial speeds up to 50 km/h	No deviation, vibration, noise or other abnormalities
6. Braking until locking or ABS activation with initial speeds up to 30 km/h	No deviation, vibration, noise or other abnormalities. Also: * Vehicles with ABS: Correct function of ABS
7. Acceleration with 3/4 accelerator up to 60 km/h	No deviation, vibration, noise or other abnormalities
8. Driving on straight up to vehicle max speed	No deviation, vibration, noise or other abnormalities
9. Activation of retarder systems (if applicable)	Verify operation and absence of abnormalities
10. Overall evaluation (to vehicle max speed)	No anomalies in operation of engine, gears or clutch during normal driving below 120 km/h

Table 27. Characteristics of safety check dynamic

The following picture of the General road shows the location to perform the activities described in the table above:

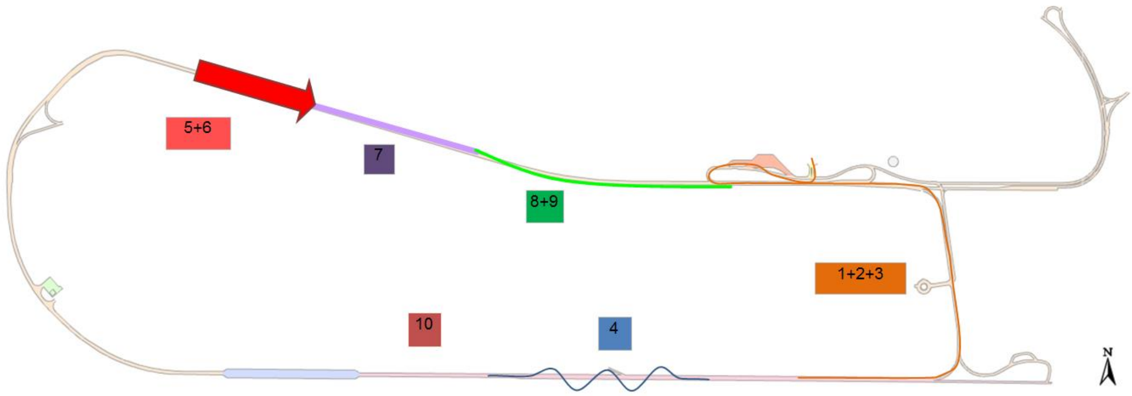


Figure 16. Safety check dynamic locations

4.2.4 Functional checklist

In addition to the vehicle set up and safety check, to ensure the vehicle proper operation condition during the testing period the following list of activities should be done:

- If necessary after a technical inspection, the air cleaner element for rented vehicles should be replaced by new ones. The OEM's should provide the specific characteristics of each part.
- If the OEM's consider necessary an initial DPF/SCR preconditioning, it is planned that an official technical service centre carries out this activity before starting the first fuel consumption tests. IDIADA will fulfil the requirement and the information provided by the OEM's to evaluate if it is necessary to repeat the DPF/SCR preconditioning during the tests.
    - The DPF preconditioning consists of a stationary forced regeneration using a service tool or other passive regeneration methods recommended by the engine or aftertreatment manufacturer.
- Aerodynamic adjustment (baseline condition) verifies that it is possible to test in all the necessary configurations
- Each vehicle properly lubricated prior to test. All fluid levels should be checked and be at prescribed levels (max level)
- Proper brake adjustment
- Force on wheel as part of the safety check and vehicle validation. This will be done according to the following force on wheel procedure for all axis:
    - The axis will be lifted from the floor.
    - Once lifted, a cord connected to a dynamometer will be wrapped around a tyre of the lifted axle and will be pulled until the tyre is unwrapped.
    - The maximum and minimum readings of the dynamometer during the procedure will be noted and evaluated according to our experience form previous tests.

Once these parameters are validated, IDIADA will start to install the measurement equipment.

4.2.5 Instrumentation

The instrumentation procedure is described in each test use-case:

See points 4.3.3 for test use-cases 1 and 2 (fuel consumption tests), point 4.4.4 for test use-case 3 (Airdrag) and point 4.5.3 for test use-case 4 (Dynamic tests).

4.2.6 Shake down

Once the entire vehicle has been instrumented, it is necessary to perform a shakedown in order to check all the measuring devices are properly recording. To do so, the instrumented vehicle will perform a 20 minute-drive at IDIADA General Test Track. Data acquired in this shakedown will only be used to check the channels, but will not be used to analyse results.

The shakedown procedure will be done for each specific instrumentation set (basically separated by test use-case 1-2, test use case 3 and test use case 4).

4.2.7 Daily vehicle checking

After measurement equipment installation and prior to carrying out any of the test use-cases, the following items shall be checked:

- Daily check and adjust tire pressure indicated in chapter 0 and vehicle loads according to the requirements of each test use-case. Cold tire pressures measured and inflated to vehicle or tire manufacturer standard. Tire pressures need to be set at the beginning of the day following the overnight cold soaks.
  - Accessory loads for each vehicle according to following requirements:
    - Air condition turned off
    - Lights turned on
    - Defroster off
    - Windows closed
  - Fully functional engine and aftertreatment systems without diagnostic trouble codes or other engine/emission service indicators illuminated.
  - All emission aftertreatment components shall be in proper working condition. Vehicles that rely on a reductant chemical to control pollutants shall have sufficient volume on board to complete all testing.
  - Entire vehicle clean and free of damage or missing parts.
  - Free of brake air system leaks.
  - Full air tank pressure.
  - Oil pressure and no oil leaks (engine, transmission, axles, etc.) verification according to the criteria described in the static safety check.
  - Verification of coolant temperature and no coolant leaks according to the criteria described in the static safety check.
  - DPF status. CAN DPF signal will be used to evaluate the condition of the DPF prior to starting the tests and will be used to identify any possible DPF regeneration during the fuel consumption tests.
  - Additional verification of the aerodynamic devices:
    - Roof deflector: correct installation and position
    - New aerodevices in proper position
    - Adaptable/flexible devices working correctly. Pre-test verification
  - Verification of the correct installation of the measurement equipment and different sensors installed for each specific test us case.
  - At the end of the daily tests, the 24V trucks and TF-VEG batteries will be externally charged to guarantee that they are fully charged at start of testing activities the next day.

4.2.8 Others

4.2.8.1 Fuel and AdBlue characteristics

The fuel type used in each test vehicle (reference, advanced reference, demonstrator and control vehicle) will be the same during the complete testing activities. IDIADA should purchase the reference fuel prior to starting the test and store it in controlled conditions.

To ensure all the vehicles are powered with identical fuel, all fuel in the vehicle tanks prior to the testing shall be removed to less than 1% by volume and then be refuelled from the dedicated source to maximum tank levels. The fuel characteristics will be according to the standard EN 590 of the European Committee.

The vehicle should also be refilled with commercially available AdBlue until maximum tank level before the start of the tests.

4.2.8.2 Tire control

In order to avoid influences on the fuel consumption results due to deviations of the tire characteristics, the tested vehicles (reference, advanced reference, demonstrator and control vehicle) shall be equipped with the same type of tires during all the testing activities.

Michelin should provide the necessary set of tires for each specific vehicle. The proposed type of tires for each vehicle configuration is indicated in the following table:

Vehicle	Type	
Tractor	Steer	Michelin X LINE ENERGY Z label B 315 70 R22,5
	Drive	Michelin X LINE ENERGY D2 label A 315 70 R22,5
Rigid truck	Steer	Michelin X LINE ENERGY F label B 385 55 R22,5
	Drive	Michelin X LINE ENERGY D2 label A 315 70 R22,5
	Trailing	Michelin X LINE ENERGY Z label B 315 70 R22,5
Semi-trailer	Drive	Michelin X LINE ENERGY T label A 385 65 R22,5
E-Dolly	1st and 2nd axle	Michelin X LINE ENERGY 275/70 R22.5
Baseline and WP3-Dolly	Steer	Michelin X LINE ENERGY 385/55 R22.5
	Drive	Michelin X LINE ENERGY 385/55 R22.5
Control vehicle	Steer	Bridgestone Ecopia H 385/55 R22.5
	Drive	Bridgestone Ecopia H 315/70 R22.5
Semi-trailer	All axles	Hankook TH22 385/65/22.5

Table 28. Tire characteristics

The testing tires shall have a minimum of 3,000 km of use. If necessary, an additional running-in should be done at IDIADA's proving ground and/or during the transport of the testing vehicle from the OEM's facilitates to IDIADA.

Michelin provides the set of tires equipped with temperature and pressure sensors. At the same time the telematics equipment necessary to record the signals installed on the different set of tires will be provided by them.

Tires shall be interchanged between vehicles to use exactly the same units in all the testing vehicles. The rolling resistance of the tires shall be followed up to be sure that the tire ageing and usage shall not affect the results.
IDIADA shall control the tire rolling resistance doing periodic verifications of one selected tire in each axle according to annex 6 of the United Nations Regulation nº117. If deviations are measured, Michelin should propose a correction in the results obtained.

The number of necessary rolling resistance measurements in each set of tires will be determined according to the indications of Michelin and the testing plan to ensure the correct tire control during the entire project.

The tire pressures during the test will be the same for each test use cases to simplify the data evaluation (especially requested for fuel consumption and air drag tests). The pressure which the tires will be inflated will be the maximum allowable pressure indicated on the tire flank.
IDIADA will ensure the values set for the different vehicle configurations and during all the testing period.

4.2.9 Flowchart of the entire vehicle preparation process

The following figure shows the preparation process for the test vehicles at IDIADA facilities:

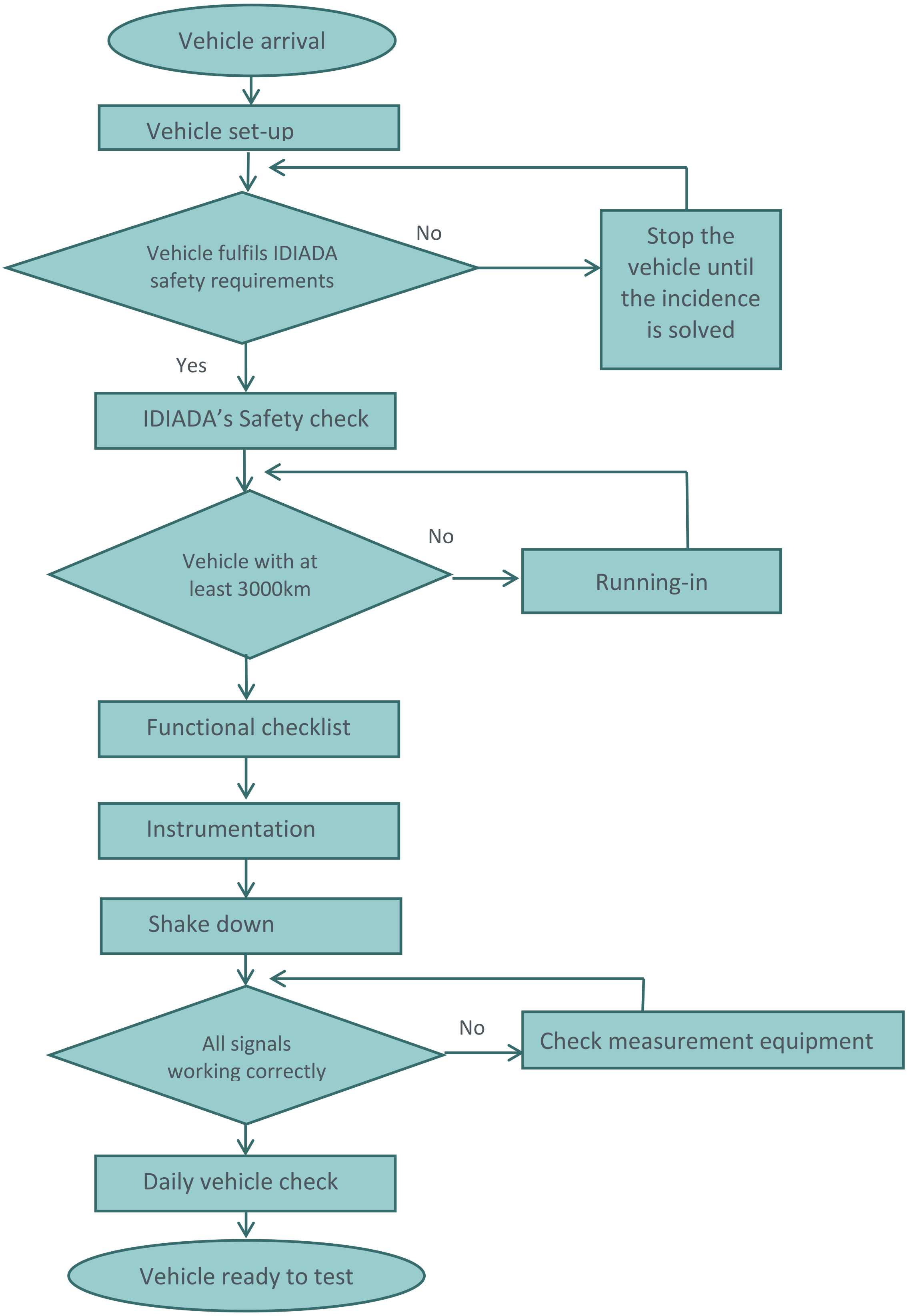


Figure 17. Vehicle preparation flowchart

4.3 Test use case 1 and test use case 2 - Fuel consumption measurement

4.3.1 Objective

The objective of the testing protocol followed in test use-cases 1 and 2 is to measure accurately and compare the fuel consumption of the different vehicles as described in the test matrix in Chapter 3.

The fuel consumption measurements are executed for 2 test use-cases:

- Test use case 1: Steady-state speed on proving ground
- Test use case 2: Real-world route Fraga

The characteristics of the specific vehicle preparation and test protocol for each test use-cases are defined in the following points:

- Test constraints
- Measurement equipment
- Control vehicle
- Fuel consumption test use case 1 protocol
- Fuel consumption test use case 2 protocol
- Additional requirement for fuel consumption measurement on hybrid vehicles.

Each point is separately described in the next subsections.

4.3.2 Test constraints

4.3.2.1 Weather conditions

The weather conditions shall be reviewed in each test performed to ensure that the constraints listed in the following table are met:

Criteria	Requirements	
	Test track	Public roadway
Wind speed	≤ 3 m/s	≤ 5 m/s
Max wind gust	≤ 5 m/s	≤ 7 m/s
Allowed average temperature range	5 to 25ºC	
Humidity level	≤ 95 %	
Atmospheric pressure	≥ 82.5 kPa	
Rain	None allowed	
Wind direction	No limits (only recorded)	

Table 29. Weather conditions during test cases 1 and 2

It is planned to perform the fuel consumption tests in the daily shift that better fulfil the weather criteria described above to minimize the influence of carrying out the tests at different times of the year.

Wind direction has an impact on aerodynamics and thus fuel consumption. Although wind speed may be similar between tests, different wind directions may produce significantly different yaw angles and thus could increase test result variability. Therefore, to minimize data variability, wind direction and wind speed of all runs and segments should be as similar as possible.

On-track weather data shall be obtained at two different locations (in each straight of the oval circuit). The data sampling for all the environmental data conditions described above shall be continuous and recorded at 1-10 samples per second. Additionally, the tested vehicles will be equipped with different specific sensors and ultrasonic anemometer (only for airdrag tests) that shall provide additional weather data.

On-route, additional weather data shall be obtained from different weather stations located close to the Fraga route, basically the information from the external weather stations will be used to ensure that the wind speed limits are not outside the requirements indicated above. For temperature and humidity, the sensors installed on the vehicle will be used as reference.
It is not possible to use the anemometer during the route tests due to the characteristics of the public roadway and the anemometer's position (restrictions in height on the public road).

Vehicle test loads

The vehicles shall be tested for two different loads taken from the FALCON project. On average, these values coincide with 50 and 100% payload and are kept constant to see the influence of the tare vehicle weights on fuel consumption. Maximum axle loads or GVW's are not exceeded in the 100% payload case.

The following table shows the two different loads for each type of vehicle:

Vehicle	Test weight
Tractor/semi-trailer	1st – 13,598 kg payload
	2nd – 40,000 kg GVW
EMS1	1st – 21,422 kg payload
	2nd – 60,000 kg GVW
EMS2	1st – 27,196 kg payload
	2nd – 74,000 Kg GVW

Table 30. Vehicle payload for type of vehicle

IDIADA will verify the load conditions prior to starting the tests using the weighing machine located in the test track facilities. The weighing machine has an accuracy of +/-0,2% per axle. The vehicle will be weighed at least twice to ensure the correct measurement.

Vehicles shall be initially measured in empty conditions (without driver and maximum level of fuel and adblue tanks) and later load with the specific test load indicated in the table above for 1st load configuration and fixed to GVW for 2nd load configuration. The test payload for the first test weight configuration shall always be the same regardless of the possible modifications in the vehicles' tare weight, especially demo vehicles.

The payload will include driver, measurement equipment, possible passengers and additional external load to reach the target test weights included in the Table 30.

The load distribution per axle shall be as similar as possible in all the vehicles, especially focused on keeping the same load distribution in the reference/baseline and demo vehicles. The load distribution will start from front of the semi-trailers and/or box and share it (without exceed the maximum axle load) according to the length of the trailer and/or box.

4.3.3 Measurement equipment

4.3.3.1 Overview of measurement equipment

To ensure the correct evaluation of the fuel consumption results, IDIADA will install the following types of measurement equipment in each vehicle:

- Fuel consumption measurement equipment (Flowmeter)
- Electrical consumption measurement equipment
- Additional GPS
- Anemometer (air drag test only)
- Telematic equipment
- Data acquisition system
- Dash-cam

All instrumentation type, specifications and calibration information of the instrumentation shall be documented.

The installation of the measurement equipment shall not affect the mechanical or aerodynamic performance of the vehicles.

4.3.3.2 Measurement equipment summary

The following table shows a summary of the equipment that will be used in test use cases 1 and 2:

Brand	Model	Description	Signals	Units
AIC	6004	Fuel consumption	Fuel	l/100km
INCA	7.1	CAN data	ECU CAN data and additional control	CAN unit
Hioki	3390	Electrical consumption	Voltage and current (Power)	kWh/km
Vbox	IISX	GPS data	For driver: reference vehicle speed Latitude, longitude	km/h ºC
Campbell	86000	Sonic anemometer	Wind speed and yaw	Km/h - Grade
Mobile devices	C4 max	Telematic	Tire temperature and pressure	°C - KPa
Go Pro	4 Hero	Cam	Route recording	File
Additional sensors	-	Specific sensors	Temperature and humidity	ºC - %

Table 31. Test use case 1 and 2 measurement equipment

4.3.3.3 Fuel consumption measurement equipment (flowmeter)

The fuel consumption measurement used to evaluate the fuel consumption efficiency KPI's will be done using a volumetric diesel flowmeter with sufficient capacity and capability to accurately measure fuel flow and volume throughout the full range of vehicle operating conditions. The values obtained from this instrument are temperature compensated for fuel temperature at the inlet to the flowmeter.

To ensure a gross error did not occur with the installation of the flowmeter and data acquisition system, a validation check should be performed. This can be accomplished by comparing the flow as measured by the meter to actual flow as measured using a graduated container. The accuracy and resolution of the equipment used to perform this validation will affect the precision of the comparison. In addition, the dispensed volume of fuel and its temperature will be recorded for comparison purposes.

The following table shows the main characteristics of the fuel consumption measurement equipment.

Concept	Remarks
Brand	AIC
Model	6004
Type	Volumetric flowmeter
Range	0 to 120 l/h
Accuracy	± 1,0% of full scale
Repeatability	+/- 0.2%
Frequency	1 Hz
Nb pulse per litre	2,000
Serial numbers	151278
Additional signal	Fuel temperature (ºC)
Power supply	External batteries

Table 32. Fuel consumption equipment characteristics

IDIADA will assign a specific flowmeter for each type of vehicle (testing and control) that as far as possible should be the same unit during the entire project. So the same flowmeter unit shall be allocated in all the reference, advanced, demo vehicles and the same unit will be allocated in the control vehicle.

Figure 18. AIC 6004 fuel consumption equipment

The fuel consumption measured values shall be brought back to a temperature of 20°C (see DIN 70030 Section 1 § 5.4.2) using a temperature sensor installed in the fuel line of the AIC flowmeter.

The fuel consumption equipment will be calibrated yearly in an external accredited laboratory.

4.3.3.4 Vehicle control signals

To control the vehicle behaviour during the tests, to identify any deviation in the results and to ensure the repeatability of the fuel consumption results on test track and on real-world route, IDIADA should measure the signals indicated in the following table.

Concept	Parameter	Units
Engine coolant temperature	ECU or sensor	ºC
Vehicle speed	ECU and sensor	km/h
Engine speed	ECU or sensor	rpm
Engine torque	ECU and sensor	Nm
DPF Regeneration status	ECU	--
Fault status	ECU	--
Accelerator and brake pedal	ECU or sensor	%
Engine oil temperature	ECU or sensor	ºC
Actual gear	ECU	--
External exhaust (tailpipe) temperature	Sensor	ºC
Fuel consumption	ECU	l/h
External tire temperature	Sensor	ºC
Asphalt temperature	Sensor	ºC
Cruise control activations*	ECU	--
Odometer	ECU	km
Fan speed	ECU or sensor	rpm
Adaptive cruise control	ECU	Radar signal

Table 33. Control signals

**The OEMS should provide the cruise control settings.*

The vehicle speed indicated in the table will be used to evaluate the fuel consumption efficiency KPI's. The rest of the signals will be used to verify the consistency and repeatability of the results.

IDIADA should use OBS-One OBD acquisition system software to read the data described above and will install if it is necessary the specific external sensors to correlate the results. If it is not possible to acquire all the control signals indicated above with the OBS-One OBD standard tool, IDIADA will install an alternative OBD tool (ETAS INCA 7.1). If it is possible, the OEM's should provide a specific dbc file to simplify the CAN signals acquisition.

The signals of the additional sensors shall be correlated and aligned based on vehicle speed and the power supply shall be external in order to not affect the vehicles fuel consumption.

4.3.3.5 Electrical consumption measurement equipment

Due to the development of the hybrid technologies in the dolly and the semi-trailer vehicles, it is necessary to measure the electrical consumption at the same time as the fuel consumption. The electrical consumption information is necessary to evaluate the fuel consumption efficiency KPI's.

The following table shows the main characteristics of the electrical consumption measurement equipment:

Concept	Remarks	
Brand	Hioki	
Model	Power analyzer 3390	
Range	Voltage	15 to 1,500 V
	Current	0.1 A to 20 kA
	Frequency	0.5 Hz to 5 kHz
Accuracy	Voltage	±0.05 % full scale
	Current	.±0.05 % full scale
Serial number	130427	
Power supply	External batteries	

Table 34. Electrical consumption equipment characteristics

Figure 19. Hioki 3390 electrical consumption equipment

If the characteristics of the e-dolly or transformer SCB semi-trailer (position, access to the measurement points, safety, etc…) do not allow correct installation of the Hioki equipment, optionally the CAN data will be used to calculate the electrical consumption instead of the measurement equipment.

4.3.3.6 Additional GPS

An additional GPS should be installed to correlate the measurement equipment signal and basically to provide to the driver a real reference of the vehicle speed. This GPS speed is used as feedback signal in the steady speed and real route tests for the driver.

The following table shows the main characteristics of the additional GPS system:

Concept	Remarks	
Brand	Racelogic	
Model	VBOX IISX at 10Hz	
Accuracy	Speed	±0.1 km/h
	Height	± 2.0 m
Power supply	External batteries	

Table 35. Additional GPS characteristics

Figure 20. Racelogic Vbox IISx

If it is necessary, the Vbox IISx is also prepared to install different modules (temperature, analogic and frequency) to record the control signals listed in Table 33.

The Vbox units can be changed during the project depending to the equipment availability.

4.3.3.7 Telematics equipment for tire signals

The testing tires provided by Michelin will have installed the temperature and pressure sensors necessary to monitor their behaviour during the test use-cases. To record the signals provided by the sensors installed on the vehicle tires, Michelin will provide the specific telematics equipment (C4 max model).

Figure 21 Telematic C4 max

Although, the tires temperature and pressure will be monitored in each test, due to the signal accuracy only the tire pressure will be reported and integrated in the data template for future evaluation of the results obtained in the different repetitions and vehicles.

4.3.3.8 Dash-Cam

In order to identify any specific incident during the real-world route, a GoPro4 dash cam will be installed in the test and control vehicles to record the complete route. The information provided in the camera should be useful to identify any possible deviation in the vehicle behaviour during the route.

Due to internal IDIADA security protocol, recording inside IDIADA's facilities is not allowed, so the tests performed on proving ground will not be recorded.

Due to the size of the recorded file IDIADA will enable an ftp server to easily upload and download the specific route files.

4.3.3.9 Data alignment

Due to the quantity of different signals recorded during the tests, it is necessary to determine criteria to improve the time alignment.

The test data listed in the tables above are split into the different categories depending on the registration equipment used.

1- Fuel consumption and OBD signals.
2- Additional GPS, control signals, anemometer and electrical consumption.
3- Tire sensors of telematics C4 max equipment.
4- Additional tested vehicles signals (semi-trailers and dollys)

The time alignment of each category with the other categories shall be verified by finding the highest correlation coefficient between these series of parameters. All the parameters in a category shall be shifted to maximize the correlation factor. To time-align the three categories the GPS of different sets of equipment shall be used.

4.3.4 Control vehicle.

4.3.4.1 Objective

As explained in the test matrix, the number of vehicles and the testing period is approximately two years. In order to control the possible deviations during the testing performance over the testing period, a control vehicle will be included in the testing protocol. A Control Vehicle obtains reference data for the test and it shall not be modified in any way or used for any other purpose during the entire testing period

4.3.4.2 Characteristics

The following table shows the characteristics of the selected control vehicle.

	Vehicle configuration	Main tractor specifications	Main trailer specifications
CV1	<u>Control Vehicle</u>  • 16,5 m combination • GVW: 40 tonne • EU directive 96/53 compliant	• SCANIA R450 A4x2NA • 4x2 tractor • CR20H (sleep cab high roof height) • DC13 148 Euro-VI (450 hp) • With adjustable roof spoiler and side air deflectors and side skirts • Predictive cruise-control • 2017 model year • Mileage at start 50,000 km	• SCB S.KO Express, 2016 • 3 axles (non-steered nor trailing) • Box type • Side underrun protection (no side skirts) • Length: 13.6m • Max. payload: 32,018 kg • Tare weight: 7,613 kg • 2016 model year • Mileage start: 273,500km • Bearing revision

Table 36. Overview of main tractor/semi-trailer reference vehicle specifications

Taking into account the testing campaign duration and according to the requirements indicated by Scania, a complete mechanical functional check and performance evaluation shall be conducted on the control vehicle which shall include engine/oil and filters considered for changing and a complete vehicle checklist.
Additionally to mechanical maintenance to evaluate a possible degradation of the control vehicle, it is planned during the testing campaign to perform different baseline tests with the Scania and MAN selected models.

The baseline test consists of repeating the fuel consumption tests on test track (test use-case 1) at the same time with the control and baseline vehicles to compare the fuel consumption results obtained and determine possible deviation from the initial behaviour of the control vehicle.
The number of baseline repetitions during the project will depend on the vehicles' availability and the testing planning; IDIADA will try to perform at least three baseline tests.

4.3.4.3 Measurement equipment to install on control vehicle

The control vehicle will be used to determine any possible additional influence of the fuel consumption behaviours in the test vehicles so it will be used only in the performance of test use-cases 1 and 2. The following table shows the measurement equipment to be installed on the control vehicle:

Concept	Remarks
Flowmeter	AIC 6004 Serial number 154684
GPS	Racelogic VBOX IISX at 10Hz
Control signals	Same of point 4.3.3.4

Table 37. Measurement equipment installed on control vehicle

4.3.5 Fuel consumption on test track (tests use-case 1).

4.3.5.1 Warm up

Test and control vehicle shall be operated for at least 90 minutes at 85 km/h prior to starting the steady-state fuel consumption tests to ensure that the vehicles achieve stabilized operating conditions in all components.
The steady-state test shall begin within 30 minutes after completing the warm-up. If it is not possible to run within this target time an additional warm-up 30 minutes shall be conducted .

It is possible that the vehicle undergoes an aftertreatment regeneration event during the warm up, the vehicle should continue with the warm up until the regeneration process is completed.

The fuel consumption during the warm up shall not be used to the final calculation but it should be recorded including the control signals to subsequent analysis.

The warm up shall be done at the same time for the test vehicle and control vehicle and the stop duration before the official steady-state tests shall also be the same.

4.3.5.2 Vehicle constraints

During the fuel consumption tests at steady-state speed the vehicles shall be in the following conditions:

- Heating and ventilation switched off
- Closed windows (including roof)
- Interior lighting is switched off.
- Air conditioner switched off
- Aftertreatment condition, i.e., state of DPF loading and regeneration state. Drivers should note dash displays that indicate or broadcast regeneration state or a DPF illuminated before keying off
- Control cruise settings will be fixed according to the OEM's requirements.
- Dipped headlights on.

4.3.5.3 Steady-state speed fuel consumption test protocol

The steady-state fuel consumption tests should be performed on HST according to the following protocol:

- Within 30 minutes of the warm-up phase, fuel consumption test will be performed at the steady-state speeds of 85.0 km/h at closer control cruise setting. The driver will take as reference the speed signal provided by the GPS described in chapter 4.3.3.6. This speed signal will be shown in an external display with easy visual access and the driver will control it to avoid possible tolerance deviations.
- The duration of the test should be approximately one hour (at least 12 complete laps to HST). The start and end point should be the same one (initial point north straight). Fuel consumption test shall be recorded during the entire tests and used for the final calculation of the results.
- Vehicle shall operate in the manufacturer recommended transmission gear points for the speed of 85 km/h.
- The control cruise will be used to set the tests speed.
- The consumption measurements for each constant speed cycle should be repeated until the 3 measurements lie within an accuracy requirement of 2%. To calculate the accuracy, the difference between the maximum and minimum consumption values of the three measurements is divided by the minimum value.

Additional test information:

- Direction of travel: clockwise
- Gradient: +0,3% north straight and -0,3% south straight
- Point 1: Parking area after the warm-up
- Time from point 1 to point 2 will be used to accelerate the vehicle and fix the constant speed
- Point 2: Fuel consumption start/end point. To perform 12 complete laps (total distance 90.0 km)

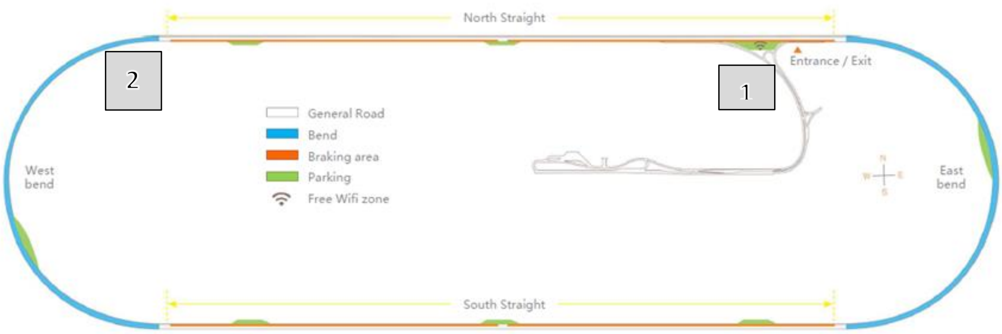


Figure 22. High speed track HST

4.3.5.4 Control vehicle in test use case 1

The warm-up phase, vehicle constraints and steady-state speed fuel consumption tests indicated above shall be the same for the control vehicle and will be done at the same time.

Additionally the following consideration will be taken in account:

- During each cycle the test and control vehicles shall be spaced at a distance of at least 2,000m. Inside the high-speed test track (HST). There are different reference marks on test track that will be used to ensure that both vehicles are spaced with target distance.
- Driver and trailers are assigned to control and test vehicles for entire test (no swapping).
- Measurement equipment shall be the same unit in each vehicle to avoid accuracy differences between different models.

4.3.6 Fuel consumption protocol on world real route (Test use-case 2)

4.3.6.1 Warm up.

The roadway test shall be performed in cold conditions so no warm-up is required. If DPF preconditioning is required according to the OEM's requirement, it should be done at least 10 hours before starting the test and the vehicle shall be parked inside a controlled area before starting the tests.

4.3.6.2 Vehicle constraints

The same vehicle constraints indicated in point 4.3.5.2

4.3.6.3 World real route test protocol

The roadway fuel consumption tests should be performed according to the following protocol:

- Roadway route indicated in point 4.1.2
- The start and end points of the route will be the same one for each test vehicle in order to compare the route for all the tested vehicles.
- The driver will adjust the acceleration and vehicle speed according to the requirements described in point 4.3.6.5.
- During the motorway part of the route the driver will drive at vehicle speed of 85,0 km/h fixed by the cruise control with the OEM's indicated setting.
  The GPS speed signal used as reference. Due to the characteristics of the vehicles, it is possible that the motorway target speed of 85 km/h may not be followed in the areas with a high gradient, in this situation the vehicle should run at its possible maximum speed.
- According to the requirements of the cruise control settings the speed tolerance should be -3.0 km/h and +5.0 km/h of the target speed defined. IDIADA will try to run the cycle inside the tolerance if the transit conditions during the route allow it.
- The driver will be trained to use the vehicles with the new technologies developed in the AEROFLEX project (AEMPT and Aeroload).
- To ensure more repeatable results, as far as possible IDIADA will try to keep total route time lower than 3% within the different tests in the same vehicle.
- The consumption measurements for each roadway cycle should be repeated until the 3 measurements lie within an accuracy requirement of 4,0%, calculated in the same way as test use case 1.

4.3.6.4 Control vehicle in test use case 2

The warm-up phase, vehicle constraints and roadway test protocol for fuel consumption tests indicated above shall be the same for the control vehicle and will be done at same time.

IDIADA will perform an initial test on the control vehicle to be used as speed reference for the different repetitions during the entire project. The reference test will be done according to the speed requirements indicated in point 4.3.6.5.

The assigned driver will receive specific training to make the control vehicle routes as repeatable as possible.

Additionally the following consideration will be taken into account:

- During each roadway cycle the test and control vehicles shall be spaced at a distance of at least 2,000 m.
- Driver and trailers are assigned to control and test vehicles for entire test (no swapping).
- Measurement equipment shall be the same unit in each vehicle to avoid accuracy differences between different models.
- The drivers should be connected using a radio device to indicate any deviation in the route profile and have the possibility to adapt the vehicle speed if necessary.
- Control vehicle should always perform the test in first position and will carry out the test at the same speed profile to guarantee the repeatability on the results.
- The drivers will have a rest period of 15 minutes when they arrive in the urban area of Fraga (see following **Error! Reference source not found.**).

4.3.6.5 Additional information of Fraga roadway route

The following table shows the main theoretical characteristics of the IDIADA-Fraga-IDIADA route:

Concept		Remarks
Trip duration		≈ 12,000 s
Trip distance	Total	237.5 km
	Urban	9.5 km
	Motorway	228.0 km
Average speed (>95% highway-distance based)		≈ 72.5 km/h
Min / max altitude		87 / 573 m
Max up- and downhill slope [%]		6.6 / -6.8 %
Traffic conditions		low

Table 38. Fraga route main characteristics

The following pictures show in greater detail the target speeds for each specific part of the Fraga Roadway route:

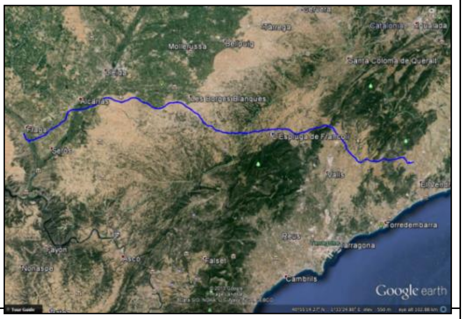
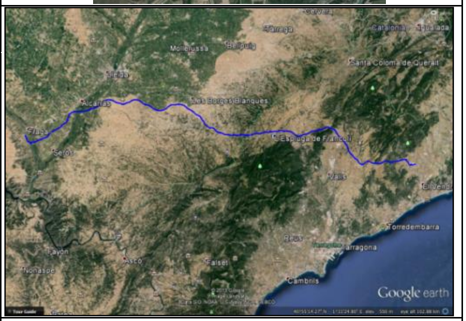
Concept	Remarks
IDIADA to motorway access (urban area) Distance: 3.5 km Maximum speed: 50.0 km/h Acceleration/decelerations according to traffic conditions	
Motorway Fraga direction Distance: 114.5 km Maximum speed: • Control vehicle: 85.0 km/h • Test vehicle: 85.0 km/h Control cruise: Activated according to OEM's setting Acceleration/decelerations according to traffic conditions	
Motorway exit/access and Fraga urban area Distance: 2.5 km Maximum speed: 50.0 km/h Vehicles stopped (ignition off) during 15 minutes. Acceleration/decelerations according to traffic conditions	
Motorway IDIADA direction Distance: 114.5 km Maximum speed: Control vehicle: 85.0 km/h Test vehicle: 85.0 km/h Control cruise: Activated according to OEM's setting Acceleration/decelerations according to traffic conditions	
Motorway exit to IDIADA (urban area) Distance: 3.5 km Maximum speed: 50.0 km/h Acceleration/decelerations according to traffic conditions	

Table 39. Fraga route detailed information

4.3.6.6 Additional requirements for hybrid vehicle configurations.

Inside the test matrix the following two vehicles with hybrid technology are included:

- SCB Hybrid-on-Demand trailer from Transformers
- AEMPT in different configurations with E-Dolly and/or E-trailer

In order to measure and know the influence of the hybrid technologies on the fuel consumption results, the test protocol also includes the control of the electrical consumption that will be measured in test use cases 1 and 2 according to the criteria defined in these points.

In addition to the measurement of the electrical consumption, the state of charge (SOC) of the batteries before and after the test must be taken into account, because too much variation in the state of charge can have a significant influence on the outcome of the fuel consumption measurement, with a positive or negative influence, which contributes to the dispersion of the results.

The measurement of the state of charge (SOC) of a battery is complex and lacks precision. It is desirable to ensure that the states of charge before and after the measurement remain within a relatively small range in order to minimize the influence of this variation on the fuel consumption.

Due to the characteristics of test use-case 1 protocol (start the tests in hot conditions) it is considered the vehicle warm up as a vehicle SOC preconditioning and the test will start with the specific SOC level indicated after the warm-up phase. . It is assumed, due to the long duration of high speed steady-state driving that the electric systems are not in operation, because it will deplete the battery completely. Consequently, the electric control strategy is not charge sustaining.

To reduce the SOC variation in test use-cases 2, carrying out the following specific test protocol for vehicles with hybrid configurations is considered:

- Initial vehicle preconditioning. The day before of the first official test, the vehicle will run an initial part of Fraga route with approximate 32.0 km until altitude of 515m and come back to the defined starting point of the Fraga route. This should be done at least 10 hours before starting the test and the vehicle shall be parked inside a controlled area before starting the actual tests
- The first official Fraga route test will start after this vehicle preconditioning
- For posterior route tests, a preconditioning will not be necessary and the vehicle conditions will be the ones at end of the previous route tests and after parking the vehicle for at least 10 hours.
- Since, all repetitions cannot be managed in a single day, it is specified that the vehicle in between the repetitions are not used for other purposes. Else, the initial vehicle preconditioning has to be repeated, before the actual tests can be continued.

After performing the tests, an additional verification will be done to ensure that the influence of the initial and final SOC test variation in the fuel consumption is not significant between the results obtained in each repetition. To do this, we will take into account the change in the state of charge and check its evolution during the test in accordance with SAE J2711.

The SAE J2711 document allows some level of tolerance between the initial SOC and final SOC to avoid correcting data that is already effectively at a net zero change in energy level. A determination of ±1% or less net change in stored energy when compared to total cycle energy expended is within tolerance levels and does not require SOC correction calculations in determining fuel economy. If the percent change in net energy change (NEC) is greater than ±1% but less than ±5%, this document allows for correction of fuel economy calculations to account for the change in energy storage if a clear relationship between NEC and fuel economy can be established.
If the vehicle has a NEC greater than 5%, the collected data may not be reliably corrected and the test should be considered invalid.

4.3.7 Deviations from reference SAE J1526 – Fuel consumption test procedure

The fuel consumption test will be performed in accordance with the SAE J1526 – Fuel consumption test procedure. However, due to the nature of this project, some of the points in the regulation will not be able to be completely fulfilled or have been improved. The following list contains the points of the SAE J1526 not complied in the test procedure:

- The weather conditions defined for test use-cases 1 and 2 in subsection 4.3.2.1 are stricter than those defined in the SAE J1526 protocol.
- Additional vehicle checklist adapted to test matrix configurations.
- Vehicle odometers. Due to the different origin of the test cases (especially rented, advanced vehicles from transformers project and demonstrator vehicles) it is not possible to comply with the odometer requirements of the SAE protocol. However, IDIADA will try to reduce as much as possible the odometer difference between vehicles. In case of high mileage, proper maintenance is performed.
- The vehicles and tires shall run at least 3,000km instead of the 805 km indicated in the SAE protocol.
- Due to the impossibility of using the OEM's tool, instead of doing the DPF preconditioning before each test it will be done at beginning of the testing activities and the DPF status verified via CAN during the tests to determine if an additional preconditioning is necessary.
- Control vehicle speed and behaviour during the route will be the same in all the tests to better correlate the results obtained. For test vehicles (standard, EMS1 and EMS2) it will be necessary to adapt the vehicle speed in accordance to their limitations (not possible to reach maximum speed of 85.0 km/h in specific parts of the route with high gradient).
- Included additional CAN data and sensors to extra control the vehicle behaviour during the tests.
- To ensure that the influence in the fuel consumption of the initial and final SOC test variation of the different HOD technologies is not significant between the results obtained in each repetition. The evaluation protocol defined in SAE J2711 is used.

4.3.8 Deviations from Grant Agreement proposed test protocol.

IDIADA as Aeroflex WP6 leader (demonstration, validation and analyses of feasibility) in collaboration with the other WP leaders involved in the testing activities MAN WP2 (Advanced Energy Management Powertrain), SCANIA WP3 (Aerodynamic Features for the Complete Vehicle), VOLVO WP4 (Smart Loading Units), TNO as main WP6 partner and MAN as Aeroflex coordinator. We have discussed the feasibility of the measurement of the pollutant emissions as proposed initially in the Grant Agreement document and the expected output that these measurements will provide.

We have agreed that to carry out the project correctly, it is not necessary to measure the pollutant emissions as indicated in the GA, for the following reasons:

- The call focusses on fuel consumption and energy consumption improvements, exhaust pollutants were not a must. Exhaust pollutant was included in the test proposal as an additional value but its specific reductions are not considered in any of the development WP's, which are more focussed on reducing fuel consumption, so it is not expected to find specific differences in the vehicle emissions results and the emissions measurements do not add additional value to main objectives of the project.
- After receiving the testing vehicles and checking exhaust layout we realised that preparation time for PEMS measurement might be increased significantly, affecting global schedule and demanded resources. In addition, the necessity to modify the vehicles exhaust line to adapt the PEMS measurement equipment could influence the fuel consumption results and the aerodynamic setting of the vehicle so we may have negative interference with the results obtained in the Aeroflex project.
- Taking in account the points described above, we have considered more interesting to allocate the resources to provide extra information and accuracy of the fuel consumption results obtained, for this reason so we have included a control vehicle that will allow us to compensate possible external influences on the results, additional repetitions on steady-speed tests and Fraga route to obtain more repeatable results and two different test loads to increase the assessment scenarios. The same criteria have been considered to reduce the number of steady-speed tests at single speed of 85 km/h.

4.3.9 Advanced data processing

An internal IDIADA tool adapted for the characteristics of the project will be used for the data processing to determine valid/invalid tests and the necessity to repeat the tests. Additionally, the fuel consumption calculation method from the SAE J1526 is applied for comparison between test vehicles and to determine the measurement accuracy for both test use-cases 1 and 2. See additional information in Chapter 5.

The data processing tool will include the information provided by the measurement equipment defined in point 4.3.3.

4.3.10 Flowchart of the test use-cases 1 and 2

The following figure shows the test protocol for test use-cases 1 and 2.

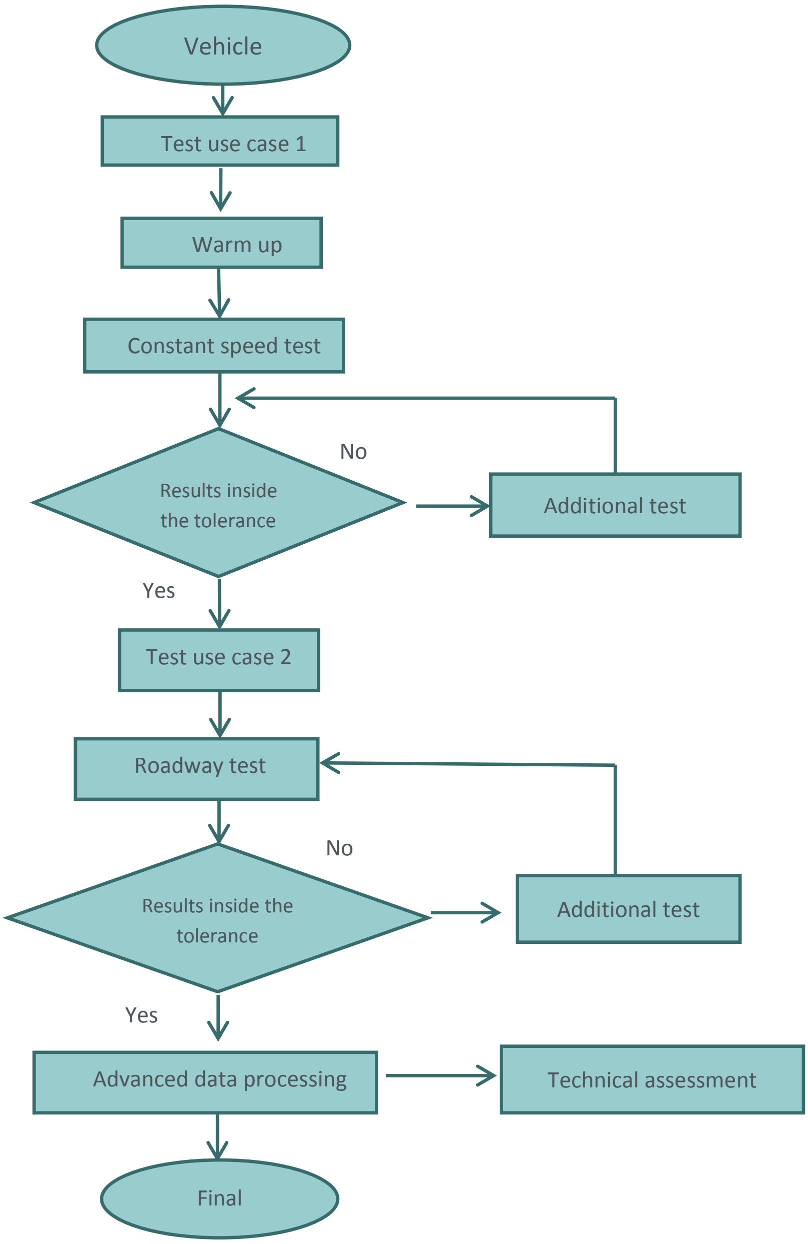


Figure 23. Flowchart test use cases 1 and 2

4.4 Test use-case 3 - Air drag measurement at proving ground

4.4.1 Objective

The aim of this test is to measure the aerodynamic resistance of the vehicles by measuring the torque applied to the drive wheels at high and low speed and compare them. During the test, the air velocity, its yaw angle and the vehicle speed will also be measured and taken into account in order to obtain a result of the influence of the wind on the vehicle.

At least three repetitions of the entire test will be performed with each use-case to obtain a representative value of air drag.

4.4.2 Air drag specific test track characteristics

The air drag test track shall fulfil the following criteria according to Commission Regulation (EU) 2017/2400.

Parameter	Unit
Measurement section	250m (±3m)
Stabilization section	25m
Maximum longitudinal slope	±1%
Minimum distance to obstacles	5m

Table 40. Air drag criteria

The regulation allows establishing multiple measurement sections of 250± 3 m with a previous stabilization area of 25 m. The starting and ending point of each measurement section will be determined with a DGPS.

IDIADA has two tracks in which the test can be conducted. The Dynamic Platform-A (DPA) which offers a straight lane of 1.700 metres long and a longitudinal slope gradient of 0%, making this track ideal for the air drag test; and the High-Speed Track (HST from now on) consisting of an oval track with two straights (North and South) of 2.000 m long each one, and 471 m of bends radius. The HST presents a slope of 0.3% on each straight so the altitude profile correction will be used in the tests performed on this test track. Even though the DPA is the most suitable track to perform the tests on, the turning area at the most east end of the track is not big enough for the longer trucks to turn.

The MAN zero case vehicle will be tested in both test tracks to obtain a minimum of three results. The average and the dispersion of the results obtained in both test tracks will be compared to check the difference between both tracks.

Based on the track availability, the use case configuration and the track comparison, the test track will be chosen in each case.

The first 90 minutes of warm-up required by the Regulation will always be performed on the HST as the required steady speed is easily achieved on this track. The tests conducted on this track will follow the requirements of Annex VIII of the Commission Regulation (EU) 2017/2400.

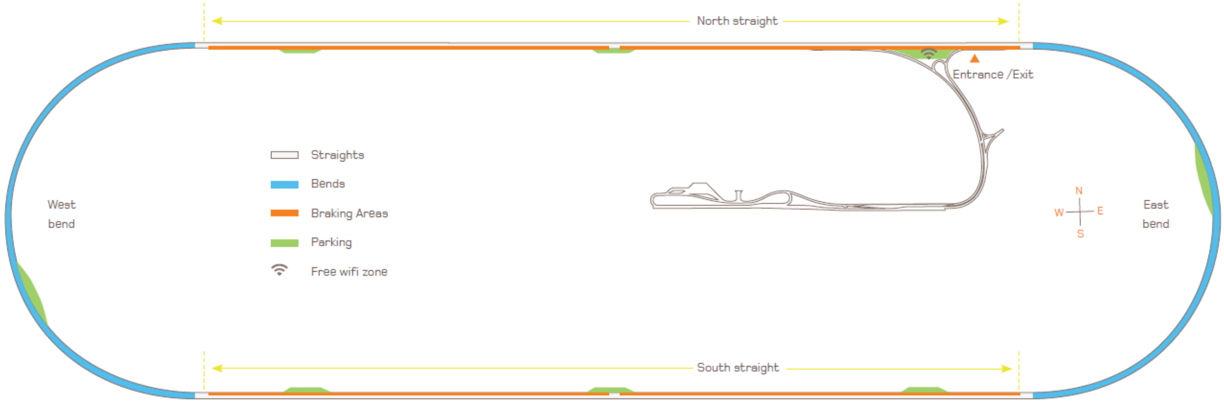


Figure 24. HST diagram

Once the test track is chosen, the several measurement sections will be determined with the DGPS by recording the latitude and the longitude of the starting and finishing points. These starting and finishing points will also be clearly marked on the test track so the driver will easily identify them during the course of the test.

The measurement sections will be redefined after the test according to the more stable test recording zones. For those tests performed on the HST, the three initial measurement sections will be defined one after another with no gaps in between. For the DPA tests, the stabilization sections will be larger to fulfil the same end.

The measurement sections will be as shown in the graphic, picking the option given by the Regulation on point 3.1.1 ii. of Annex VIII. The air drag test will be conducted at the DPA test track alternating the directions as shown in the image below.

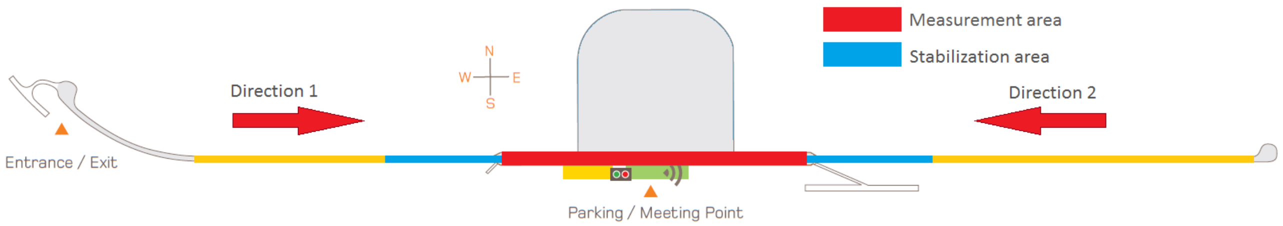


Figure 25. DPA measurement sections scheme

4.4.3 Test constraints

During the air drag test, the following environmental constraints have to be considered:

- The air temperature measured on the vehicle during the low-high-low-speed sequences shall be between 0ºC and 25ºC.
- The ground temperature measured on the vehicle during the low-high-low-speed sequences shall not exceed 40ºC.
- The road shall be dry during the test.
- The average wind velocity will be lower than 5 m/s and the central moving average every second will not exceed 8 m/s (this condition only applies to the high-speed sequence).
- The yaw angle variation will be less than 3º for the high-speed test.

Apart from the environmental constraints, the following points shall be taken into account:

- The vehicle will be measured without payload.
- If any axle on the entire vehicle (including rigid trailer or dolly trailer) has electric motor or any other hybrid system aimed at improving the vehicle's performances, this system will be disabled by disengaging the electric motor from the transmission.
- Vehicles shall be tested at kerb weight with fuel and adblue tanks full and the instrumentation mounted. Two occupants will be on the vehicle while it is performed.

4.4.4 Measurement equipment

All the measurement equipment fulfils the specifications of ISO/IEC 17025 and all the requirements stated in Annex VIII of the Commission Regulation (EU) 2017/2400.

4.4.4.1 Test track pressure and humidity

A stationary weather station located at the DPA will measure the pressure and the humidity during the tests. This weather station is located at less than 2000 m of the south straight of the HST and its measurements will be valid for tests conducted on both test tracks.

4.4.4.2 Wind speed and yaw

An ultrasonic on board anemometer will be installed on the vehicle in order to measure the airflow velocity and yaw angle with respect to the truck.

The position of the mobile anemometer must be within these limits:

- *X*: ±0,3m from the front face of the semi-trailer or box body
- *Y*: Plane of symmetry ±0,1m of tolerance
- Z: At 1/3 of the total height of the vehicle within a tolerance of 0m and +0,2m

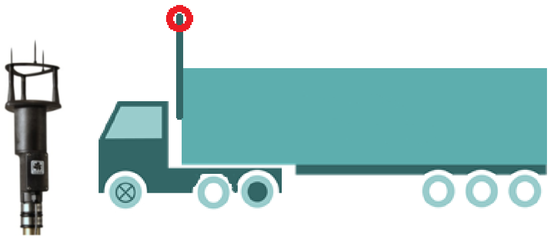


Figure 26. Ultrasonic anemometer and its position

The following table shows the main characteristics of the additional ultrasonic anemometer:

Concept	Remarks	
Brand	Campbell Scientific	
Model	86000	
Accuracy	Wind Speed	± 0.1 m/s
	Wind direction	± 2.0º
Power supply	External batteries	

Table 41. Anemometer characteristics

The anemometer units can be changed during the projected depending on the equipment availability.

A misalignment calibration will be conducted using the data from the high speed test. The result of this calibration will give the misalignment error that will be used to perform the according correction.

4.4.4.3 Temperature

Three different temperatures will be measured from the vehicle:

- The ambient temperature will be measured with a K-type thermocouple installed on the same pole where the anemometer will be mounted.
- The test track temperature will be measured with a contactless IR installed underneath the truck.
- The tire temperature will be also controlled through an IR contactless sensor.

4.4.4.4 Vehicle speed

The vehicle speed will be recorded though the CAN signal and the DGPS:

- For the CAN signal, the VBOX will be connected directly to the OBD connector and will be read from the EBS signal.
- The vehicle speed measured using a DGPS system will use an antenna placed on the roof above the cabin and an IMU sensor inside to prevent any signal losses[5]. Using a DGPS system it is possible to clearly check the start and finish of the measurement sections.

Figure 27. Racelogic VBox 3i with DGPS acquisition (VBox)

4.4.4.5 Position

The DGPS will also be used to define the starting and the finishing recording point of each measurement section.

4.4.4.6 Wheel torque

The torque signals will be recorded using a telemetry system. The measurement will come from a combination of strain gauges mounted on each half shaft. Each gauge will be placed on the surface of the axle and will measure the angular deformation due to the torsional effort. Torque will be measured in both half shafts, left and right. The calibration of the strain gauges will be outsourced to IBM.

$$M_t = \frac{G \cdot I \cdot \varphi}{L_{axis}}$$

Where:

- M_t → Torque measured in the axle [Nm]
- G → Shear modulus of the material [MPa]
- I → Moment of inertia of the axial section [m^4]
- φ → Twisting angle of the drive axle [rad]
- L_{axis} → Length of the axle [m]

[5] In order to this system works correctly, it is important to establish the relative position (coordinates X,Y and Z.) of the antenna respecting the IMU (Inertial Measurement Unit) sensor

Figure 28. Strain gauges on half shafts and telemetry system

The torque meter will ensure the following constraint by calibration:

- Non-linearity < ± 6 Nm
- Repeatability < ± 6 Nm
- Crosstalk < ± 1 % FSO
- Measurement rate ≥ 20Hz

Where:
'Non-linearity' means the maximum deviation between ideal and actual output signal characteristics in relation to the measurand in a specific measuring range.
'Repeatability' means closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement.
'Crosstalk' means signal at the main output of a sensor (My), produced by a measurand (Fz) acting on the sensor, which is different from the measurand assigned to this output. Coordinate system assignment is defined according to ISO 4130.
'FSO' means full-scale output of calibrated range.

The recorded torque data will be corrected for the instrument error determined by the supplier.

4.4.4.7 Engine speed

The engine speed will be measured on the crankshaft pulley using an optoelectronic sensor. This will acquire the revolutions per minute directly.

4.4.4.8 Cardan shaft speed

The cardan shaft speed will be measured on the propeller shaft using an optoelectronic sensor. This will acquire the revolutions per minute directly.

4.4.5 Deviations from the Regulation

The air drag test will be performed in accordance with Annex VIII of Commission Regulation (EU) 2017/2400. However, due to the nature of this project, some of the points in the regulation will not be able to be fulfilled. The following list contains the points of the regulation not complied in the test procedure:

- Items 3.3.1 to 3.3.6 which define the vehicle geometry in accordance with other annexes of the Regulation will not be fulfilled since the vehicles to be tested are defined in accordance with the test matrix.
- Item 3.3.7 which refers to the status of the tires will not be fulfilled since the tires will be maintained during the entire test campaign.
- Item 3.3.10 regarding the active aerodynamics devices will not be in accordance with the regulation. The affected vehicles will be tested with the active aerodynamic features in static situation.

4.4.6 Test procedure

4.4.6.1 Measurement data

The measured data is indicated in the following table:

Instrumentation on track

Parameter	Unit
Ambient temperature	ºC
External pressure	KPa
External humidity	%

Instrumentation on vehicle

Parameter	Unit
DGPS	lat/lon
Vehicle speed (CAN)	km/h
Position	m
Wind speed	m/s
Wind direction (β)	º
Engine or cardan speed	rpm
Torque meter (Left)	Nm
Torque meter (Right)	Nm
Ambient temperature on anemometer	ºC
Proving ground temperature	ºC
Tyre outer temperature	ºC

Table 42. Measurement data

4.4.6.2 Vehicle reception and instrumentation

In accordance with chapter 4.2.

4.4.6.3 Constant speed test procedure

Prior the beginning of the test, the weather conditions will be checked in order to ensure the fulfilment of the requirements stated before.

The air drag test will be performed as per Annex VIII of Commission Regulation (EU) 2017/2400 constant speed test procedure and will include the following phases:

- 1st warm-up
- Torque metres zeroing
- 2nd warm-up
- 1st low-speed test
- 3rd warm up
- High-speed test / Anemometer misalignment
- 2nd low-speed test
- Drift check of torque meters

4.4.6.3.1 Warm-up phases

1st warm-up phase

Before the test begins, vehicle will be driven minimum 90 minutes at the high-speed test velocity. In case of any standstill, another warm up will be necessary, at least as long as the standstill. This warm-up phase is different from the rest since it will always be performed on the HST regardless of the test track where the final test will be conducted.

2nd warm-up phase

After the zeroing has been performed, a minimum 10 minute warm-up will be driven on the track where the test will be conducted, at the same target speed as the high-speed test phase.

3rd warm-up phase

Before the high-speed phase begins, another warm up of at least 5 minutes will be performed under the same conditions as the second warm up.

4.4.6.3.2 Zeroing of torque meters

To zero the torque meters, the vehicle will stop on flat surface. The instrumented axle will be lifted off the ground and, with the engine turned off; the zero will be performed through the telemetry display.

4.4.6.3.3 Low-speed phase

Both low-speed phases will be performed at a constant speed of 14 km/h, measured by DGPS. The starting and finishing points of each measurement section will be fixed using virtual doors established by the GPS as stated before. The regulation does not allow these phases to last longer than 20 minutes each. That is why there will only be time to record between four and eight runs per phase. The manoeuvres between the several measuring sections will be done as fast as possible and the unnecessary ones will be avoided.

4.4.6.3.4 High-speed phase / Anemometer misalignment

The high-speed test phase will be performed at a constant speed of 87 km/h, measured by DGPS. A minimum of thirty runs (fifteen per heading) per phase will be recorded since there is no time limitation for this phase. Since the regulation requires five runs at high speed for the misalignment calibration test, the information of this phase will be used to this end.

4.4.6.3.5 Drift check of torque meter

Once the test has been completed, a drift check of the torque meters will be conducted by lifting the instrumented axle as in the initial zeroing. If the average reading during 10 seconds does not exceed 25 Nm, the check is considered to be correct. If the drift check does not fulfil the requirement the test will be repeated.

4.4.6.3.6 Flowchart of the entire process

The following figure shows the test protocol for test use-cases 3.

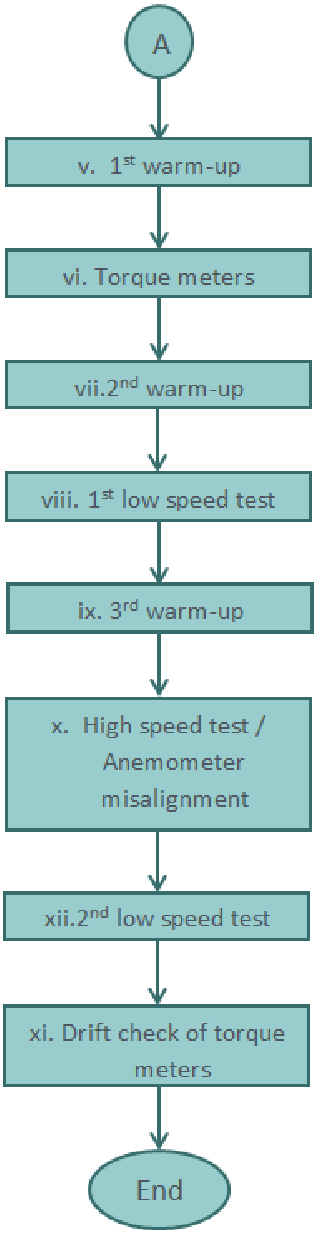


Figure 29. Flowchart of the entire process.

4.4.7 Data processing

The air drag data processing tool used to obtain a result will be Vecto as foreseen in Commission Regulation (EU) 2017/2400.

The Air Drag data processing tool will include the following extra information apart from the one obtained on the test track:

Parameter	Unit	Remarks
Vehicle test mass	[kg]	
Gross vehicle mass	[kg]	
Axle ratio	[-]	
Gear ratios	[-]	
Anemometer height	[m]	
Vehicle height	[m]	
Gearbox type	MT/AT	
Vehicle max speed	[km/h]	

Table 43. Data processing

All the information collected will be introduced in the excel book given by the Commission to obtain the required archives in the correct format. A synchronized weather archive will be generated with the data obtained from the stationary weather station. All the archives will be processed with the VECTO Air Drag module to obtain a final result of Cd*A.

4.5 Test use-case 4 - Dynamic vehicle behaviour

4.5.1 Objective

The objective of this part of the test protocol developed for test use-case 4 is to compare the dynamic behaviour of the following vehicle configurations as indicated in the test matrix:

- MAN or SCANIA EMS1 reference
- MAN EMS1 AEMPT demo
- SCANIA EMS1 AeroLoad demo
- MAN EMS2 AEMPT demo

Moreover, it serves as safety check for the developed demonstrator vehicles before applying on the public road (test use-case 2). The assessment method is based on the Australian Performance Based Standards.

4.5.2 Test constraints

4.5.2.1 Weather conditions (dynamic limits)

IDIADA will perform the dynamic behaviour tests within the weather conditions indicated in **Error! Reference source not found.**, but for ambient temperature the minimum value will be increased towards 15ºC.

4.5.2.2 Tire

The dynamic test shall be performed using the original testing tires provided by Michelin.

4.5.2.3 Vehicle test load

The vehicle test load for the dynamic test shall be 90% of the GVW, so 40t, 60t and 74t for the tractor semi-trailer, EMS1 and EMS2 respectively.

The load distribution per axle will be as similar as possible in all the vehicles, especially focused on keeping the same load distribution in the reference/baseline and demo vehicles. The same method is applied as described in Chapter 0.

4.5.3 Measurement equipment

4.5.3.1 Overview measurement equipment and specifications

To ensure the correct evaluation of the vehicle dynamic behaviour, IDIADA will install the following types of sensors:

- GPS platform (RT3100)
- Dynamometric steering wheel
- Acquisition system

The instrumentation for dynamic vehicle behaviour might include inertial measurement (GPS Platform) for both traction truck and trailer, as well as steering inputs (dynamometric steering wheel).

The following table shows the main characteristics of the dynamic behaviour measurement equipment.

Sensor	Brand	Signal	Range	Accuracy	Unit
GPS platform (RT3100)	Oxford T.	Longitudinal speed	-	± 0.1	km/h
		Lateral speed	-	± 0.1	km/h
		Longitudinal acceleration	± 100	± 0.1	m/s2
		Lateral acceleration	± 100	± 0.1	m/s2
		Vertical acceleration	± 100	± 0.1	m/s2
		Roll angle	± 100	± 0.05	º
		Pitch angle	± 100	± 0.05	º
		Yaw angle	± 180	± 0.1	º
		Roll rate	± 100	± 0.1	º/s
		Pitch rate	± 100	± 0.1	º/s
		Yaw rate	± 100	± 0.1	º/s
		Position	-	± 1.8 m	m
Dynamometric steering wheel	Kistler	Steering angle	± 200/400	± 0.20	º
		Steering torque	± 60	± 0.25	Nm

Acquisition system
MOSES MeasX

Table 44. Dynamic behaviour measurement equipment

4.5.4 Dynamic vehicle behaviour protocol

4.5.4.1 Introduction

Based on the PBS Scheme – The Standards and Vehicle Assessment Rules of the NTC (National Transport Commission) of Australia and with the support of HAN, it is planned to carry out the following types of tests to evaluate the dynamic behaviour:

- Startability
- Gradeability
- Acceleration capability
- Low speed swept path width
- Tail swing
- Static rollover threshold
- Rearward amplification
- Directional stability under braking
- High speed transient offtracking (HSTO)
- Yaw damping
- 360º Circle

Each test is described in the successive subsection.

Due to the characteristics of the different vehicle configurations and specific dynamic tests, a preliminary evaluation at IDIADA facilities will be necessary to confirm the dynamic test fulfils security test track protocols. If IDIADA notice that that exist any limitation in the test protocol for security reasons, IDIADA will try adapt the test requirements. If these corrective actions do not ensure the test security, IDIADA will not able to perform the specific test and IDIADA will inform to the partners involved the reasons of any possible modification in the test protocol.

4.5.4.2 Startability possibly on high-friction surfaces

Object

This test intends to measure the vehicle capability start and accelerate on steep hill (start motion on grade).

Procedure

Starting from standstill on a hill, with a slope not lower than specified, the vehicle must be driven in a straight line to reach a steady forward motion..

Test Condition

- High-friction surface
- Test to be done in Hills test track

Grade

- L2 ≥ 12%
- L3 ≥ 8%

4.5.4.3 Gradeability

Object

This test intends to measure the vehicle’s capability to keep a steady velocity on an upgrade.

Procedure

The vehicle must be driven at constant or increasing speed, over an upgrade and maintain a steady motion. It has been considered two different types of gradeability tests according the following characteristics:

Test Condition A

- Maintain motion on grade at stable or increasing speed for at least 5 m.
- Increasing speed for at least 5m
- Test to be done in hills test track.

Grade

- L2 ≥ 12%
- L3 ≥ 8%

Test Condition B

- Maintain motion on grade at stable or increasing speed for at least 5 m.
- Increasing speed for at least 5m
- Test to be done in general road.

Grade

- 2.6%

4.5.4.4 Acceleration capability

Object
This test intends to measure the vehicle's capability to accelerate on a flat surface.

Procedure

From a standing-still position, the vehicle must be driven for at least 100 m going through the gears as needed

Test Condition

- Flat surface
- Standstill start
- Test to be done in dynamic platform.

4.5.4.5 Low-speed swept path width

Object
This test intends to measure the required area for the vehicle to clear a low-speed corner.

Procedure
At a constant low speed, the vehicle must be driven through a 90º turn, so the swept path width can be measured.

Test Condition

- Constant speed (<5 km/h)
- 90ºcorner
- Test to be done in dynamic platform.

4.5.4.6 Tail swing

Object
This test intends to measure the required area for the vehicle tail while clearing a low-speed corner.

Procedure
At a constant low speed, the vehicle must be driven through a 90º turn, so the tail deviates from the axle path.

Test Condition

- Constant speed (<5 km/h)
- 90ºcorner
- Test to be done in dynamic platform.

4.5.4.7 Stability rollover threshold

Object
This test intends to measure the vehicle limit for rollover stability.

Procedure
Starting at a constant speed of the vehicle, keeping a constant radius path, the vehicle must be accelerated at a constant rate, until reaching a given lateral acceleration level or the rollover stability limit.

Test Condition

- Vehicle acceleration (<0.13 m/s^2)
- Path radius (>100 m)
- Lateral acceleration limit (3m/s^2)
- Test to be done in dynamic platform.

Due to the characteristics of the static rollover threshold and for security reasons, it is necessary to perform this activity adapting outriggers on the semi-trailer. The installation of the outriggers cannot be done on rental and demo vehicles so if it is possible to include in the test schedule (limitation of vehicles and semi-trailer availability) IDIADA will use one of his prepared semi-trailers for this specific test. Carry on this activity one configuration of the baseline EMS1 vehicles will allow HAN to validate his simulation software.

4.5.4.8 Directional stability under the braking

Object
This test intends to measure vehicle stability during straight-line heavy braking situations.

Procedure
Starting at a constant speed driving, the brakes must be applied in order to reach a mean deceleration larger to the one set in the requirements.

Test Condition

- Constant speed (60 km/h)
- Deceleration (> specified by standard)
- Test to be done in dynamic platform.

4.5.4.9 Rearward Amplification, high speed transient Offtracking (HSTO) and yaw damping

Object
This test intends to measure vehicle’s trailer response compared with that from the traction truck.

Procedure
Driving at a constant speed the vehicle must be given a sinusoidal constant amplitude steering input in order to generate an excitation in the trailer response

Test Condition

- Lateral acceleration (1.5 m/s^2)
- 90ºcorner
- Test to be done in dynamic platform.

4.5.4.10 360º turning circle

Object
This test intends to measure vehicle’s trailer turning at 360º.

Procedure
Driving at a low constant speed the vehicle turn in a 360º circle.

Test Condition

- Vehicle speed lower than 5 km/h
- 90º turn
- Test to be done in dynamic platform.

4.6 Loading and unloading (test case 5)

This Section describes in detail the test use-cases, containing objective, required equipment and measurement and planning template.

4.6.1 Objective of the test use-case:

Quantification of the WP4 KPI's payload capacity, fill speed and volume factor for the TF-VEG trailer at a roundtrip between two P&G warehouses, the distribution centres in Euskirchen and Cralsheim.

4.6.2 Description of the tests to quantify the KPI's

- All the WP4 KPI's, payload capacity, fill speed and load factor, are measured in the same shipments.
- The baseline tests of three weeks, about 15 shipments, will give a good average of the current values of the KPI's.
- KPI description for:
  - Fill speed: the Fill speed is the net time needed by the fork lift driver to move all pallets in the trailer including the time to set the flex floors in minutes. The time is starting when the forklift enters the trailer and stops when he goes out the trailer .For the time between loads, to get a pallet in the DC, the minimum time between leaving the trailer and entering the trailer again is taken. The registration of the fill time is done by the Cargo Cam and will be in minutes per shipment. If the Cargo Cam is not available the registration must be done by video or time measurement by the driver with less accuracy of course. In the fill speed also all handling of the driver is measured.
    The driver needs to open and close the trailer, fold out the ramp support frame, fold the trailer aero devices, parking the trailer to the dock. These values are added to the fill speed.
  - Payload [kg] and payload improvement (%)
    The pay load is measured in kg . To be able to calculate the energy efficiency improvement also the gain compared to the baseline measurements need to be calculated.
  - Load factor [m3] and load factor improvement (%)
    The load factor is measured in m3. To be able to calculate the energy efficiency improvement also the gain compared to the baseline measurements need to be calculated.

4.6.3 Needed equipment

Battery charge connection to the truck.
The batteries that are needed to drive the motors of the roof, need to be recharged. Best way is to charge the battery by the truck while driving. For emergency purposes a 220 V battery charger is mounted on the front wall. The truck need to be foreseen with a battery load connection.

Figure 30: Connector on trailer to charge battery

Forklift

To lift the flex floors to the desired heights a fork lift with long levers, 1,5 m, is needed. The pallets need to be picked up two by two, to put them on top and under the flex floor. In most warehouses they are available, but not used in the loading area.

Figure 31: Fork lift needed to lift the flex floor

4.6.4 The measurement /planning template

For the tests a special Excel calculation sheet is designed to registrate all needed data and to plan the new shipments. In the first section the data from the VEG trailer is pre filled in. The planner needs to fill in the green and yellow cells. The yellow cells are data from the "standard "shipment , the green cells are the extra pallets that are planned for the test shipments phase 3. The data filled in in the yellow cells come from the standard planning tool, the green cells are the extra pallets per shipment, from these pallets the number, the weight and height need to be filled in, like has been done by the yellow shipments.

	test result/planning sheet								date:	17-3-2017		
									by:	T.Bertens		
	specs volume optimized trailer											
		VEG-Trailer		kingpin weight	2150	kg						
				axle weight	6500	kg						
				total weight	8650	kg						
				wheel base	7,7	m						original shipment
		Truck			7500	kg						
												extra in Transformer trailer
		Max pay load			23850	kg						
		max usable Volume			88	m^3						
	original shipment nr.			6254348942	distance	600	km					
	pallet table											
		pallets	euro pallet		dim	800	1200					
	id	nr	weight	height	total							
			kg	mm	weight	volume			**original shipment**			
5	1	2	760	1409	1520	2,70528			total	Total	Total	
	2	25	365	1602	9125	38,448			pallets	Weight	Volume	
24	3	2	227	918	454	1,76256			33	12073	47,5891	
	4	1	227	918	227	0,88128						
	5	1	270	1200	270	1,152			pallet	weight	volume	
2	6	1	112	1166	112	1,11936			fill	efficiency	efficiency	
	7	1	365	1584	365	1,52064			100%	51%	54%	
	8				0	0						
	9				0	0						
	10				0	0						
	11				0	0						
	12				0	0						
	13				0	0						
	14				0	0						
	15				0	0						
extra	16	5	760	1409	3800	6,7632			pallets from same shipments extra			
pallets	17	24	227	918	5448	21,1507			5x1en 24x3 and 2x6			
	18	2	112	1166	224	2,23872						
	19		365	1584	0	0						
	20				0	0						
		64			21545	77,7418						

Table 45. Section 1 pallet Description per shipment

In the orange fields the load factor and pay load from original shipment are calculated, but also a insight of the weight and volume efficiency is shown.

Next step is the planning, where the extra pallets can be placed without overloading the axles. Section 2 is made to do it. In the yellow columns only the “id” of the pallet must filled in on positions on the loading floor, the weight and height are automatically filled in. In the green column the id of the extra pallets can be filled in and so the optimal fill of the trailer can be made.

shipment description																
												weight				Roof
												contribution				areo profile
	Flex-Floor	pallet	weight	height	space	pallet	weight	height	space	total	total	king pin	axles	height		setting roof
		on top			on top	under				weight	height			cargo		
pallet nr		id	kg	mm	mm				mm	kg		kg	kg	mm		
1	1	2	365	1602	1038	3	227	918	120	592	2520	693,8	-101,8	3910	3910	3910
2		2	365	1602	1038	3	227	918	120	592	2520	693,8	-101,8	3910		
3	2	2	365	1602	1038	4	227	918	120	592	2520	592,0	0,0	3910		
4		2	365	1602	1038	3	227	918	120	592	2520	592,0	0,0	3910		
5		2	365	1602	1038	3	227	918	120	592	2520	592,0	0,0	3910		
6		2	365	1602	1038	3	227	918	120	592	2520	592,0	0,0	3910	3910	3910
7	3	2	365	1602	1038	3	227	918	120	592	2520	469,0	123,0	3910		
8		2	365	1602	1038	3	227	918	120	592	2520	469,0	123,0	3910		
9		2	365	1602	1038	3	227	918	120	592	2520	469,0	123,0	3910		
10		2	365	1602	1038	3	227	918	120	592	2520	469,0	123,0	3910		
11	4	2	365	1602	1038	3	227	918	120	592	2520	346,0	246,0	3910		
12		2	365	1602	1038	3	227	918	120	592	2520	346,0	246,0	3910		
13		2	365	1602	1038	3	227	918	120	592	2520	346,0	246,0	3910		
14		2	365	1602	1038	3	227	918	120	592	2520	346,0	246,0	3910		
15	5	2	365	1602	1038	3	227	918	120	592	2520	223,0	369,0	3910	3910	3910
16		2	365	1602	1038	3	227	918	120	592	2520	223,0	369,0	3910		
17		2	365	1602	1038	3	227	918	120	592	2520	223,0	369,0	3910		
18		2	365	1602	1038	3	227	918	120	592	2520	223,0	369,0	3910		
19	6	2	365	1602	1038	3	227	918	120	592	2520	23,1	568,9	3910		
20		2	365	1602	1038	3	227	918	120	592	2520	23,1	568,9	3910		
21		2	365	1602	1038	3	227	918	120	592	2520	23,1	568,9	3910		
22		2	365	1602	1038	3	227	918	120	592	2520	23,1	568,9	3910		
23	7	2	365	1602	1038	3	227	918	120	592	2520	-36,1	628,1	3910	3910	3910
24		2	365	1602	1038	3	227	918	120	592	2520	-36,1	628,1	3910		
25		2	365	1602	1038	3	227	918	120	592	2520	-36,1	628,1	3910		
26		7	365	1584	1056	3	227	918	138	592	2502	-36,1	628,1	3892		
27	8	7	365	1584	1056	3	227	918	138	592	2502	-126,9	718,9	3892		
28		1	760	1409	1231	5	270	1200	31	1030	2609	-220,7	1250,7	3999		
29		1	760	1409	1231	5	270	1200	31	1030	2609	-220,7	1250,7	3999		
30		1	760	1409	1231	5	270	1200	31	1030	2609	-220,7	1250,7	3999		
31	9	1	760	1409	1231	5	270	1200	31	1030	2609	-334,3	1364,3	3999	3999	3999
32		1	760	1409	1231	6	112	1166	65	872	2575	-283,0	1155,0	3965		
33		1	760	1409	1231	6	112	1166	65	872	2575	-283,0	1155,0	3965		
34		1	760	1409	1231	6	112	1166	65	872	2575	-283,0	1155,0	3965		

Table 46. Pallet positioning per shipment

The sheets give, in the light green column, the height of the flex floors to be set by the driver. The table also calculates the total height of the cargo in one roof segment, so the height of the roof to get the optimal reduction of drag, can be taken from these figures.

In section 3 of the sheet the different efficiency effects of the double floor are calculated. First the total amount of pallets is shown with the total weight. The sheet automatically calculates what the axle forces will be, due to the positioning of the pallets. The king pin and axle loads are shown and the improvement of fill, weight and volume is shown. For all to be tested transport types these tables are made.

	Results															
		pallets	weight				weight	total weight			volume					
		nr	kg				extra kg	ton								
		68	15175				7545	22,72			82,7184					
						34		34								
	total load from pallets on trailer						transformer					**time measurement**				
	kingpin	axles					fill	weight	volume			put trailer on dock		8	min	
	5,9	16,8	ton					efficiency	efficiency			fill trailer		35	min	
							206%	95%	94%			close trailer on dock		4	min	
transfo	kingpin	axle load					improvement					open trailer		4	min	
total	load						fill	weight	volume			empty trailer		40	min	
	8,0	23,3	Ton				106%	88%	74%			close trailer		5	min	
max	12	27	Ton													

Table 47. Efficiency improvements per shipment

The end result of the sheet is the improvement in payload and load factor for the shipment. In the yellow cells in section 3 the fill time data can also be filled in. The intention is to make the new PUZZLE Software so that all the functionality from the calculation sheet is integrated and preferably coupled or synchronized to the existing planning system to get the data from the pallets in the PUZZLE tool.

5 Measurement data

Due to the large amount of information generated during the test program and the important to be shared with the other partners in a standard format that allow the easy understanding and post processing. It is necessary to define and explain how this information will be shared. The following points explain the data format, storage, logging and final report information that will be provided.

5.1 Data format

To ensure the data traceability and provide a common document to be used as standard for the different partners, IDIADA will provide specific templates in Excel format for each valid test performed.
These templates will include a summary of the main results of each test use case and the time-trace data/signals measured during the tests.

5.2 Data storage

Due to the size of the templates and the information generated during the tests, IDIADA will enable an ftp server where the test data will be uploaded and classified for each vehicle and test.

Jointly with the different WP leaders involved in the WP2, WP3 and WP4, it will be decided who will have access to which specific information.

5.3 Data synchronization and logging

The data logged and synchronized will be provided according to the characteristics of the following templates.

5.3.1 Fuel consumption tests (test use case 1 and 2)

The data recorded and the calculations executed for the fuel consumption tests will be summarized in a general data sheet that will include an overview of the main results obtained and specific information of the vehicle and test conditions. For each vehicle configuration, for each repetition a datafile will be created. This datafile includes the test vehicle data as well as the control vehicle data.
Additionally, an Excel template is created for the fuel consumption comparisons and measurement accuracies according to the SAE J1526 protocol. This allows for the final comparison of the different vehicles according to Section 3.4.1 as well as the judgement of the measurement accuracy for the number of repetitions executed.

The following table shows the information that will be provided in the summary sheet of the Excel data template for the fuel consumption measurements (test sheet):

Parameter	Unit	Remarks
Time	s	
Speed (GPS)	km/h	
Distance	km	Calculated from GPS signals
Height	m	
Latitude	º	
Longitude	º	
Fan Speed	rpm	
Fuel Consumption	l	
Asphalt Temperature	ºC	
External tire temperature	ºC	
Exhaust Temperature	ºC	
Fuel Temperature	ºC	
Humidity	%	
Ambient Temperature	ºC	
Current gear	nº	

Table 48. Signals measured using external sensors and at least stored with 1 Hz, except for the tire related signals

This data will be complemented with the vehicle signals described in chapters 5.3.4 and 5.3.5

It is planned to provide all this data synchronized at 1Hz, but for assessment purposes, IDIADA will also include data alignment at 10Hz for specific recorded signals that allows it.

5.3.2 Aidrag tests (test use case 3)

The data recorded and the calculations obtained during the Airdrag tests will be summarized in a specific data template that will include a summary of the general results obtained and the information of each run done to calculate the Airdrag results. For each vehicle configuration, a data file will be created. This means that the repetitions for each vehicle configuration are covered in this Excel file too

The following table shows the general information that will be provided in the summary sheet of the excel data template for the Air drag measurements:

Parameter	Unit
Position error correction factor for measured air speed	-
Position error correction factor for measured air inflow angle	-
Misalignment correction for measured air inflow angle	°
Calibration factor for CAN vehicle speed	-
Average ambient temperature during first low speed test	°
Average vehicle speed used datasets low speed tests	km/h
Average vehicle speed used datasets high speed tests	km/h
Average Cd*A (β) for Heading 1	m^2
Average absolute β for Heading 1	°
Average Cd*A (β) for Heading 2	m^2
Average absolute β for Heading 2	°
Average Cd*A (β) (before yaw angle correction)	m^2
Average absolute β	°

β-influence on Cd*A calculated with beta and the generic drag curve	m^2
Average measured Cd*A for zero yaw angle	m^2
Correction of Cd*A to reference vehicle height (flat test track)	m^2
Cd*A influence from anemometer (established by regulation)	m^2
Cd*A value for zero cross-wind conditions (= Cd*A (0)meas + delta_ Cd*A _height + delta_ Cd*A _anemo)	m^2

Table 49. Calculated airdrag results

The following table shows the information that will be provided in the summary sheet of the excel data template for the Air drag measurements:

Code name	Description	Unit
delta t	Time spent in the run	s
v (s)	Driven distance inside the measurement section derived from vehicle speed signal divided delta t	m/s
vair_ic	Average air speed (after instrument error correction)	m/s
beta_ic	Average yaw angle (after instrument error correction)	°
valid	Validity of the run according to all the following checks.	-
used	Usage of the run in the calculation.	-
val_User	Validity of the run performed by the user	-
val_vVeh_avg	Validity of the vehicle speed range	-
val_vVeh_f	Validity of the vehicle speed stability (low speed tests)	-
val_vVeh_1s	Validity for the vehicle speed stability (high speed test)	-
val_vWind	Validity for the maximum average wind speed (5m/s)	-
val_vWind_1s	Validity for the maximum gust wind speed (8m/s)	-
val_tq_f	Stability of torque signal (high speed test)	-
val_tq_1s	Stability of engine (low and high speed test)	-
val_beta	Average absolute beta below limit (only for high speed test)	-
val_n_eng	Stability of engine (low and high speed test)	-
val_dist	Validity of distance from vehicle speed signal	-
val_t_amb	Ambient temperature stability	-
val_t_ground	Maximum ground temperature check	-
vair	Average air speed (on board)	m/s
v_wind_avg	Average wind speed (static weather station)	m/s
v_wind_1s	Average 1s moving average of wind speed	m/s
v_wind_1s_max	Maximum of 1s moving average of wind speed (=gust)	m/s
beta_avg	Average yaw angle	°
beta_abs	Average absolute yaw angle	°
v_air_sq	Squared average air speed (squared in 100Hz, then aver-aged!)	m2/s2
n_eng	Average engine speed	rpm
n_eng_1s_max	Maximum of 1s moving average of engine speed	rpm
n_eng_1s_min	Maximum floating average of engine speed	rpm
n_eng_float_max	maximum floating average of engine speed	rpm
n_eng_float_min	minimum floating average of engine speed	rpm
r_dyn	Dynamic tyre diameter	Nm
tq_sum	Average torque (sum l+r)	Nm
tq_sum_1s	Average 1s moving average of torque sum	Nm
tq_sum_1s_max	Maximum 1s moving average of torque sum	Nm
tq_sum_1s_min	Minimum 1s moving average of torque sum	Nm
tq_sum_float	average floating average of torque sum	Nm
tq_sum_float_max	maximum floating average of torque sum	Nm
tq_sum_float_min	minimum floating average of torque sum	Nm

tq_grd	Gradient torque	Nm
t_float	Averaging floating period ("floating" refers to averaging as defined for stability for low speed tests)	s
F_trac	Average total traction force	N
F_acc	Average acceleration force	N
F_grd	Average gradient force	N
F_res	Average force from driving resistances	N
F_res_ref	Average force from driving resistances at reference conditions	N
v_veh_1s	Average 1s moving average of vehicle speed	m/s
v_veh_1s_max	Maximum 1s moving average of vehicle speed	m/s
v_veh_1s_min	Minimum 1s moving average of vehicle speed	m/s
v_veh_acc	Average “averaged” vehicle speed (as calculated for acceleration correction)	m/s
a_veh_avg	Average acceleration calculated from “averaged” vehicle speed	m/s
v_veh_float	Average floating average of vehicle speed (“floating” refers to averaging as defined for stability for low speed tests)	m/s
v_veh_float_max	Maximum floating average of vehicle speed	m/s
v_veh_float_min	Minimum floating average of vehicle speed	m/s
t_ground	Average ground temperature	C°
t_amb_veh	Average ambient temperature measured on the vehicle	C°
t_amb_stat	Average ambient temperature from stationary measurement	C°
p_amb_stat	Average ambient pressure from stationary measurement	mbar
rh_sta	Average relative humidity from stationary measurement	%
vp_H2O	Average H2O vapour pressure	Pa
rho_ai	Average air density	kg/m3
CdxA(ß)_singleDS	CdxA value for single high speed dataset with all low speed datasets from similar MS and Dir ID	m2
t_tire	Average tire temperature	C°
Satelites	Average number of satellites	nº
<n_card1>	Average cardan speed	rpm

Table 50. Calculated data from different airdrag runs

5.3.3 Dynamic tests (test use case 4)

The information provided for the dynamic tests is described in **Error! Reference source not found.**

5.3.4 Additional information from truck or tractor

The following table shows the information recorded from the ECU for the MAN and SCANIA test vehicles and control vehicle.

Parameter	Unit	Remarks
Speed	km/h	
Engine Speed	rpm	
Oil Temperature	ºC	
Actual Gear	-	
Accelerator pedal	%	
Brake pedal	%	
Fuel Consumption	l	
Coolant Temperature	ºC	

Table 51. Additional information from truck and tractor measured with at least 1 Hz

If these signals cannot be recorded from the ECU, if It is possible, IDIADA will install additional sensor to directly measure it and integrate signals in the data template.

In addition, the Scania EMS1 AeroLoad demonstrator vehicle will incorporate the signals described on the following table dedicated to the advanced (active) aerodynamic actuators:

Parameter	Unit	Remarks
Active flow control set point 1	nº	
Active flow control set point 2	nº	
Actual value of active flow control 1	nº	
Actual value of active flow control 2	nº	

Table 52. AEROLOAD specific signals

At the time of writing this deliverables, this demonstrator is not yet defined. This means, that additional signals might be added to the data.

5.3.5 Semi-trailer, dolly and tires

5.3.5.1 TF-SCB semi-trailer

The following table shows the information acquired from TF-SCB semi-trailer:

Parameter	Unit	Remarks
EBS6__EBS6_VehicleSpeed	Km/h	
EBS_Control__Vehicle_Speed_wheelbased	Km/h	
EBS_HighResVehicleDist__EBS_TotalVehicleDistance	km	
EMG_state_1__EMG_current_actual	A	
EMG_state_1__EMG_temperature_coolant_actual	ºC	
EMG_state_1__EMG_torque_actual	Nm	
EMG_state_1__EMG_voltage_actual	V	
EMG_state_2__EMG_rot_speed_actual	rpm	
ESU_MSG05_BPCM__HVBatCrn	A	
ESU_MSG05_BPCM__HVBatVl	V	
ESU_MSG09_BPCM__HVBatSOC	%	
TDMSResponse__EMG_clutch_state	-	
TDMS_ESU_Cooling__EsuCoolingHeatPower	%	
TDMS_Emg_Cooling__EmgFanSpeed	rpm	
TwdV_GPM5__Actual_EMotor_Speed	rpm	
TwdV_GPM5__Actual_EMotor_Torque	Nm	
TwdV_Electronic_Brake_System_1__Wheel_based_Vehicle_Speed	km/h	
TDMS_ESU_Cooling__EsuCoolingFanSpeed	%	
Electric power	kW	Calculated
Energy	kWh	Calculated
Positive energy	kWh	Calculated
Negative energy	kWh	Calculated

Table 53. Information from TF-SCB semitrailer

5.3.5.2 TF-VEG semi-trailer

If available, the same specific signals of **Error! Reference source not found.** will be reported and included in the data template.

5.3.5.3 WP2 E-Dolly

The following table shows the information to at least record from WP2 E-dolly. Since, the E-dolly is under development, additional signals might be added in a later stage.

Parameter	Unit	Remarks
State-of-charge	%	
Current	A	
Voltage	V	
Actual wheel torque [Nm]	Nm	
Rotational speed	RPM	
EBS state	-	
State-of-charge	%	
Current	A	

Table 54. Data from WP2 E-dolly

5.3.5.4 Baseline and WP3 Dolly

The drawbar length can be manually adapted. Especially, the distance between rigid truck and semi-trailer in the EMS1 AeroLoad demonstrator might be shortened to reduce vehicles air drag. This information will be reported for both EMS1 reference vehicles and AeroLoad demonstrator.

5.3.5.5 Tires

Although, the tires temperature and pressure will be monitored in each test, due to the signal accuracy only the tire pressure will be reported and integrated in the data template for future evaluation.

5.4 Vehicles reports

5.4.1 Individual report for each test vehicle

For each tested vehicle, IDIADA will prepare a report with the main results obtained for the airdrag, fuel consumption and dynamic tests. The structure of these reports will be as follows:

- Objective
- Test process
- Vehicle specifications
    - Vehicle characteristics
    - Vehicle test configuration
    - Mass configuration
    - Tire configuration
    - Vehicle instrumentation
- Test preparation
- Measurement logbook
- Main results
    - Airdrag

        - General results
        - Results per direction
    - Fuel consumption
        - Steady state speed test and Fraga route
        - Test vehicles and control vehicle
    - Dynamic tests
        - Start-ability possibly on high-friction surfaces
        - Gradeability
        - Acceleration capability
        - Low-speed swept path width
        - Tail swing
        - Directional Stability under the Braking
        - Static Rollover Threshold
        - Rearward Amplification
        - Steering angle gradient
        - Cornering stability under acceleration/deceleration
- Annexes
    - Instrumentation pictures
    - Airdrag run charts
    - Tire rolling resistance results
    - Additional measurement
    - Instrumentation pictures

This report will be complemented with the data template provided in each test.

5.4.2 Overview vehicle comparative reports

In addition to the individual reports for each tested vehicle, IDIADA will prepare a separated summary report comparing the results obtained in the different vehicle categories and the references vehicles according to the information indicated in **Error! Reference source not found.** and **Error! Reference source not found.**.

5.5 Data post-processing

IDIADA will provide to the partners the specific data templates as explained in the previous sections. Each partner will have to decide how to integrate this information inside their post-processing tools. Since the data is shared in Excel files, easy transformation to other data analysis software packages is possible.

5.6 Data/ test validity-check

IDIADA will use its internal validation tool to ensure the repeatability of the results and possible to detect any external influence that could modify the results. This internal validation tool will reduce the post-processing timing to validate each test run and will allow fast adaptation on the vehicle or protocol if necessary.

6 Risk and quality assurance

6.1 Risk Register

Risk No.	What is the risk	Probability of risk occurrence[6]	Effect of risk[7]	Solutions to overcome the risk

6.2 Quality Assurance

The following questions should be answered by all reviewers (WP Leader, peer reviewer 1, peer reviewer 2 and the technical coordinator) as part of the Quality Assurance Procedure. Questions answered with NO should be motivated. The author will then make an updated version of the Deliverable. When all reviewers have answered all questions with YES, only then the Deliverable can be submitted to the EC.
NOTE: For public documents this Quality Assurance part will be removed before publication.

Question	WP Leader Àlex Freixas (IDIADA)	Peer reviewer 1 Paul Mentink (TNO)	Peer reviewer 2 OEM's (MAN, SCANIA, CNH, VOLVO)	Technical Coordinator Ben Kraaijenhagen (MAN)
1. Do you accept this deliverable as it is?	YES	YES	YES	
2. Is the deliverable completely ready (or are any changes required)?	YES	YES	YES	
3. Does this deliverable correspond to the DoW?	YES	YES	YES	
4. Is the Deliverable in line with the AEROFLEX objectives?	YES	YES	YES	
a. WP Objectives?	YES	YES	YES	
b. Task Objectives?	YES	YES	YES	
5. Is the technical quality sufficient?	YES	YES	YES	

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

[7] Effect when risk occurs: 1 = high, 2 = medium, 3 = Low

7 References

1. AEROFLEX Grant Agreement. AeroFlex Consortium. 2017
2. Transformers Project. [Online] 2017. http://www.transformers-project.eu/.
3. SAE J1526 - 1987 Joint TMC/SAE Fuel consumption in-service test procedure Type III
4. SAE J1526 - 2015 Fuel Consumption Test Procedure (Engineering Method)
5. SAE J1321 – 2012 Fuel consumption test procedure type II
6. SAE J2711 - 2002 Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid-Electric and Conventional Heavy-Duty Vehicles
7. UNE – EN 16258-2016 Methodology for the calculation for the energy consumption and emissions pollutants in the transport services (transport of goods and passengers)
8. Commission Regulation (EU) No 582/2011 of 25 May 2011 implementing and amending Regulation (EC) No 595/2009 of the European Parliament and of the Council with respect to emissions from heavy duty vehicles (Euro VI) and amending Annexes I and III to Directive 2007/46/EC of the European Parliament and of the Council Text with EEA relevance
9. Commission Regulation (EU) 2017/2400 of 12 December 2017 implementing Regulation (EC) No 595/2009 of the European Parliament and of the Council as regards the determination of the CO2 emissions and fuel consumption of heavy-duty vehicles and amending Directive 2007/46/EC of the European Parliament and of the Council and Commission Regulation (EU) No 582/2011 (Text with EEA relevance.)
10. PBS Scheme – The Standards and Vehicle Assessment Rules of the NTC (National Transport Commission) of Australia
11. Report on defined key performance indicators (KPI) of Sergio Barbarino. EU Transformers, 31-08-2014.

8 Acknowledgement

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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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9 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 data sources 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 authorization 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.
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.

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 cannot 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 of selected 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 performed 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.

10 Appendix B – Vehicle specifications

This Appendix contains detailed specifications of the tractors, rigid trucks, trailer and dollies used in the WP6 testing phase. The connection of the specific vehicle units and the AEROFLEX WP6 test vehicles are given, such that the reader can connect each unit to a particular test vehicle lay-out.

Name	MAN tractor TGX 18.500 4x2 XLX	SCANIA tractor R 500 A4x2NA CR20N	MAN truck TGX 26.580 6x2-2 LL L21XSL35 XLX	SCANIA truck R 650 B6x2*4NB CR20N	Guillen Semi-trailer curtain sider	Schmitz Cargobull Semi-trailer box	Schmitz Cargobull Semi-trailer TF-SCB	Van Eck Group Semi-trailer TF-VEG	Schmitz Cargobull Conventional dolly	Van Eck Group E-dolly
0. MAN zero-case	X				X					
1. MAN EMS1 reference			X		X				X	
2. SCANIA EMS1 reference				X		X			X	
3. Advanced reference AEMPT	X						X			
4. Advanced reference AeroLoad		X						X		
5. AEMPT+ EMS1			X		X					X
6. AEMPT++ EMS1			X				X			X
7. AEMPT++ EMS2	X						X	X		X
8. AeroLoad EMS1				X				X	X	

Table 55. Overview of test vehicle units and its application for the different test vehicle configurations

10.1 Pulling units: tractor/truck

The test matrix requires 2 tractor units and additionally a third tractor is required as control vehicle for the fuel consumption tests:

1. MAN tractor TGX 18.500 4x2 XLX

2. SCANIA tractor R 500 4x2 CR20N

[

3. SCANIA tractor R450 4x2 CR20H [CONTROL VEHICLE]

From the test matrix, 2 different rigid truck units are applied of which both are upgraded and used for the AEROFLEX EMS1 demonstrator vehicles:

1. MAN truck TGX 26.580 6x2-2 LL L21XSL35 XLX

2. SCANIA truck R 650 B6x2*4NB CR20N

Note: this picture is a reconstructed visualization of the ordered truck, which might deviate a bit with the actual vehicle which has to be produced at the time of writing. The truck will be equipped with a box bodywork.

Table 56. Overview of tractor specifications

	1: TV_MAN_Tractor	2: TV_SCA_Tractor	3: CV_SCA_Tractor	4: TV_MAN_truck	5: TV_SCA_truck
Used in what vehicle configuration	MAN zero-case (0) MAN baseline MAN Adv. Ref. (3) MAN EMS2 AEMPT++ (7)	SCA baseline SCA Adv. Ref. (4)	Control vehicle	MAN EMS1 ref. (1) MAN AEMPT+ EMS1 (5) MAN AEMPT++ EMS2 (6)	SCA EMS1 ref. (2) SCA AeroLoad EMS1 (8)
Reference name	MAN TGX 18.500 4x2 XLX	SCANIA R 500 A4x2NB CR20N	SCANIA R 450 A4x2NA CR20H	MAN TGX 26.580 6x2-2 LL L21XSL35 XLX	SCANIA R 650 B6x2*4NB CR20N
Manufacturer	MAN	SCANIA	SCANIA	MAN	MAN
Model	TGX500	R-Line 500	R-Line 450	TGX580	R-Line 650
Emission compliance	EURO VI	EURO VI	EURO VI	EURO VI	EURO VI
Date of first admission and VIN	23.02.2017 WMA05XZZ6HM737075	21.03.2018 YS2R4X20002147024	30.11.2017 YS2R4X20002142014	~2018 WMA21XZZ7JM797439	~05.2019
Axis configuration	4x2	4x2	4x2	6x2-2	6x2-2
Fuel tank capacity	490+490 L	400+600 L	500+700 L	590+590 L	600+600 L
Diesel Emission Fluid tank capacity	60 L	80 L	105 L	80 L	105 L
Weights and dimensions					
• Gross Vehicle Weight [kg]	18,000	19,000	19,000	26,000	26,000
• Net Vehicle Weight [kg]	7,540	8,750	8,750	unknown	unknown
• Towing weight [kg]	44,000	44,000	44,000	40,000	74,000 (techn.)
• Max. front axle load [kg]	7,500	8,000	7,500	8,000	7,500
• Max. rear axle load [kg]	11,500	11,500	11,500	11,500	11,500
• Max. trailing axle [kg]	NA	NA	NA	7,500	7,500
• Wheel base [mm]	3600	3600	3750	4800	4750
• Distance rear axles [mm]	NA	NA	NA	1350	1350
• 5th wheel height to ground [mm]	1146	~1140	~1140	NA	NA
Aerodynamics					
• Sun visor	No	No	Yes	Yes	No
• Hood mirrors	Yes	Yes	Yes	Yes	Yes

• Cabin type	XLX	CR20N	CR20H	XLX	CR20N
• Cabin height above ground [mm]	3529/3470	~3600	~3600	-	-
• Cabin width [mm]	2440	2490	2490	2240	
• Adjustable roof spoiler	Yes	Yes	Yes	Yes	Yes
• Side air deflector	Yes	Yes	Yes	Yes	Yes
• Side skirts	Yes	Yes	Yes	Yes	Yes
Powertrain label information					
• Engine type	D2676LF51	DC13 155/500hp	DC13 148/450hp	D3876LF07	DC16 118/650hp
• Engine SW version	-	-	-	-	-
• Aftertreatment SW version	-	-	-	-	-
• Engine rated power [kW] @ (x-y [rpm])	367 kW@ (1800)	368 kW @ (1900)	331 @(1900)	427 @(1800)	478 @(1900)
• Engine rated torque [Nm] @ (x-y [rpm])	2500 @ (930-1350)	2550 @(1000-1300)	2350 @(1000-1300)	2900 @(930-1400)	3300 @ (950-1350)
• Number of cylinders	6 In-line	6 In-line	6 In-line	6 In-line	8, V
• Gearbox type	TipMatic 12 speed automated	GRS905R, 12 speed automated	GRS905R, 12 speed automated	TipMatic 12 29 DD	GRSO925R, 12 speed automated
• Gear box ratios	15.86, 12.33, 9.57, 7.44, 5.87, 4.57, 3.47, 2.70, 2.10, 1.63, 1.29, 1 (R 14.68)	11.32, 9.164, 7.194, 5.823, 4.632, 3.75, 3.019, 2.444, 1.918, 1.553, 1.235	Crawler: L:16.41, H:13.28 11.32, 9.16, 7.19, 5.82, 4.63, 3.75, 3.02, 2.44, 1.92, 1.55, 1.24, 1 (R 14.77)	16.69, 12.92, 9.93, 7.69, 5.89, 4.57, 3.66, 2.83, 2.17, 1.68, 1.29, 1	Crawler L:13.28, H:10.63 9.16, 7.33, 5.82, 4.66, 3.75, 3.00, 2.44, 1.96, 1.55, 1.24, 1.00, 0.80 (R 11.95)
• Final drive ratio	2.53	2.59	2.59	2.71	3.07
• Engine brake	EVBec	with	Exhaust brake	EVBec	without
• Retarder	without	R4100D	R4100D	Retarder 35	R4100D
Other vehicle features					
• Predictive cruise control	Yes	Yes	Yes	Yes	Yes
• Eco roll	Yes	Yes	Yes	Yes	Yes
Odometer reading at start [km]	5900	unknown	50000	6500	unknown

10.2 Trailer

From the test matrix, 3 different trailers are applied:

1. Conventional semi-trailer curtain-sider

2. Conventional semi-trailer box (test vehicle unit)

3. Conventional semi-trailer box (control vehicle unit)

4. Transformers SCB trailer

5. Transformers VEG trailer

The detailed specifications as used in the testing phase are given in **Error! Reference source not found.**.

Table 57. Overview of trailer specifications

	1: TV_Semi-trailer_curtain	2: TV_Semi-trailer_box	3: CV_Semi-trailer_box	2: TF-SCB semi-trailer	3: TF-VEG semi-trailer
Used in what vehicle configuration	MAN zero-case (0) MAN baseline MAN EMS1 Ref. (1) MAN AEMPT+ EMS1 (5)	SCA baseline SCA EMS1 Ref. (2)	Control vehicle	MAN Adv. ref. (3) MAN AEMPT+ EMS1 (5) MAN AEMPT++ EMS2 (6)	SCA Adv. ref. (4) SCA AeroLoad EMS1 (8)
Reference name	Guillen curtain sider semi-trailer	SCB TV box semi-trailer	SCB CV box semi-trailer	TF-SCB semi-trailer	TV-VEG semi-trailer
Manufacturer	Guillen-group	Schmitz Cargo Bull	Schmitz Cargo Bull	Schmitz Cargo Bull	Van Eck
Trailer date of first admission and VIN	03-01-2014 VWFSP3SNRSD004994	11-08-2005 WSM00000005007862	07-03-2016 WSM0000005158483	12-09-2016 WSM00000003217078	05-04-2017 XRHG12275H0000330
Model	Guillen GSRE3	Schmitz Cargobull S.KO 24/L – 13.62 FP 25-EXPRESS	Schmitz Cargobull S.KO 24/L – 13.62 FP 25-EXPRESS	Semi-trailer prototype	Semi-trailer prototype
Weights and dimensions					
• **Gross Vehicle Weight [kg]**	41,000	39,000	39,000	36,000	27,000
• **Tare Weight [kg]**	6,500	7,613	7,613	8,300	10,000 (estimated)
• **Payload [kg]**	27,000	32,018	32,018	24,000	27,000
• **King pin load [kg]**	Unknown	15,000	15,000	12,000	12,000
• **Axles**	3x9,000 kg	3x9,000 kg	3x9,000 kg	3x9,000 kg	
• **Axle spacing [mm]**	1,310/1,310	1,310/1,310	1,310/1,310	1,300/980	1,310/1,310
• **Wheel base [mm]**	~6,500	7,700	7,700	7,700	7,600
• **Tyres***	385/65R22.5	385/65R22.5	385/65R22.5	385/65R22.5	385/65R22.5
• **Overall width [mm]**	2,550	2,550	2,550	2,550	2,550
• **Overall length [mm]**	13,630	13,625	13,625	13,620 (excl boat tail)	13,789 (excl boat tail)
• **Overall height front at normal ride height [mm]**	~4,000	3,993	3,935	3,990	4,000
• **Overall height rear at normal ride height [mm]**	~4,000	3,993	3,395	3,955	4,000
• **Towing capabilities**	NA	NA	NA	NOT POSSIBLE	Yes, coupling will be mounted for EMS2
Aerodynamics					
• **Trailer fairing devices**	No	No	No	No	No

• **Front fairings**	No	No	No	Yes (bulkhead cover)	Yes (bulkhead cover)
• **Underbody fairings**	No	No	No	No	Yes
• **Rear fairings**	No	No	No	Boat tail	Boat tail
• **Movable roof**	No	No	No	Yes (front, rear)	Yes (4 segments)
Electric drivetrain					
• **EMG type**	NA	NA	NA	unknown	NA
• **EMG rated power [kW] @ (x-y [rpm])**	NA	NA	NA	105 (@360V)	NA
• **EMG rated torque [Nm] @ (x-y [rpm])**	NA	NA	NA	250	NA
• **Battery type**	NA	NA	NA	unknown	NA
• **Battery capacity [kWh]**	NA	NA	NA	23	NA
• **Nominal voltage [V]**	NA	NA	NA	216.9-402.5	NA
• **Plug-in**	NA	NA	NA	Yes, only for testing purposes	NA
• **Overall gear ratio**	NA	NA	NA	11.72	NA

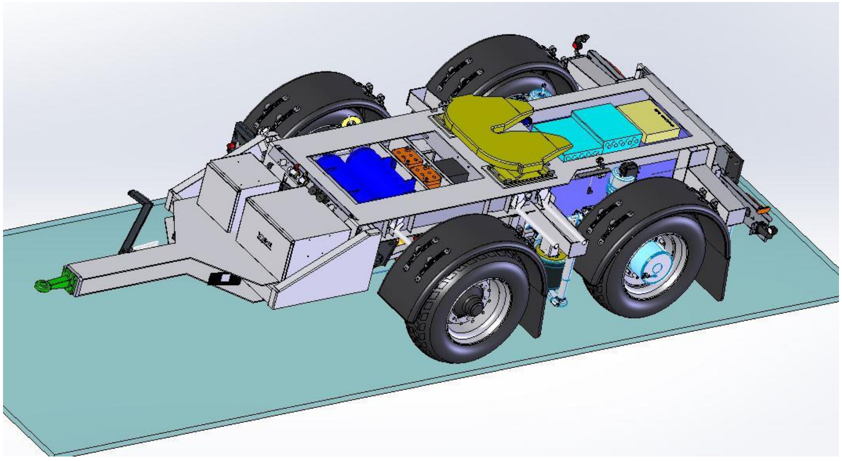
10.3 Dolly

In the test matrix, in principle 3 different dollies are applied. However, it turned out that due to several reasons the WP3 AeroLoad dolly will not me made retractable, resulting in the use of a single dolly as conventional and WP3 AeroLoad dolly. Besides that, the WP2 E-dolly will be developed as second dolly in the test matrix. Since this dolly is currently being developed, technical details at this stage are limited.

1. Schmitsch Cargobull Dolly DO 18/L-2"

This dolly is used for as conventional dolly in the reference vehicles and as WP3 AeroLoad demonstrator dolly

2. VEG E-dolly



Dolly is under development, so the picture given is indicative

The detailed specifications as used in the testing phase are given in **Error! Reference source not found.**

	1: conventional/WP3 dolly	2: E-dolly
Used in what vehicle configuration	MAN EMS1 ref (1) SCA EMS1 ref (2) AeroLoad EMS1 (8)	MAN AEMPT+ EMS1 (5) MAN AEMPT++ EMS1 (6) MAN AEMPT++ EMS2 (7)
Reference name	Schmitz Cargobull Dolly DO 18/L-2"	Van Eck Group E-dolly
Manufacturer	Schmitz Cargobull	Van Eck Group
Type	DO 18/L-2"	E-dolly
Weights and dimensions		
• Trailer load [kg]	16,000	unknown
• Gross Vehicle Weight [kg]	16,000	unknown
• Net Vehicle Weight [kg]	2,501	unknown
Axles	2 axles, non-steered	2 axles, steered 1st axle, electrically driven 2nd axle
Axle spacing [mm]	1,360	~
Coupling length [mm]	3230-3830	unknown
Tyres	385/55R22.5	275/70R22.5
Overall width [mm]	2,550	unknown
Overall length [mm]	5,110	unknown
Coupling height [mm]	650 (700)	unknown
5th wheel height [mm]	1100 (1150)	unknown
Steering axle	NA	unknown
E-axle type	NA	ZF AVE130
Max. Axle load [kg]	NA	13,000
Axle weight [kg]	NA	1,220
Max. output torque [Nm	NA	2x 11,000
Overall gear ration [-]	NA	17.8
Max. wheel speed [rpm]	NA	485
EMG type	NA	2x A-synchronous
EMG rated power [kW] @ (x-y [rpm])	NA	2x 125kW (peak), 2x87kW (30 min), 2x60kW (cont.)
EMG rated torque [Nm] @ (x-y [rpm])	NA	
Battery type	NA	Unknown
Battery capacity [kWh]	NA	46-80
Nominal voltage [V]	NA	600
Energy density [Wh/kg]	NA	unknown
Power density [kW/kg]	NA	unknown
Battery pack weight [kg]	NA	unknown
Number of modules	NA	unknown
Plug-in	NA	No

Table 58. Overview of dolly specifications

11 Appendix C – FALCON payload conversions

In the FALCON project, average payloads are investigated for EU countries and the EU average. The EU average cargo densities is specified as 156.3 kg/m^3 supplemented with 20% for safety resulting in 187 kg/m^3. This safety factor was introduced for vehicle dynamic evaluations and is also applied in the AEROFLEX project, although it unnecessarily increases the transport efficiency.

The second payload used in the FALCON project is what is called the critical cargo load and equals 280 kg/m^3. This payload complies with the highest payload not exceeding the axle and GVW loads.

For both cargo densities, the values are calculated towards the AEROFLEX situations, meaning a semi-trailer of length 13.6m and swap or rigid body of length 7.825m. The 13.6m semi-trailer has an internal volume of 87m$^{3.}$ Using this volume gives us the information required:

- Density 187 kg/m^3:
  - 13.6m semi-trailers: 187 kg/m^3 * 87 m3 = 16,269 kg
  - 7.825m swap body: 187 kg/m^3 / 87 m3 * 7.825 m / 13.6 m = 9,361 kg
- Density 280 kg/m3:
  - 13.6m semi-trailers: 280 kg/m^3 * 87 m3 = 24,360 kg
  - 7.825m swap body: 280 kg/m^3 * 87 m3 * 7.825 / 13.6 = 14,016 kg

Note: it is assumed that the internal width and height of the rigid/swap body is equal to the semi-trailer to determine its payload.

	Cargo density: 187 kg/m^3	Cargo density: 280 kg/m^3
Tractor/semi-trailer	16,269 kg	24,360 kg
EMS1	25,630 kg (9,361 kg + 16,269 kg)	38,376 kg (14,016 kg + 24,360 kg)
EMS2	32,538 kg (2x16,269 kg)	48,720 kg (2x24,360 kg)