TRANSFORMERS

FINAL PUBLISHABLE SUMMARY REPORT

DELIVERABLE N^0:	**-**
DISSEMINATION LEVEL:	**PUBLIC**
TITLE:	**FINAL PUBLISHABLE SUMMARY REPORT**
DATE:	**31/10/2017**
VERSION:	**FINAL**
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GRANT AGREEMENT N^0:	**605170**
PROJECT TYPE:	**THEME 7 TRANSPORT – SST GC.SST.2012.1-5: INTEGRATION AND OPTIMISATION OF RANGE EXTENDERS ON ELECTRIC VEHICLES**
PROJECT ACRONYM:	**TRANSFORMERS**
PROJECT TITLE:	**CONFIGURABLE AND ADAPTABLE TRUCKS AND TRAILERS FOR OPTIMAL TRANSPORT EFFICIENCY**
PROJECT START DATE:	**01/09/2013**
PROJECT WEBSITE:	**WWW.TRANSFORMERS-PROJECT.EU**
COORDINATION:	**VOLVO (SE)**
PROJECT MANAGEMENT:	**UNIRESEARCH (NL)**

Executive summary

TRANSFORMERS developed and demonstrated 2 highly innovative road tractor and semi-.trailer combinations, and achieved its goal of reducing energy use per tonne.kilometre of goods transported by up to 25% within the current EU regulatory framework. This was achieved by innovations including:

- Improved and mission adaptable loading efficiency measures,
- Mission adaptable whole vehicle aerodynamics,
- A distributed, trailer mounted electric driveline known as "hybrid-on-demand" for tractor and semitrailer combinations.
- The combination of innovations creates a transformable, mission adaptable semi-trailer combination which can be optimised to suit individual transport missions.

The report focuses on providing background to the project, an overview of the innovations developed within the project, and the main results and conclusions that were drawn from the wide range of work undertaken within the project. It covers both the "Energy Efficiency" and the "Load Optimisation" combinations which were developed and tested within the project.

TRANSFORMERS received co-funding from the European Commission.

Contents

1 Project Context and Objectives

1.1 Background & Introduction

Raw materials and finished goods can be transported from the manufacturing site to the distribution centre and onwards to the end consumer by air, rail, road or water-based transport services. However, the transport of goods by road accounts for 75% of the tonne-kilometres of freight transported within the European Union [1]. Road transport is particularly dominant in the distribution of finished products within the supply chain. Presently, road freight transport is to a very large extent dependent on diesel fuel. Some alternative fuels are available but their economic viability and market acceptance needs to be improved for them to have a significant impact.

In its 2011 Transport Policy White Paper [2], the European Commission indicated that road freight transport is expected to continue to play a predominant role in the multimodal freight transport network. The White Paper presented a CO_2 reduction target for the transport sector of 60% by 2050. Improving the energy performance of transport, including heavy duty vehicles was identified as one of the routes that could contribute to reaching this objective. The TRANSFORMERS project directly addressed this goal through topic GC.SST.2013-5 "Configurable and Adaptable Truck" of Call FP7-SST-2013-RTD-1 of the EC Seventh Framework Programme, that falls under the European Green Cars Initiative, under the RTD pillar "Research for Heavy Duty Vehicles for Medium and Long Distance Road Transport". TRANSFORMERS is a 13 partner European research project, which has received funding under the Seventh Framework Programme under Grant Agreement No. 605170.

Current semi-trailer combinations are very much a one size fits all solution, being optimised for a limited number of use cases and for maximum payload. At the same time there is an ever increasing need for transport efficiency to be optimised for each transport mission.

The TRANSFORMERS project successfully developed and demonstrated a range of innovations to improve transport efficiency within the road haulage industry. The project combines these innovations in semi-trailer combinations that are easily adaptable so that they can be optimised for each transport mission.

1.2 Key Facts

The TRANSFORMERS consortium comprises 13 partners (see Figure 1-1) from 6 European countries plus 2 international organisations, representing all sides of the road transport industry.

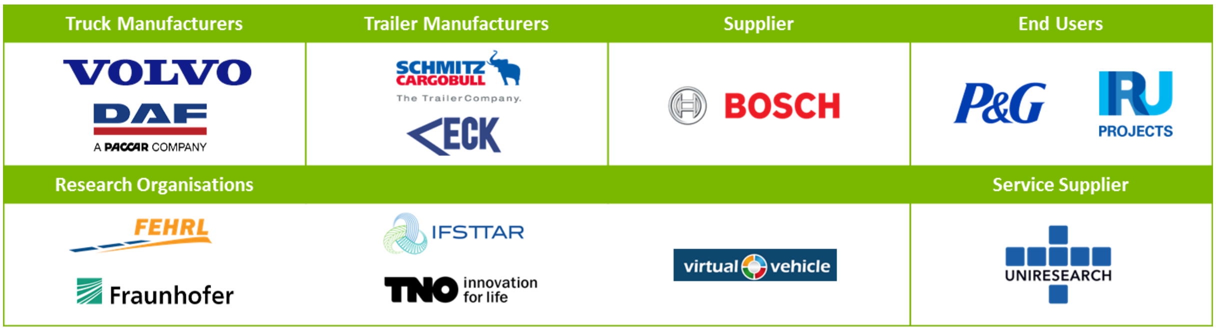


Figure 1-1: The TRANSFORMERS consortium

- Acronym: **TRANSFORMERS**
- Full name: **Configurable and Adaptable Trucks and Trailers for Optimal Transport Efficiency**
- Funding: EC FP7, Grant Agreement No. 605170
- Duration: 4 years
- End date: 31 August 2017
- Budget: €7.9M of which €5.2M EC funding
- Public website: http://www.transformers-project.eu/
- Contact: Paul Adams, paul.adams@volvo.com

The TRANSFORMERS project was divided into 8 closely integrated Work Packages:

- WP1 Use cases and requirements
- WP2 Holistic simulation
- WP3 Electric hybrid-on-demand framework
- WP4 Mission adaptable truck trailer architecture
- WP5 Infrastructure aspects and compliance, regulatory framework
- WP6 Demonstration, validation and evaluation
- WP7 Dissemination and exploitation
- WP8 Project management

The integration and cooperation between Work Packages was during the whole project excellent. The project structure and results are clearly visualised in Figure 1-2.

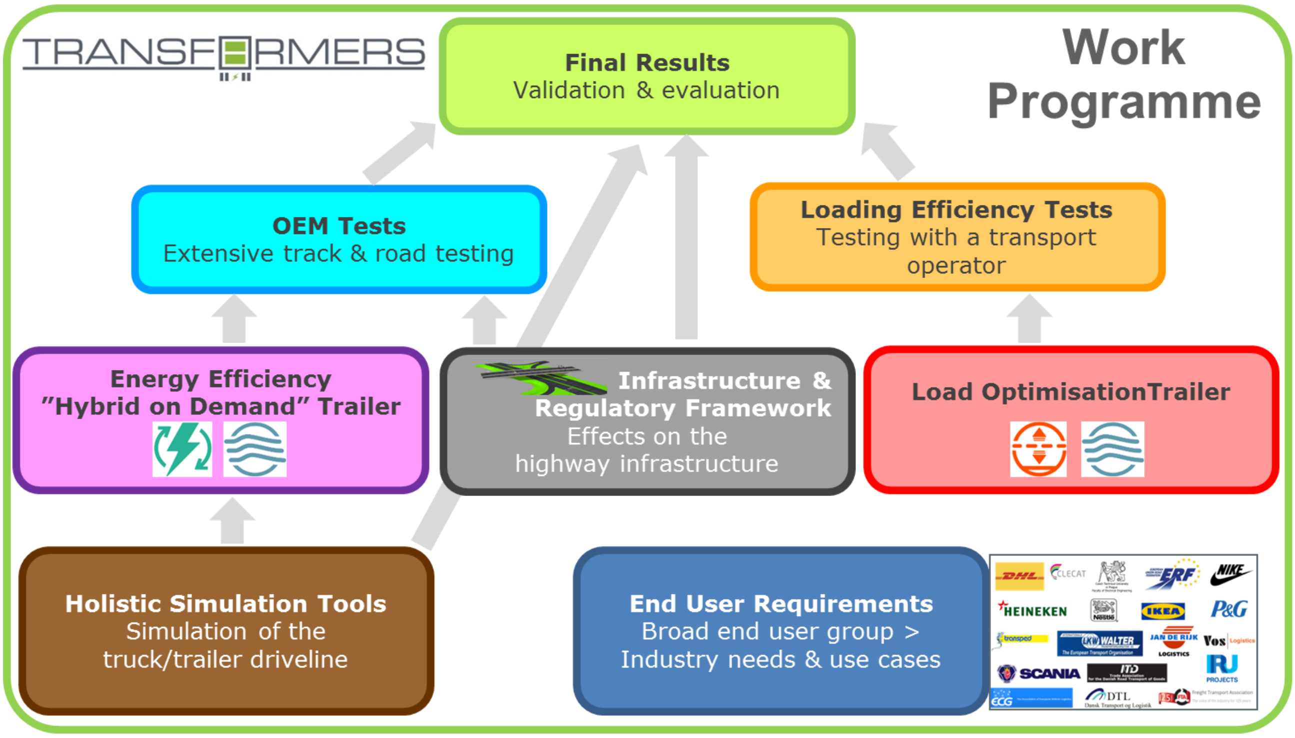


Figure 1-2: The TRANSFORMERS Work Programme

1.3 Scope & Target Markets

Comparison of distance classes, shipment types and goods shipped, along with a study of the inherent structure of the long distance road freight transport sector led to the development of the TRANSFORMERS innovations.

Looking at road freight transport statistics for Europe in 2015; road freight transport accounted for 75.8% of the total EU-28 tonne-kilometres, while 84.6% of EU-28 road transport was by vehicles with a maximum permissible laden weight over 30 tonnes, and road tractors and semi-trailers carried 77.6% of the modal share of tonne-kilometres [3]. In 2012 there were approximately 1.5 million road tractors and 1.7 million semi-trailers in the EU-28 countries [4]. An articulated road tractor and semi-trailer combination consisting of a two-axle tractor and three-axle semi-trailer with one axle which can be lifted is one of the most common vehicle combinations used for intra-EU freight transport. In 2015, 42% of the goods shipped over all distances in the EU-28 were palletised [5], and 56% of the goods transported (tonne*kilometres) are over distances greater than 300 kilometres.

Based on European road freight transport statistics, TRANFORMERS focusses on road tractor and semi-trailer combinations transporting palletised goods on regional to long haul missions greater than 300km, where palletised goods dominate, see Figure 1-3.

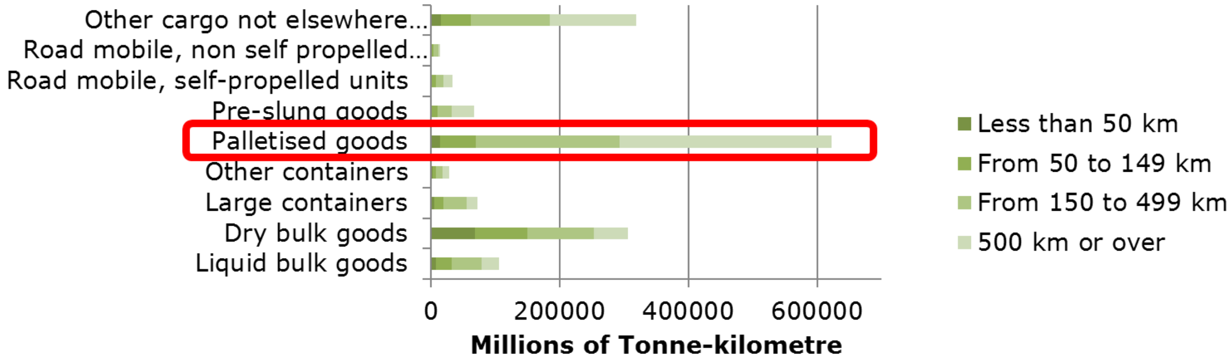


Figure 1-3: Road Freight Statistics

Fuel accounts for approximately one third of the total operating costs for road transport operators in the EU, see Figure 1-4. By reducing fuel consumption transport costs can be reduced, and results in reduced emissions which provides environmental benefits.

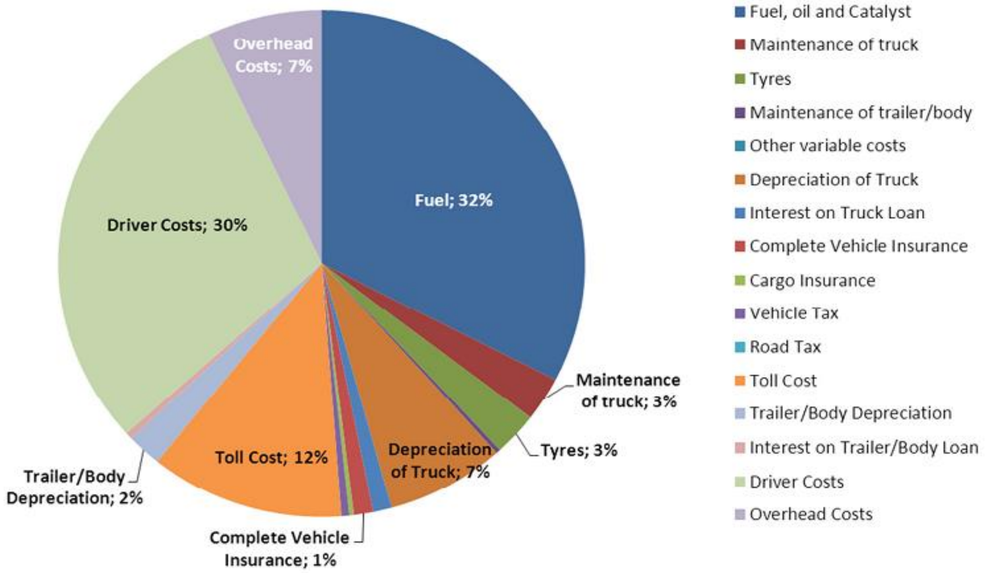


Figure 1-4: European Transport Cost Breakdown

TRANFORMERS targets reduced fuel consumption, in part through the distributed, trailer mounted Hybrid-on-Demand electric drivetrain. The aim of the drivetrain is to recuperate energy during braking, either due to the need to avoid over speed due to the topography of the particular route (hills) or the need to brake frequently in heavy traffic. The recuperated energy is then used to provide supplementary power to the conventional drive train when needed.

The standard cross-border European road tractor and semi-trailer combination has a Gross Combination Weight of 40 tonnes, and the average empty weight of such a combination running on diesel is 14 tonnes. Within the restrictions on vehicle dimensions, e.g. maximum combination length of 16.5m, the payload is limited to approximately 26t or 85 to 90m^3 of volume. The weight and volume dimensions equates to an ideal commodity density of approximately 300kg/m^3. As can be seen in the Figure 1-5, commodities with the ideal density are relatively few. In the case of heavy materials such as liquids or construction materials, the transport is typically weight limited and the volume is underutilised. For lighter commodities such as white goods or mixed parcels, the transport is volume limited and the weight capacity is underutilised. TRANSFORMERS improves overall transport efficiency in two ways by looking at the weight and volume limited assignments separately. For volume limited assignments TRANSFORMERS explores increasing the load capacity within current weights and dimensions regulations. Reduced fuel consumption can also be achieved by improved aerodynamics. In this respect TRANSFORMERS looks at the complete vehicle, but in relation to transport assignments which are weight limited, or for other reasons do not operate at maximum volume. If the full volume is not needed it is not necessary to pull a partly empty 4m high vehicle through the air, and instead TRANSFORMERS investigates the possibility to change the shape of the vehicle in relation to the loading characteristics of the specific mission to improve the aerodynamic characteristics of the full vehicle.

EXAMPLE COMMODITIES	DENSITY (kg/m^3)
HEAVY	
Construction materials	700-790
Liquids	600-1000
IDEAL	
Beer crates with empty bottles	300
LIGHT	
Parcels	150
White goods, e.g. refrigerators	130
Plastic foam	40

Weight limited - Volume capacity under utilised

Perfect weight and volume utilisation

Volume limited - Weight capacity under utilised

Figure 1-5: Example Commodity Densities

TRANSFORMERS also explores the potential benefits of these innovations in the context of offering a mission adaptable solution, so that the complete vehicle can be reconfigured to the optimum configuration for each transport assignment.

1.4 Targets

The overall objective of the TRANSFORMERS project is to develop and demonstrate innovative, energy efficient and load optimised semi-trailer combinations for long haul transport missions. By looking at the tractor/ semi-trailer combination holistically to reduce overall fuel consumption while in parallel improving load efficiency, TRANSFORMERS targeted, and achieved, a 25% energy consumption reduction per tonne.km of goods transported in real world scenarios within the existing European regulatory framework. This reduction is targeted without affecting the road infrastructure. This is achieved through the following innovations, whose targets are illustrated in Figure 1-6:

- A semi-trailer mounted, distributed "Hybrid-on-Demand" (HoD) electric driveline.
- Mission-based, transformable whole vehicle aerodynamics.
- An internal trailer design offering increased load capacity.
- Mission adaptability to allow optimisation of the vehicle combination for each journey.

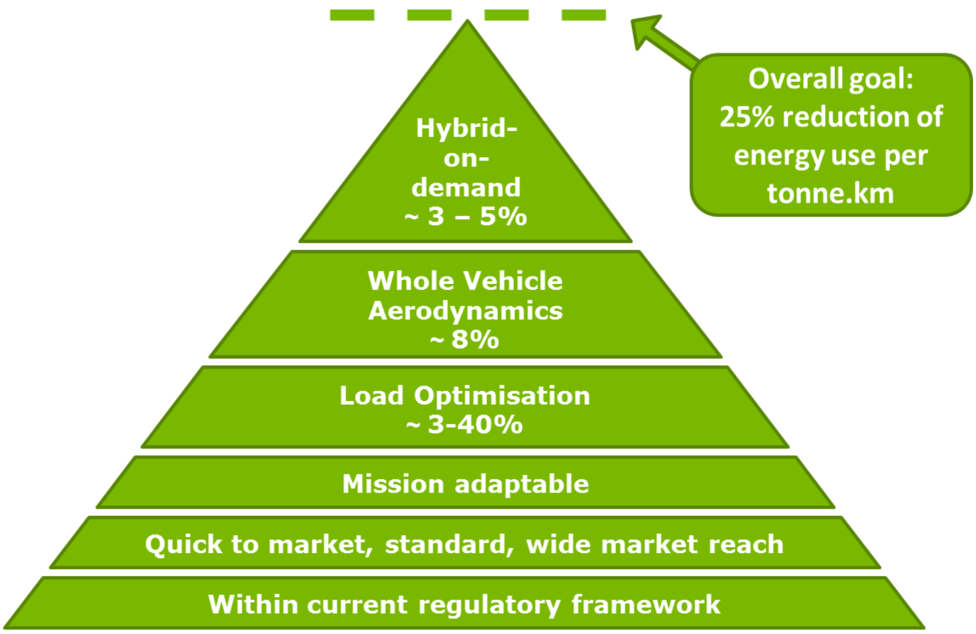


Figure 1-6: The TRANSFORMERS Targets

2 Main Scientific & Technical Results

2.1 End User Requirements & Use Cases

2.1.1 End User Requirements

In order to understand the needs, requirements, and the day to day challenges of the road transport industry, the project team engaged with all sides of the industry. This was achieved in part through the diverse range of project partners, but in particular through the establishment of a broad End User Group (EUG) representing all sides of the road transport industry in Europe (see Figure 2-1) which includes the vehicle industry, and transport service providers and transport buyers. This provided a good understanding of the different perspectives of the various actors, taking into account their role in the industry and scale of their operations. The EUG was in addition to a scientific Advisory Board.

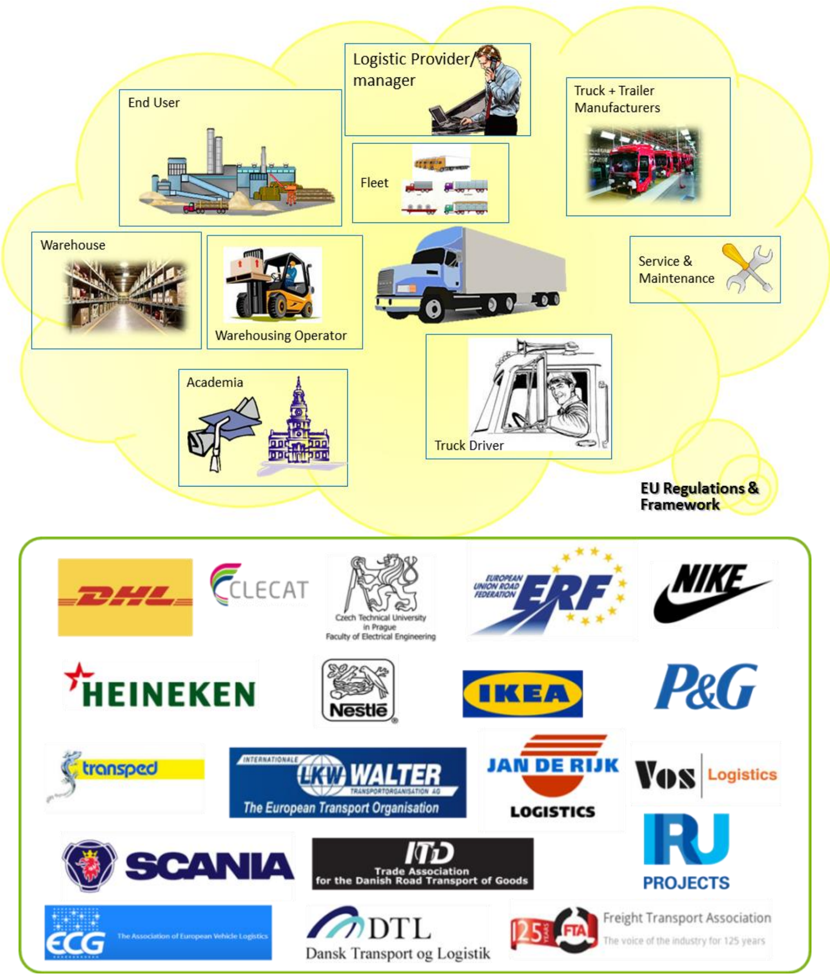


Figure 2-1: The TRANSFORMERS End User Group

An analysis of the European road freight transport market was undertaken to understand the interaction of a road tractor and semi-trailer configuration, and the needs of the key stakeholders involved. Its purpose was to identify end user requirements, and to prioritise those that should be considered in the development of the TRANSFORMERS demonstrators, see Deliverable 1.1. The work is partly based on the experience of Procter & Gamble's operations in Europe, the International Road Transport Union (IRU) and the TRANSFORMERS EUG. Input from the EUG was through workshops, telephone interviews, and online questionnaires.

The major performance evaluation areas are a broad set of parameters that the end users (shippers) consider are important for evaluating their transportation options, and the transport service providers consider are important for the success of their business in order to provide good, reliable service to their customers. The demand for goods transportation is a secondary demand, i.e. it arises primarily from the end customer, and the producer must evaluate factors such as loading and shipping time, cost, capacity, reliability, etc. to ensure that the end-customer is completely satisfied. From the standpoint of TRANSFORMERS, measurement of some of these parameters may not lie within the scope of the project, but developing a solution that enables road freight service providers to improve transport capacity for shippers at competitive cost and with a lower impact on the environment could lead to better acceptance of the innovations. A clear requirement is that the potential added values, primarily in terms of fuel economy, maintenance costs and emissions, must be greater than the total additional cost incurred for the new innovations, and must be measurable and comparable with existing vehicles.

The proposed solution should be able to deliver on four key areas:

- Environmental: Reduction in greenhouse gas emissions, noise nuisance, other local pollutants, energy usage, etc.
- Financial: Pricing and affordability, operational efficiency demonstrated by compliance with or exceeding key performance indicators, etc.
- Social: Accessibility in services, networks, rolling stock, infrastructure, capacity to adapt to demographic changes, etc.
- Logistics: Loading and unloading time, transport capacity, capacity utilisation, etc.

The end user requirements are summarised in Figure 2-2.

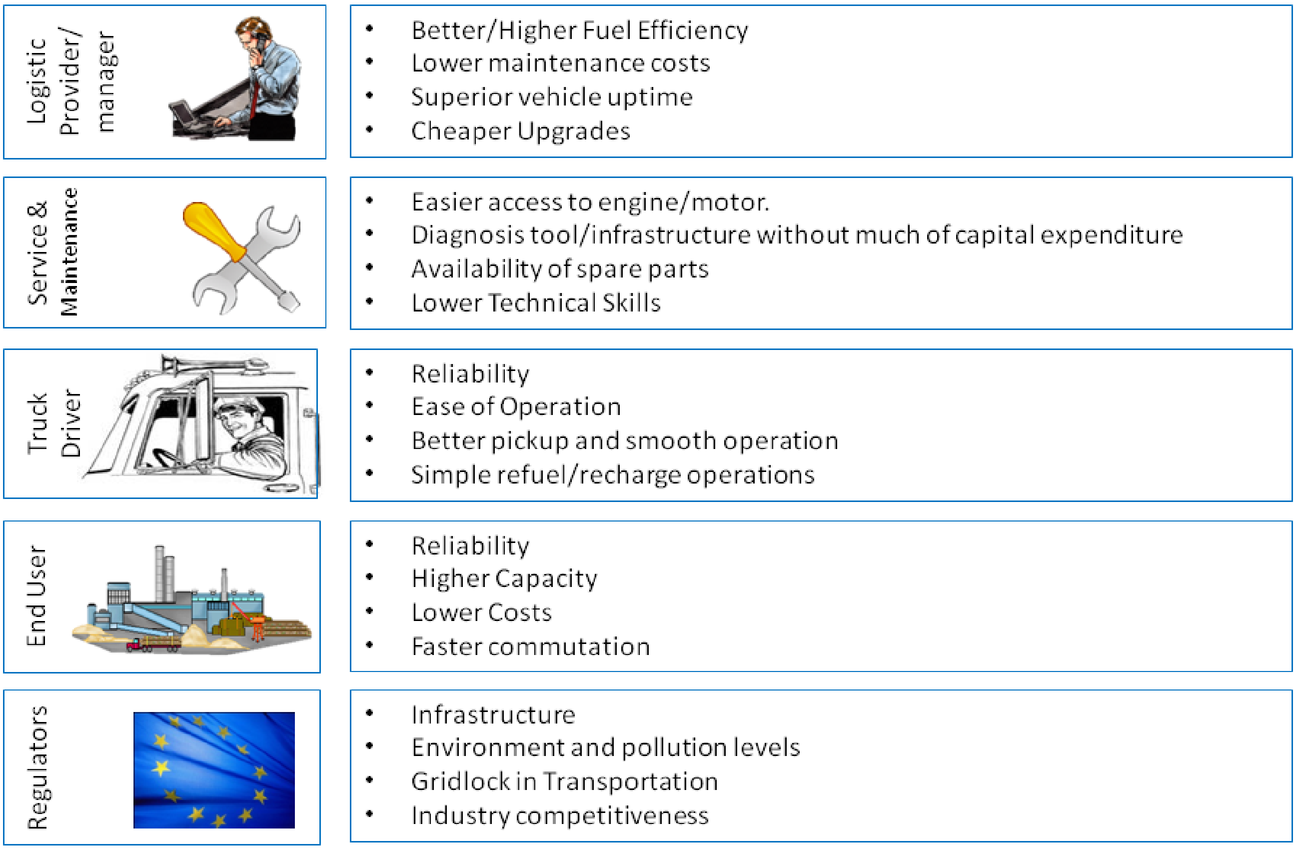


Figure 2-2: End Users Needs and Requirements

2.1.2 Key Performance Indicators

The EUG also supported identification of appropriate Key Productivity Indicators (KPI). The model used to identify KPIs is illustrated in Figure 2-3.

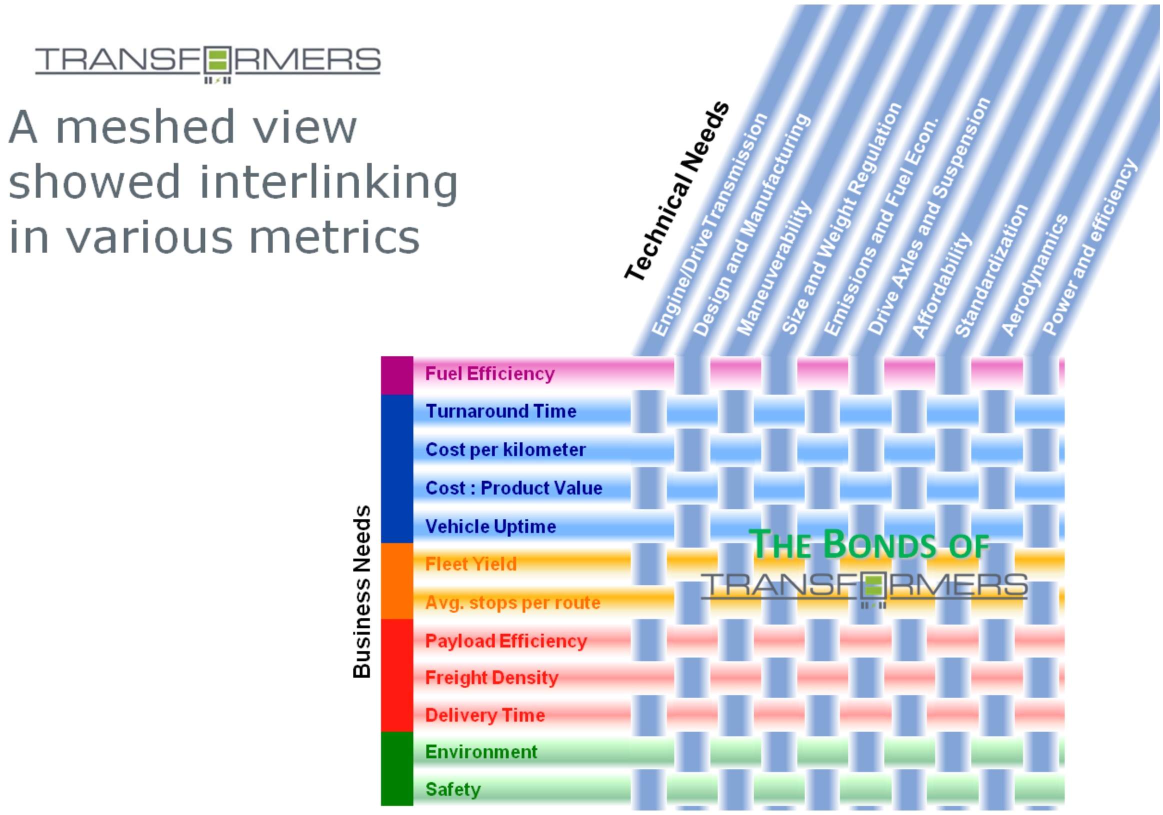


Figure 2-3: KPI Identification Model

Successful market acceptance of the TRANSFORMERS innovations is evaluated by comparing the performance against existing state-of-the-art tractor/semi-trailer combinations. The EUG allowed 'End User' KPIs to be established for different key performance areas, see Figure 2-4. Rather than evaluating the innovations from a purely technical standpoint, it is based on parameters that affect the road transport businesses which would operate these vehicles. The Key Performance Indicators are reported in Deliverable D1.2.

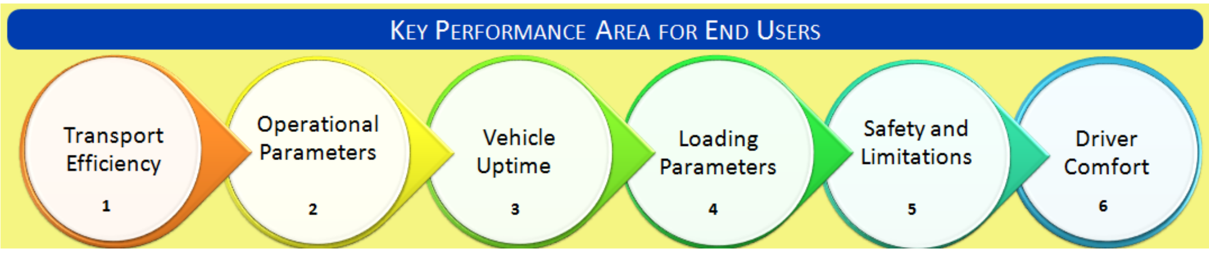


Figure 2-4: Key Performance Areas

It was evident that some of the parameters were qualitative and some difficult to measure within the scope of TRANSFORMERS due to limited time and technological maturity. Therefore it was decided to split the KPIs into those which will be measured during the project (more concrete measurement formulas). Others belong to a "soft" section and are mentioned as being relevant to end users in general, but will not be tested nor measured during the project.

The evaluation makes use of the Key Performance Indicators (KPIs) which were defined in WP1 and reported in Deliverable D1.2. These definitions were further elaborated for the test phase and resulted in a test plan (Deliverable D6.5).

2.1.3 Scenarios & Route Profiles

Possible routes and mission scenarios have been identified as the basis of the evaluation of the test results in WP6. Due to the limited scope for real world testing, one of the main indications of benefits delivered by the TRANSFORMERS innovations was obtained from simulations validated against limited test measurements. The main process for choosing the routes was consultation with members of the

International Road Transport Union (IRU Projects is a partner of TRANSFORMERS), which are representatives of national hauliers from Europe and beyond. The wide agreement amongst national representatives of road haulier companies is that there is no "typical" environment for delivery of goods by road in Europe, and that it is essential to investigate how project solutions can reduce fuel consumption in different environments. Therefore, the following driving "environments" have been selected which were then matched with routes for which data such as heavy goods vehicle speed profiles were available:

- Motorway driving - flat surface (Scenario S1)
- Motorway driving - mixed environments (Scenario S2)
- Route with frequent elevation changes (Scenario S3)
- Steep hills (Scenario S4)
- Urban driving (Scenario S5)

Detailed explanations of the scenarios and selection of the evaluation routes are provided in Deliverables D1.3 and D1.6. Following the selection of routes in D1.3 and D1.6 based on the input from haulier representatives, the expectation was, already from the definition stage, that some of them might change, e.g. because of data availability. From the road hauler representatives' point of view, this was not a problem as long as the final routes used in the simulation have similar characteristics to the ones initially proposed. An energy calculation was done for every route to make sure that the new routes can be compared to the previously defined routes. In order to increase the number of simulations and to reduce the time required to perform them, a representative part of the long routes was selected for scenarios S2, S3 and S4.

2.2 The TRANSFORMERS Innovations

TRANSFORMERS goal of a 25% energy consumption reduction per tonne.km of goods transported in real world scenarios was achieved through the following innovations (also see figure below):

- A semi-trailer mounted, distributed "Hybrid-on-Demand" (HoD) electric driveline
- Mission-based, transformable whole vehicle aerodynamics
- An internal trailer design offering increased load capacity
- Mission adaptability to allow optimisation of the vehicle combination for each journey

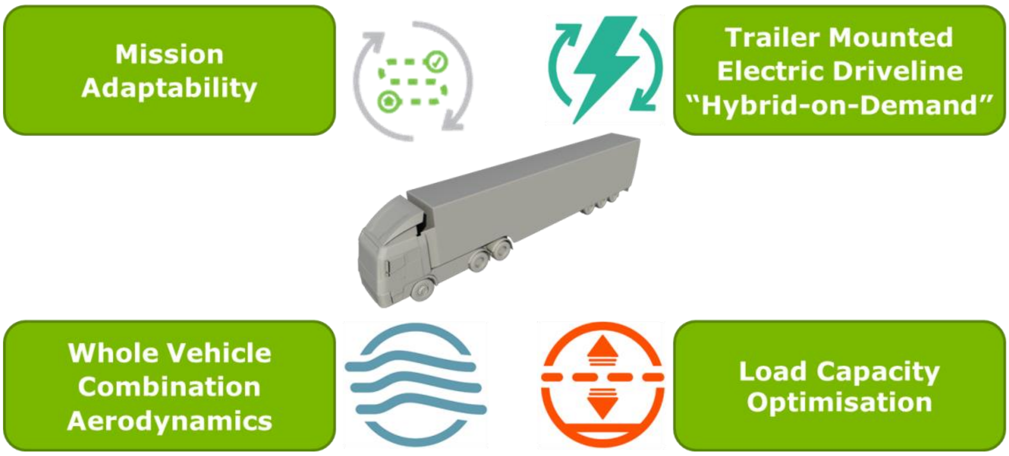


Figure 2-5: TRANSFORMERS Innovations

2.3 The TRANSFORMERS Demonstrators

TRANSFORMERS developed and demonstrated 2 tractor/ semi-trailer combinations:

- Energy Efficiency or "Hybrid-on-Demand" combination
- Load Optimisation combination

2.3.1 Energy Efficiency Combination

The Energy Efficiency combination is based on a curtain-sider trailer, targeting reduced fuel consumption and mission adaptability through 2 primary innovations: "Hybrid-on-Demand" and holistic whole vehicle aerodynamics, see Figure 2-6.

Figure 2-6: TRANSFORMERS Energy Efficiency Combination

2.3.2 Hybrid-on-Demand

A distributed, trailer mounted "Hybrid-on-Demand" (HoD) electric driveline, which is supplementary to the conventional diesel driveline on the road tractor. The HoD driveline is entirely mounted on the trailer, including battery pack, electric machine (EMG), transfer gearbox, drive axle and control system (see Figure 2-7, while more details can be found in Deliverable D3.4). Electric braking on the rear trailer axle is used to recuperate braking energy due to the route topography or heavy traffic. The electric braking is blended with the trailer service brakes to maximise recuperation, but is immediately disabled in the event of ABS or stability control intervention. The recuperated energy is then used to assist the conventional driveline by providing supplementary propulsion from the trailer when certain conditions are fulfilled.

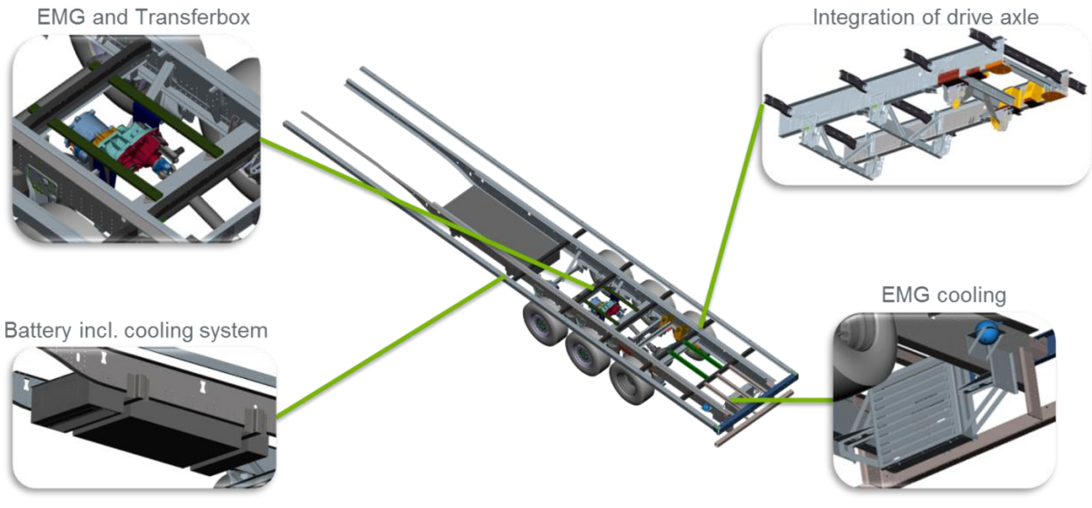


Figure 2-7: TRANSFORMERS Hybrid-on-Demand Driveline

Early in the project the need of a minimal communication between the tractor and trailer was identified. The system as implemented is based on uni-directional control with limited additional signals sent from the largely standard tractor to control the trailer driveline, and has been referred to as Case A within the project (see Figure 2-8). This simplicity is one of the keys behind the fast market potential of the TRANSFORMERS HoD concept. The Trailer Drivetrain Management System (TDMS) uses its internal Trailer Energy Management System (TEMS). The TDMS controls the functionality on the trailer and requests torque from the Electric Motor Generator (EMG).

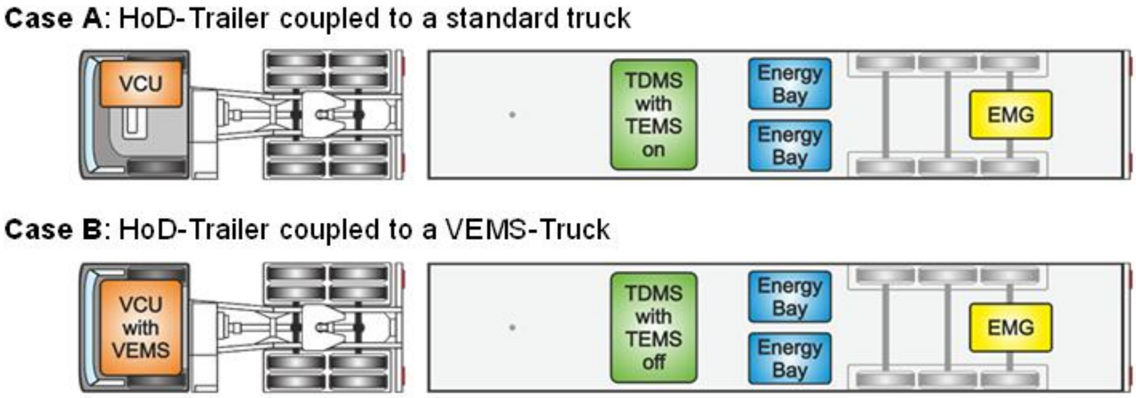


Figure 2-8: Hybrid-on-Demand Cases A (as demonstrated) and B

In the future, when tractors and especially hybridised tractors, may already include a Vehicle Management System (VEMS), a more advanced version referred to as Case B could be developed to optimise fuel savings potential. Case B would have bi-directional communication, i.e. a full vehicle energy management system (VEMS). If the trailer detects a VEMS equipped tractor, the TEMS is switched off and the trailer can be used as an electric propulsion and braking device by the truck. The detection is based on the presence or absence of messages from the tractor. Case B was beyond the scope of the TRANSFORMERS project. The Case B concept is more challenging, in part as different systems would have been necessary to cope with the different tractor electronic architectures.

A pre-standardisation tractor-trailer communication HoD “framework” document has been developed to enable market introduction and provide planning certainty for future research activities, and is described in Deliverable D3.2. With testing results now available, the next step is to gain industry consensus before presenting it to the standardisation bodies via national mirror groups (this process will be continued by the recently started AEROFLEX project).

The logical system architecture as defined in the HoD-Framework is depicted in Figure 2-9.

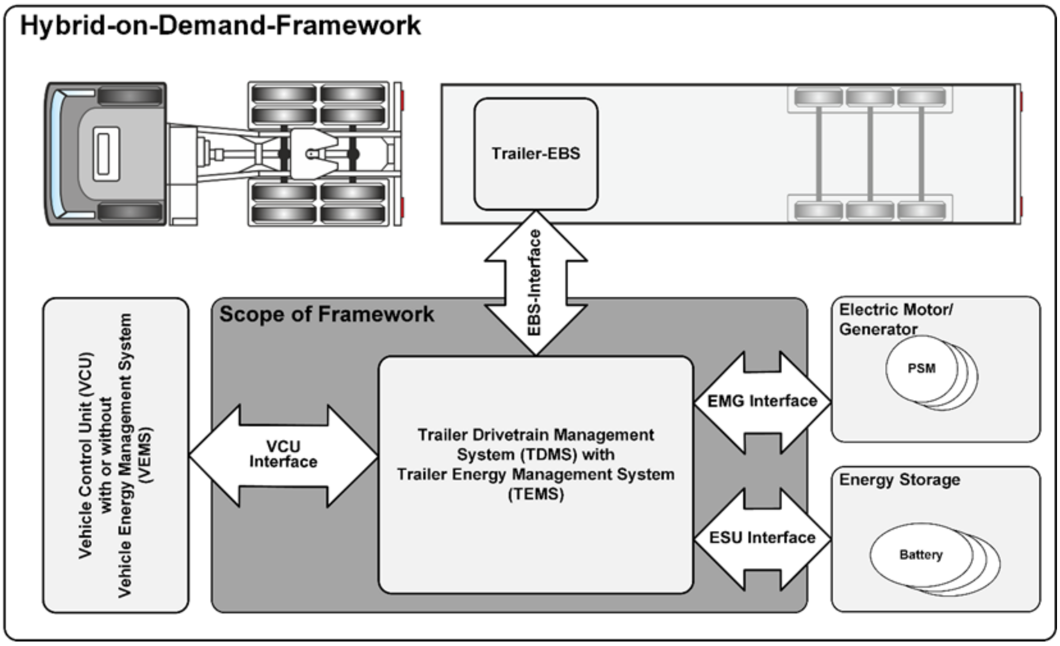


Figure 2-9: System Architecture of the HoD-Framework

Besides the basic functionality of the TDMS the HoD Framework defines the interfaces between the subsystems and the outside world:

- VCU-Interface: The communication interface between tractor and trailer for the HoD system.

- EBS-Interface: This interface to the electronic braking system on the trailer. It is important to ensure both safety and a brake blending functionality between service brakes and electric braking, see [6].
- EMG-Interface: This interface includes the communication between the TDMS and the EMG to control the EMG power flow as well as the electrical interface.
- ESU-Interface: This interface includes the communication between the TDMS and the Electrical Storage Unit (ESU) as well as the electrical interface. The framework is not limited to batteries.

2.3.2.1 Whole Vehicle Aerodynamics

The TRANFSFORMERS innovations take a holistic, mission adaptable view of the aerodynamics of the complete combination. The combination looks at transport assignments which are weight limited, or for other reasons do not utilise the full volume of the trailer. If the full volume is not needed for payload, the possibility to change the shape of the trailer to improve the aerodynamic characteristics of the complete vehicle is incorporated. The trailer features enhanced mission-based, transformable vehicle aerodynamics including curved front bulk head, side skirts, boat tail, and a single segment lowerable roof, see Figure 2-10. The roof can be moved into 4 alternative positions, see Figure 2-11, with the roof deflector on the tractor adjusted to suit. The roof position is set manually in the demonstrator. To complement the trailer aerodynamics, the tractors have adjustable roof deflectors to suit the trailer configuration. The various aerodynamic innovations provide a toolbox of solutions to reduce aerodynamic drag in comparison to today's solutions.

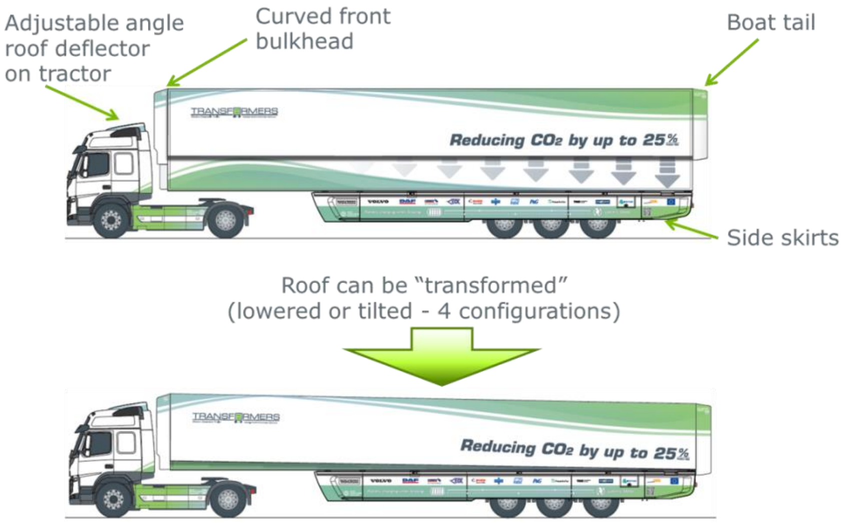


Figure 2-10: Energy Efficiency Combination Aerodynamic Measures

Figure 2-11: Energy Efficiency Combination Alternative Roof Positions

2.3.3 Load Optimisation Combination

The Load Optimisation Combination is based on a box trailer, targeting increased loading efficiency, reduced fuel consumption through holistic aerodynamics, and mission adaptability, see Figure 2-12 and Figure 2-13. In comparison to today's one size fits all semi-trailers, the various innovations introduced in the TRANSFORMERS Load Optimisation trailer provide a toolbox of solutions to improve load optimisation in conjunction with mission adaptability.

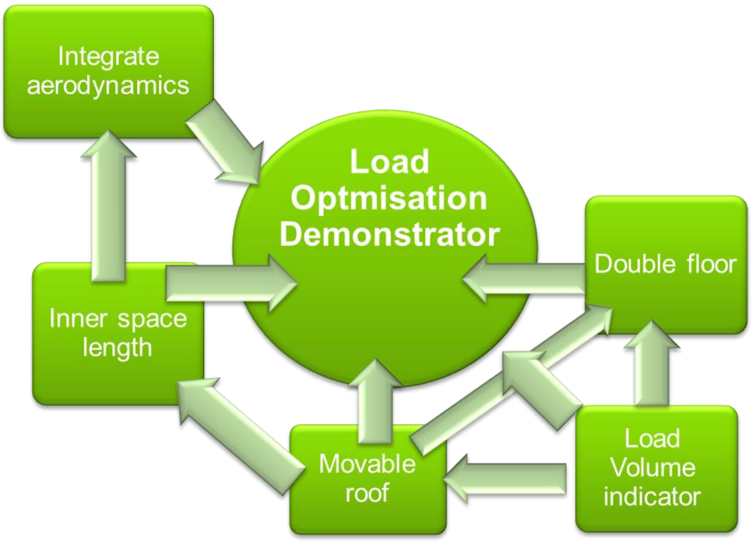


Figure 2-12: Load Optimisation Trailer Combination Features

Figure 2-13: Load Optimisation Trailer

The internal trailer design is optimised for volume limited assignments to increase the load capacity within current weights and dimensions regulations. This is achieved through increased inner floor length, and an innovative double floor system. Increased inner floor length is achieved by changes to the front bulkhead and addition of a collapsible docking plate support, see Figure 2-14.

a) Side view b) Plan view

Figure 2-14: Load Optimisation Trailer: Collapsible Docking Plate Support

An innovative multi-section, independently adjustable, double “flex floor” system was developed and demonstrated to focus on palletised goods that may be difficult to double stack, e.g. for the transport of mixed palletised goods, see Figure 2-15. The floors sections are simply lifted and locked at the desired height with the aid of a fork lift truck and a ratchet mechanism in the support columns. Adjoining sections can be set at different heights. When not in use the double floor system fits flat on the trailer floor and acts as a conventional trailer floor.

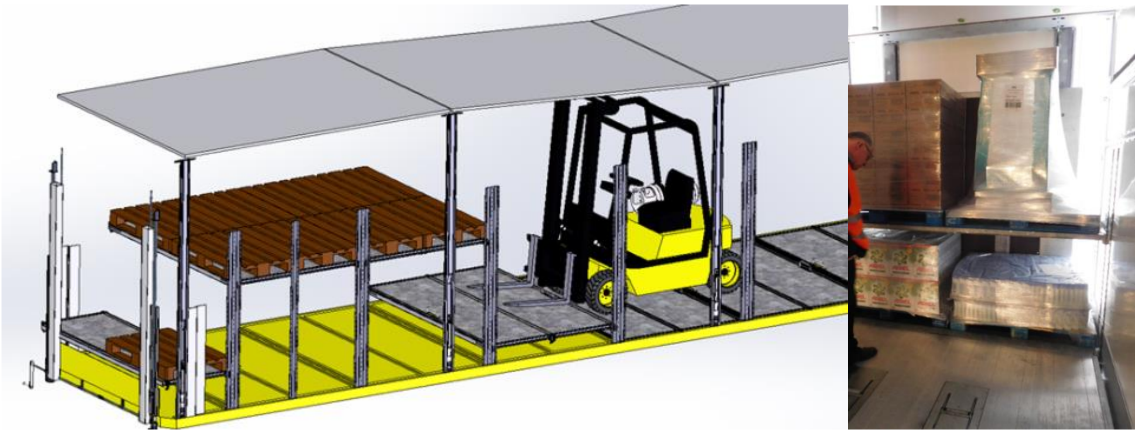


Figure 2-15: Load Optimisation Trailer: Flex Floor System

For transport missions that are weight limited, or for other reasons do not utilise the full volume of the trailer, the trailer features enhanced mission-based, transformable vehicle aerodynamics including side skirts, boat tail and a four segment lowerable roof which can be configured into a wide variety of shapes (two of which are seen in Figure 2-16). The roof adjustment system is electrically operated, and automatically controlled from a control panel at the side of the trailer close to the rear doors. In combination with the Load Volume Indicator (LVI) system described below, the roof system has the potential to be developed into a flexible toolbox solution. The LVI system could provide input to the roof control system which adjusts the roof to the optimum shape for the current loading conditions.

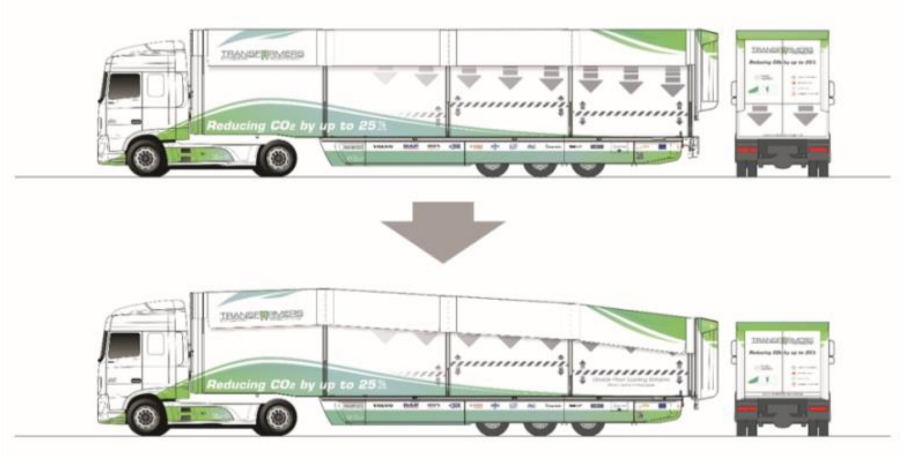


Figure 2-16: Load Optimisation Trailer: 4 Segment Moveable Roof

A Load Volume Indicator (LVI) system was integrated and demonstrated in the Load Optimisation trailer, see Figure 2-17. The objectives of the LVI system are to allow on-board load volume and pallet height detection at low cost, which could be utilised to configure the adjustable roof to the best aerodynamic position for the current load. While the LVI is integrated into 1 of the moveable roof sections and demonstrated, it is not linked to the moveable roof system. To enable the LVI a low cost ultrasonic sensor network was developed which is integrated into the trailer roof **to** measure pallet heights **and** calculate the load volume. For commercialisation a standardised communication architecture would be necessary.

Figure 2-17: Load Optimisation Trailer: Load Volume Indicator System

2.3.4 Demonstrators In Use

Both demonstrator combinations were tested in realistic environments (see Figure 2-18) more details of which are discussed in Section 2.6.

Figure 2-18: TRANSFORMERS Demonstrators On The Road

2.4 Impact On Highway Infrastructure

It is important to ensure the compatibility of new vehicle combinations and technologies with the highway infrastructure and to understand their impacts, especially with respect to the interaction of standards and regulations for both the infrastructure and vehicles, see Figure 2-19. TRANSFORMERS looked at the impact of the innovations on the existing highway infrastructure in comparison to conventional combinations and the combinations used in the infrastructure standards.

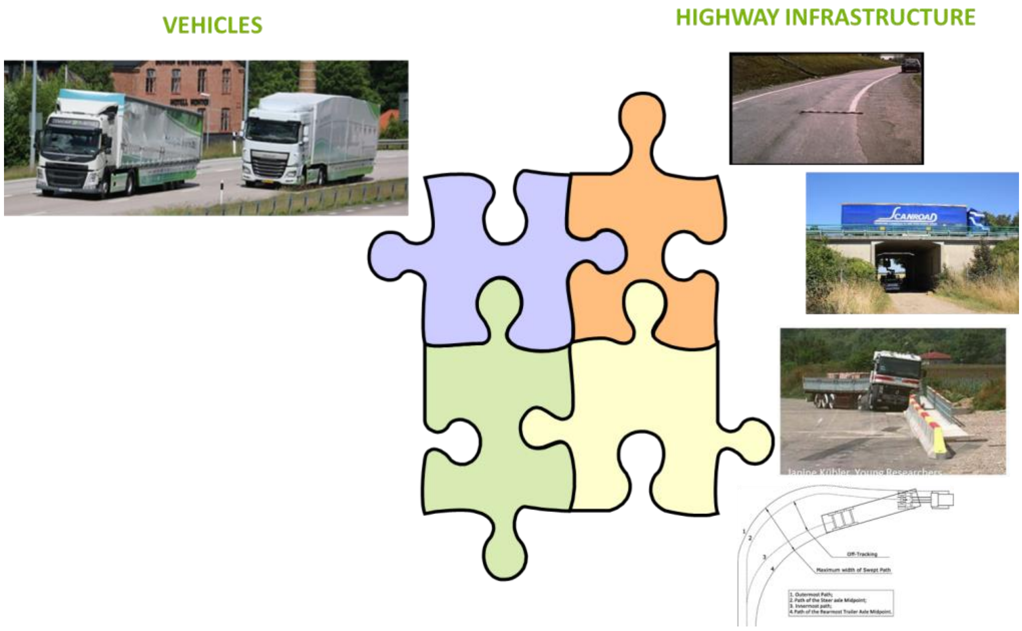


Figure 2-19: Compatibility of New Vehicle Combinations with Highway Infrastructure

The impacts on the highway infrastructure that were considered included pavement loading (see Deliverable D5.1), bridge loading (see Deliverable D5.2), impacts with safety barriers (see Deliverable D5.3, and [9]), and dynamic behaviour affecting highway geometry (see Deliverable D5.4).

Based on simulations and dynamic measurements taken on the test track, the TRANSFORMERS innovations were found to have a marginally higher effect than the conventional 40 tonne articulated vehicle. The TRANSFORMERS innovations had a lower impact than the 44 tonne articulated vehicle combination, allowed in several Member States countries for domestic transport, and for combined transport. The research on safety barriers has shown the necessity to limit the height of the centre of gravity of the payload. Three recommendations were made for amending Directive 96/53/EC on weight and dimensions as amended by Directive (EU) 2015/719, see Deliverable D5.5:

- The extra tonne allowance for "alternative fuels" should also be applied to articulated vehicle combinations.
- Directive (EU) 2015/719 should provide provisions on the height of the payload centre of gravity (impacts on safety barriers, dynamic behaviour of the truck) and on the longitudinal load distribution, i.e. the balance of axle loads (impact on pavements and on bridges). In this case, the guidance should be targeted at road freight transport operators and shippers on a general, systematic basis, and how compliance could be verified. This should be discussed with the relevant parties.
- Directive (EU) 2015/719 should include a bridge formula to ensure that the structural effect remains acceptable, adapted to the European bridge stock allowing the current combinations complying with the Directive 96/53/EC. However, such a formula should remain valid for many years and avoid future combinations inducing increased load effects in existing bridges, which are designed with a life of several decades. This approach already exists in the United States for Interstate traffic, and in several other countries (Canada, Mexico, Australia, South Africa, etc.). Such a formula limits the total mass distributed on a series of any consecutive axles, and therefore the gross combination weight, depending on the number of axles, their spacing or the distance from the first to the last one. This automatically limits the load effects, such as the mid-span bending moment on any bridge span. However, axle loads should NOT be increased.

If the European Directive is revised again introducing a maximum Gross Vehicle Weight (GVW) for 5 or 6 axle combinations above 40 tonnes, e.g. up to 44 tonnes, 1 tonne should be allocated to "alternative fuels", and only 3 tonnes for extra payload. If longer combinations such as the EMS are allowed for international transport, the same provision (1 tonne) should be made. Moreover, these combinations should comply with a bridge formula which guarantees that the impact remains acceptable for the existing bridge stock.

2.5 Evaluation Framework

In order to assess the project goal of a 25% reduction of energy use per tonne.kilometre, an evaluation framework was defined. The data sources and process steps in the evaluation framework are shown in Figure 2-20.

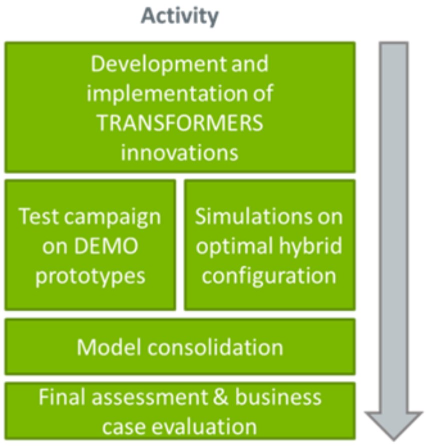


Figure 2-20: TRANSFORMERS Evaluation Framework

Due to the limited scope for real world testing, one of the main indications of benefits delivered by the TRANSFORMERS innovations was obtained from simulations validated against the test measurements. Different scenarios for the evaluation were identified with industry input as explained in Section 2.1.3. The evaluation steps include real world testing, high fidelity simulations, evaluation of the results, and assessment of the economic potential. While the fidelity of the results decreases from the test results, through high fidelity simulation output to evaluation model output, the numbers of configurations and scenarios that can be assessed increases significantly, see Figure 2-21. Based on the vehicle tests and high fidelity simulation results, a consolidated model was used for the final evaluation of the effectiveness of the TRANSFORMERS innovations under various influencing parameters such as road type, payload and traffic conditions. The improvement potential for selected transport missions has been compared to current heavy-duty vehicle technology used for similar assignments. The chosen assessment methods to evaluate the project were a trade-off between fidelity and number of applications/scenarios assessed. Full details and results are presented in Deliverable D6.4.

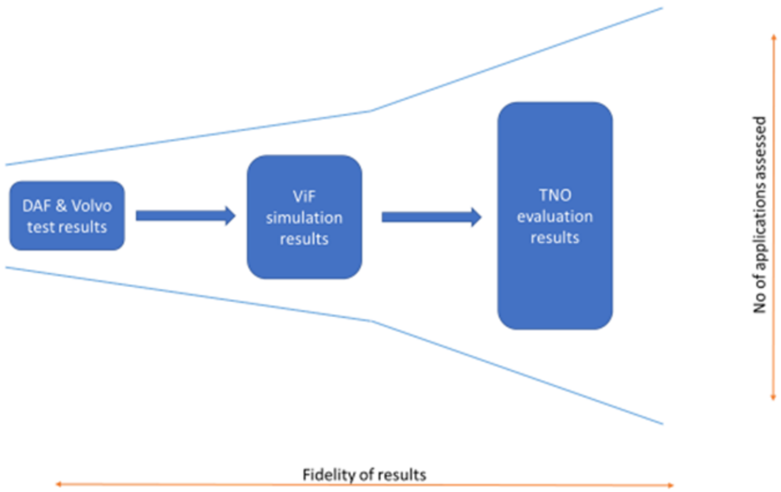


Figure 2-21: TRANSFORMERS Final Assessment Procedure

2.6 Test Results

The demonstrators have undergone extensive testing both on the test track and on the public road. The following tests were undertaken to verify the safety of the combination, or to provide input to the simulation and evaluation activities:

- Safety testing
- Vehicle dynamics test measurements and test driver responses
- Impact on loading efficiency
- Impact of the aerodynamic measures
- Impact of the HoD system in real world conditions (public road, simulated urban heavy traffic)
- Load volume sensors were demonstrated

The test vehicles are described in Deliverable D6.1, and the results are more fully summarised in Deliverable D6.4.

2.6.1 Safety Testing and Vehicle Dynamics

Safety related testing, including assessment of vehicle dynamics, has been of paramount importance and as a key enabler to allow the performance tests to be undertaken. The testing included the following items in addition to extensive risk analyses:

- Preliminary theoretical model-based evaluation of the vehicle dynamics
- Commissioning tests
- Functional safety and functionality tests developed together with TÜV Rheinland
- Development and testing of the brake blending functionality with Knorr Bremse
- Internal OEM road approval (braking, handling and HMI aspects)
- Driving dynamics testing to validate the driving dynamics models
- Interviewing of the test drivers regarding driving dynamics

The outcome of all tests was positive. The results showed that the dynamic behaviour is similar to the behaviour of a standard tractor and semi-trailer combination, and no additional control measures are needed for the current configuration. In particular all test drivers interviewed perceived the same or better controllability of the TRANSFORMERS vehicle combination in comparison to a conventional combination. Under specific conditions the torque supplied from the HoD driveline was felt to be uncomfortable, revealing that the control software requires further optimisation.

2.6.2 Loading Efficiency

Loading efficiency tests were undertaken on the Load Optimisation Trailer to investigate the effect of the configurable roof, increased inner floor length and double floor system in terms of ease of docking, loading and unloading. Functional performance was tested in a P&G distribution centre, and was shown to be successful according to the project KPI, see Figure 2-22. The increased inner floor length was shown to successfully allow 34 euro-pallets to be loaded instead of the more common figure of 33 pallets. The "flex floor" system was tested successfully, and the time to load or unload 4 pallets is approximately 5 minutes when the double floor system is used, compared to approximately 2½ minutes when the double floor is not used. The additional time required for loading/unloading the double floor was used in the economic assessment. The four segment configurable roof was found to take approximately 1 minute to change to a new configuration.

Figure 2-22: TRANSFORMERS Load Optimisation Trailer: Flex Floor Optimally Used

2.6.3 Aerodynamics

The aerodynamic features of the Energy Efficiency Combination were tested, using both the DAF and Volvo tractors. The tests were undertaken at the DAF and Volvo test tracks with the aerodynamic aids in relevant settings, such as boat tail folded in or out, and with the different roof configurations.

The Volvo tests focused on measuring the fuel consumption benefit of the aerodynamic measures at various constant speeds increasing from 60 km/h. The results show that the fuel consumption can be reduced by up to **5.7% at 80kph** (high tapered roof and boat tail), and **9.2% at 90kph** (low tapered roof and boat tail). The results are relative to the reference case of the Energy Efficiency Combination with the trailer in the "high flat" position with boat tail folded in. This means that the results indicated above have a "hidden" potential, since gains due to the aerodynamic front bulk head and side skirts are not taken into account.

In tests using the DAF tractor, the primary goal was to calculate the air drag (Cd*A) of the combination by measuring the reduced torque required to drive at a constant speed of 90 km/h. During these tests, the boat tail was both folded in and out, along with the different roof configurations. The best results were obtained with the roof in the high tapered position with the boat tail folded out giving a **14.3% reduction** in air drag. The impact of the boat tail varies depending on the roof position. The air drag results are used for calculations in the evaluation phase.

2.6.4 Hybrid on Demand Fuel Savings

The HoD system on the Energy Efficiency trailer was tested in simulated urban heavy-traffic conditions on a test track using a DAF tractor, and on Swedish public roads using a Volvo tractor. The results are influenced by the payload, road type, topography and driving cycle dynamics since they influence the energy recuperation potential of the system.

For the simulated heavy traffic conditions a speed profile was developed to be representative of dense urban traffic, see Figure 2-23.

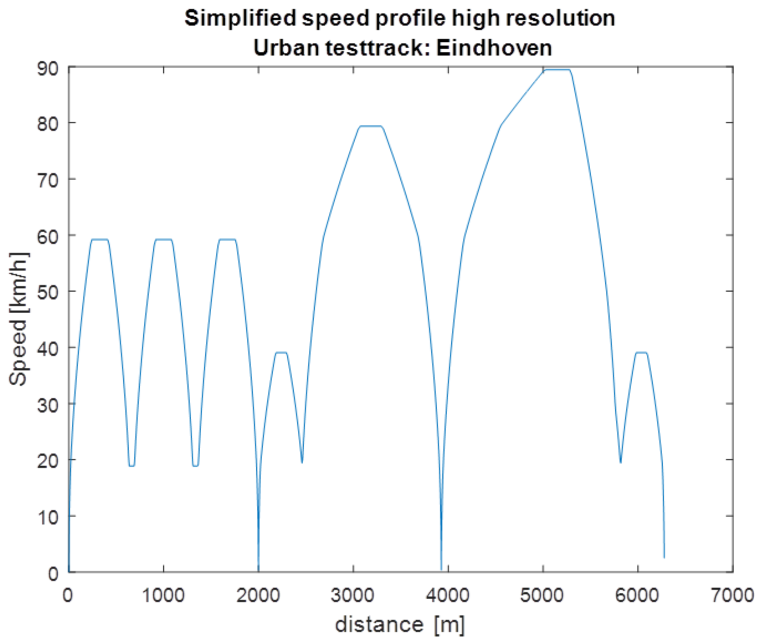


Figure 2-23: Speed Profile For Dense Traffic Urban Driving Conditions

Fuel consumption was measured with the HoD both switched on and off, and for two loading conditions, i.e. empty and 15 tonnes payload. To compensate for the mass of the HoD system 1.2 tonnes extra weight is added during measurements with the HoD system. After correction of results for the state of charge (SoC) difference before and after the test, the test results show a **reduction in fuel consumption of 5.9 to 6.6%** with the HoD system engaged for simulated heavy traffic conditions.

On country roads and motorways with free flowing traffic, the HoD system is dependent on the route topography (elevation changes and gradient). Fuel measurements were undertaken on different Swedish routes, which predominantly have a hilly and low traffic character. In the tests the payload was varied. Two different cycles were used, see **Figure 2-24** and **Figure 2-25**. BOGA is a 129 km long cycle and is composed of country road and motorway parts. BOB is a 262 km long cycle, only on motorway.

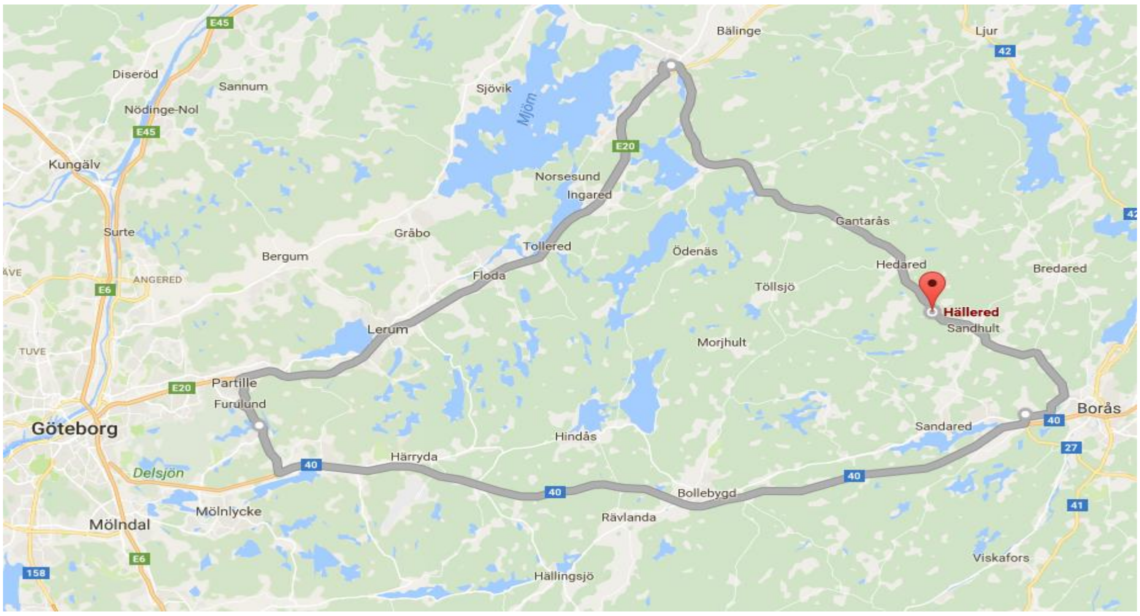


Figure 2-24: BOGA (Borås-Gothenburg-Alingsås) Cycle

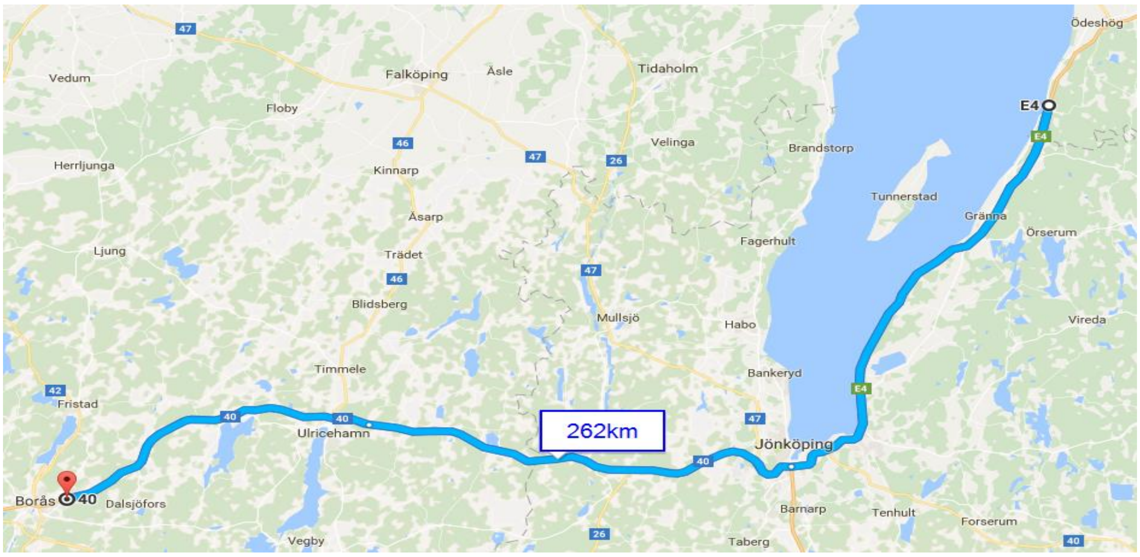


Figure 2-25: BOB (Borås-Odeshög-Borås) Cycle

The corresponding altitude profiles are shown in **Figure 2-26**. Altitude varies most in the BOGA cycle, but sharpest changes in altitude occur in the BOB cycle.

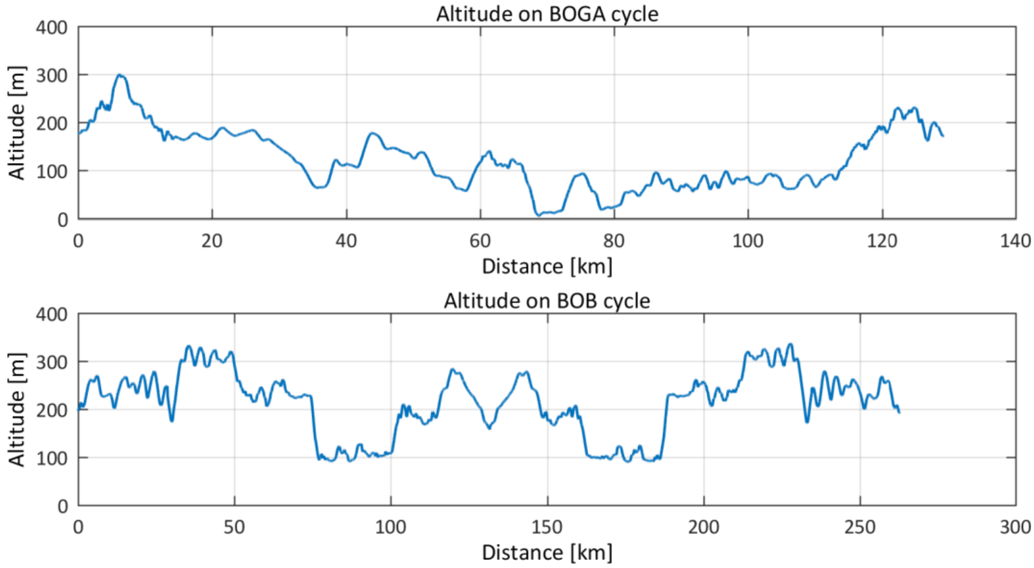


Figure 2-26: Altitude Profile of the BOGA and BOB Cycles

With 15 tons payload, the fuel consumption reduction on a motorway route is **2.2%**. For 40 tonnes GCW (maximum payload), the results vary between **3.3%** for a motorway route, to **3.8%** for a route with a mix of country road and motorway. More details about the HoD test drive results are provided in Deliverable D6.4. Alternative control strategies should be investigated, as a short trial at the end of the main testing showed that significant potential for improvement remains with the current system and configuration.

2.7 Holistic Simulations

The simulation model developed during this project consists of different component models coupled together in the co-simulation platform AVL Model.CONNECT to perform holistic simulations. With this method it was possible to include components remotely from different organisations, see Figure 2-27. Variant and case management aided the simulation of a high number of variations. The HoD component models represent the real HoD system. The tractor components represent a generic tractor, while the trailer model was based on the actual configuration. Details can be found in Deliverable D6.3.

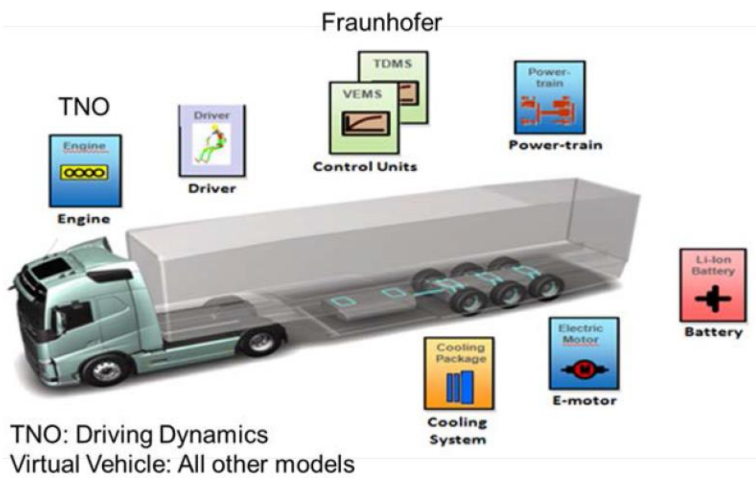


Figure 2-27: Energy Efficiency Combination Model

Initially the models were validated against the real world test results. Subsequently, the high-fidelity simulations were used to determine an optimal HoD component configuration to maximise fuel savings potential by varying key system parameters. The system parameter variations were agreed within the consortium and resulted in a large number of variations in a "simulation matrix", which were simulated for different route scenarios. The main variations considered were payload, EMG power, and battery size. During the course of the work approximately 700 high fidelity holistic simulations were undertaken.

The results of the high fidelity simulations show the potential of several configurations on different types of route, and also served as input to the low fidelity evaluation model. Results are summarised below, while detailed results can be found in Deliverables D6.3 and D6.4:

- Increased EMG power (240kW compared to the 80kW demonstrated) enabled greater short term energy recuperation and gave the best fuel consumption reduction results.
- A smaller battery (10kWh compared to the 20kWh demonstrated) gave better or equivalent results.
- An alternative control strategy was found to offer 1-3% higher SoC corrected fuel savings for the hillier motorway scenarios compared with the system tested.
- Plug-in scenarios do not show improvements for all cases, but offers up to 4% higher fuel savings for some routes.

The holistic simulations highlighted that there is a high potential for improvements using different control strategies for different route scenarios. More investigation of the optimum system strategy is needed for different routes. The strategy should also consider the possibility of changing EMG torque limits depending on SoC, especially in case of plug-in scenarios. In future, it could be interesting to change the HoD strategy dynamically during driving, to suit the route. Predictive energy management systems could take actual road and traffic conditions into account and would be able to optimise fuel savings.

2.8 Evaluation

In order to assess the project goal of a 25% reduction of energy use per tonne.kilometre, an evaluation framework was defined as described in Section 2.6. The data sources and steps in the evaluation process are shown in Figure 2-28. The test measurement results show the potential of individual TRANSFORMERS innovations for a limited number of configurations and test routes. The hi-fidelity simulation results investigated the effectiveness of the HoD under different route conditions, and for variations in the configuration of the system. The evaluation of these results aimed to understand under which conditions the innovations perform best on their own and when combined, what are the trade-offs or synergies, and how can optimal savings be achieved. The evaluation targeted the impact of the TRANSFORMERS innovations in terms of the key goal of the project: reduced energy use per tonne.kilometre of goods transported. Since the impact on energy use and CO_2 is equivalent to the impact on fuel consumption, the latter is used as the primary metric.

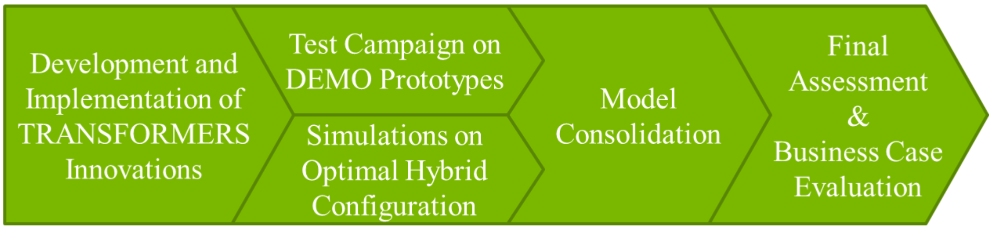


Figure 2-28: Final Evaluation Process

Based on the vehicle tests and high fidelity simulation results, a consolidated evaluation model was used for the final evaluation of the effectiveness of the TRANSFORMERS innovations under various influencing parameters such as road type, payload and traffic conditions. The improvement potential for selected transport missions has been compared to current heavy-duty vehicle technology used for similar transport assignments. The chosen assessment methods were a trade-off to evaluate the project in terms of fidelity and the number of applications assessed.

In order to compare and combine the large amount of results from the tests and the simulations, a harmonised vehicle model is used for the evaluation. This model makes use of a "Willans lines" approach, which describes the relation between the power demand at the wheels and the fuel rate of the engine. The evaluation model was calibrated and validated against the high-fidelity simulation results. The fuel saving potential of the TRANSFORMERS innovations are shown in Figure 2-29 for an average 15 tonnes payload on different types of route and for different system configurations. In the evaluation model, loading efficiency was modelled in terms of additional payload that can be carried during the trip. More details can be found in Deliverable D6.4.

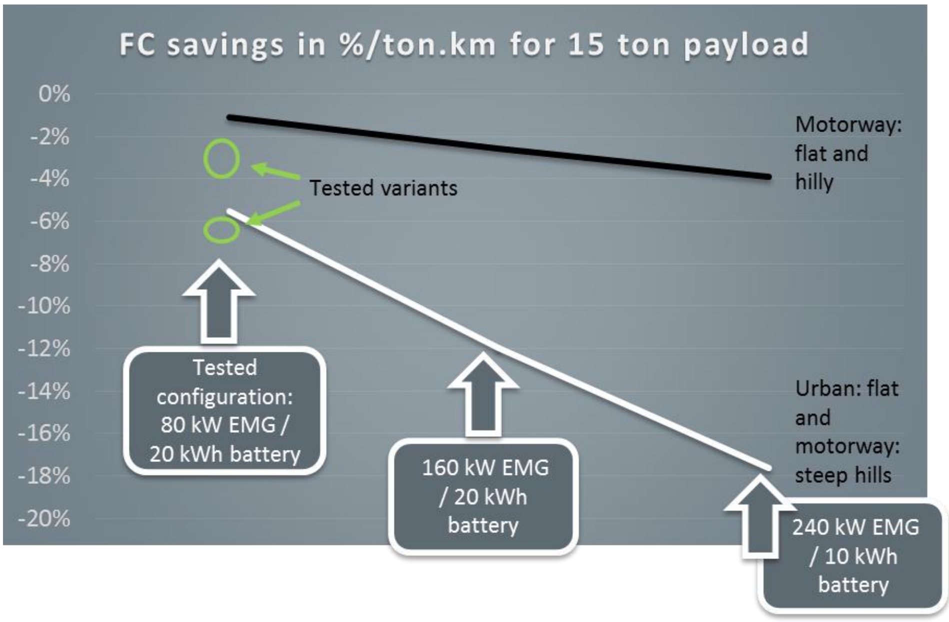


Figure 2-29: Fuel Saving Potential Of Different HoD Configurations

When comparing the evaluation results against the original goals of the project in terms of reduction of energy use per tonne.km of goods transported, the following can be concluded:

- The HoD system shows highest potential with a relatively small battery (e.g.10 kWh) and a large electric machine (motor-generator) (e.g. 240 kW). The short term regeneration potential determines the potential reduction in energy use, meaning that the highest savings can be reached in urban areas with high traffic dynamics, and with frequent and steep elevation changes. In these situations, the savings potential is **up to 18%**, where flat and slightly hilly routes show a potential of **up to 4%**.
- Aerodynamic measures are not effective at low speeds, i.e. in urban situations. At typical long haul speeds the savings potential of the boat tail is **up to 3%**, which is similar to the savings potential of the configurable roof. The combined savings are **up to 6.5%**. The project goal of 8% is in reach, especially when it is considered that the impact of the optimised side skirts and bulkhead are <u>not</u> included in the results due to the choice of the reference configuration.
- The load optimisation measures show a wide variation in the potential for energy use reduction. The additional floor space allows for 1 additional pallet, resulting in **3%** reduction of energy use per t.km. The double floor potential is dependent on the type of cargo. When assuming up to 5 tonnes additional cargo, the energy use reduction compared to an original cargo payload of 8t is **up to 31%** per t.km. In case of an original cargo payload of 15 tonnes, the energy use reduction is **up to 17%** per t.km.
- When all TRANSFORMERS innovations are combined, **a reduction in energy use per t.km of goods transported of more than 25% can be achieved** for almost all mission profiles at average payload (15t). At higher payloads, the savings are lower, and at lower payload the savings are higher. In a largely level motorway scenario with an average 15t payload, the savings are 24%. On all other routes, the potential is higher, i.e. up to 31%. These savings are achievable **with optimum system configurations and scenarios**, i.e. a large electric machine and a “small” battery pack (240kW/10kWh vs 80kW/20kWh tested), full use of the aerodynamic aids (high tapered + boat tail), and 5t extra payload due to loading efficiency improvements.

2.9 Economic Assessment

The simulation results are used as the basis for the economic assessment. The economic potential of the TRANSFORMERS innovations is evaluated for a number of representative use cases. Since no cost data is used within the project for confidentiality reasons, the assessment is limited to the economic savings derived from the impact on fuel consumption, and extra docking(loading/unloading time. The evaluation has been done for the three innovation areas separately, as well as when combined.

The economic assessment indicates savings can be achieved with all of the TRANSFORMERS innovations in the following scenarios:

- Three realistic use cases
    - Short distance international transport
    - Long distance international transport
    - Urban round trip)
- Three different scenarios
    - Low potential
    - Middle potential
    - High potential

Whether or not this leads to a positive business case depends on the technology costs. In general, it can be concluded that the calculated economic savings and net present values (NPV over 8 years) show the potential for a viable business case for all innovations.

The best cases for the different innovations differ. The best use case for the combined TRANSFORMERS innovations is long distance international transport, when the NPV is approximately €70000. In this case, all TRANSFORMERS innovations profit from the large amount of annual mileage (200000 km). The loading efficiency profits from large distances between loading and unloading locations which means the additional loading/unloading time is stretched out over the mission. At motorway speeds, aerodynamic measures achieve their highest savings. Strictly speaking, this use case is not the best case for HoD measures. However, when hilly and steep hills are included in the mission profiles this is beneficial. Even at lower fuel savings potential for the HoD, the business case can still be positive, since high mileages compensate this effect. Detailed results can be found in Deliverable D6.4.

2.10 Conclusions

Future configurable and adaptable road tractor and semi-trailer combinations need to be an economically viable alternative to existing combinations that are on the market today. The new combinations need to be attractive and efficient from an environmental, energy, operational and a logistics point of view. Furthermore, they must comply with the needs and expectations of logistics providers and end users, with regulations, and they must be able to operate on the existing road and multimodal infrastructure network.

By looking at the road tractor and semi-trailer combinations holistically to reduce overall fuel consumption while in parallel improving load efficiency, **TRANSFORMERS targeted, and achieved, a 25% energy consumption reduction per tonne.km of goods transported** in real world scenarios within the existing European regulatory framework. This reduction was achieved without significant effect on the road infrastructure.

TRANSFORMERS developed ways of improving overall transport efficiency for both weight and volume limited assignments:

- For volume limited assignments the TRANSFORMERS innovations offer increased load capacity within current weights and dimensions regulations.
- Reduced fuel consumption can also be achieved by improved aerodynamics. In this respect TRANSFORMERS looks at transport assignments which are weight limited, or for other reasons do not utilise the full volume of the trailer. If the full volume is not needed for the payload, the TRANSFORMERS innovations offer the possibility to change the shape of the trailer to improve the aerodynamic characteristics of the complete combination.

The TRANSFORMERS goals were achieved through the following innovations:

- A semi-trailer mounted, distributed "Hybrid-on-Demand" (HoD) electric driveline, including a pre-standardisation tractor-trailer communication framework to enable market introduction and provide planning certainty for future research activities.
- Mission-based, transformable whole vehicle aerodynamics.
- An internal trailer design offering increased load capacity.
- TRANSFORMERS developed these innovations in the context of offering a mission adaptable solution rather than accepting a one size fits all solution, so that the complete vehicle can be reconfigured to the optimum configuration for each transport assignment.

The TRANSFORMERS partners have worked together to develop and successfully demonstrate two highly innovative semi-trailer combinations, see Figure 2-30.

Figure 2-30: The TRANSFORMERS Combinations on the Public Road in Sweden

In general, it can be concluded that the TRANSFORMERS project was very successful. All innovations developed within the project have demonstrated saving potentials when assessed against the project goals depending on the mission profile. Additionally, all innovations have shown the potential for a viable business case in the future, and offer further improvement potential. The highest potential for a positive business case is offered by the load optimisation measures, followed by the aerodynamic measures, and the Hybrid-on-Demand system. The TRANSFORMERS innovations were shown to have negligible impact on the road transport infrastructure in comparison to the vehicle combinations which can be seen today on Europe's roads. Nonetheless, the TRANSFORMERS innovations require further development to improve the market potential before commercialisation is possible:

- Demonstration of acceptable durability in different conditions, i.e. field testing
- Optimisation of components, and especially of the HoD system
- Reducing the complexity of the solutions
- Reducing the weight of the solutions
- Reducing the cost of ownership of the solutions while retaining the targeted functionality
- Ensuring their applicability to as wide a range of applications as possible
- Looking for new features and services that the TRANSFORMERS innovations can enable

The following improvements are believed to be feasible based on the simulation work:

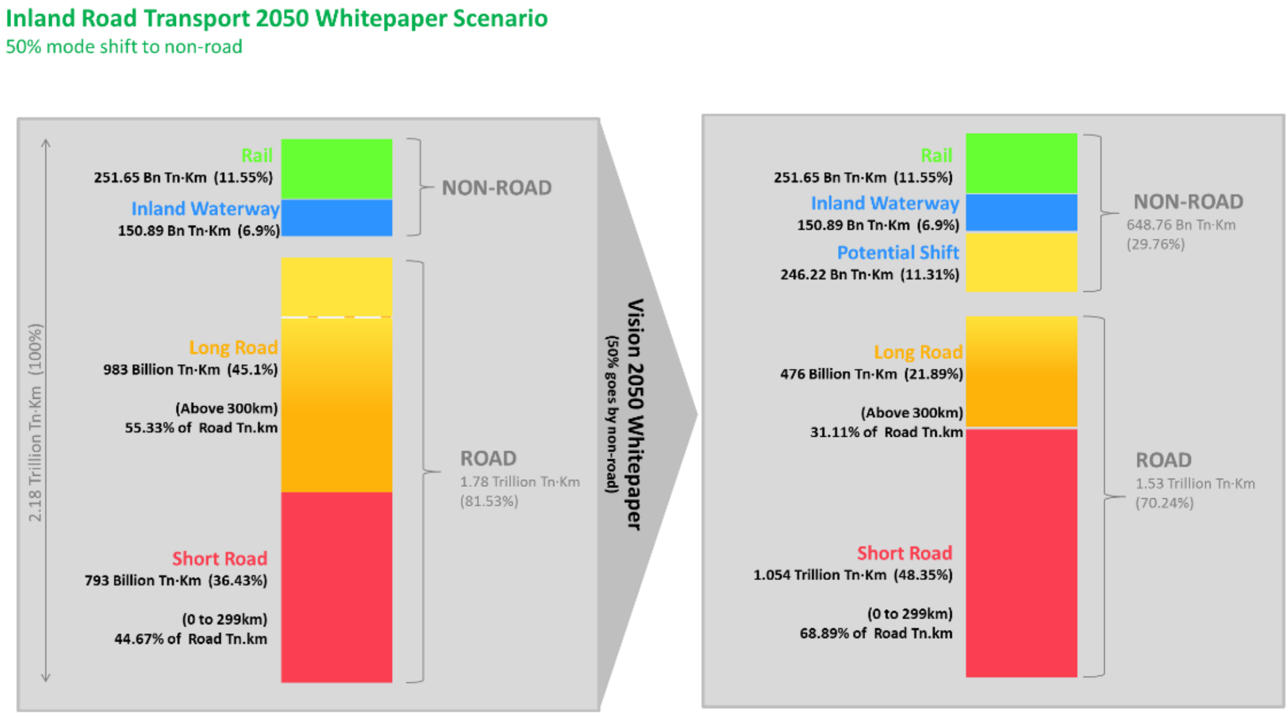
- Weight reduction for the HoD system and aerodynamic measures may result in an additional reduction of 0.5 to 1% in energy use.
- Optimising the HoD control strategy may result in additional benefits of approximately 4%. Further development and a more a dynamic strategy based on predictive energy management could show even more potential.
- Adding plug-in functionality to the HoD system will bring additional benefits in certain mission profiles with limited energy recuperation potential.

The TRANSFORMERS approach is to consider the tractor-trailer combination holistically, as a complete vehicle, which can be reconfigured for each transport assignment. The toolbox of innovations offered by TRANSFORMERS provides the ability to optimally select the correct measures, depending on the loading condition and mission. This allows the end user to fully exploit the fuel saving potential without needing to rely on a predefined fixed "one size fits all" configuration. As a result of the reconfigurable approach, TRANSFORMERS is able to combine the optimisation potential of the innovations, rather than the average fuel saving potential.

The European Commission, national and local governments, must work continuously to evolve the regulatory environment in order to create a platform which enables the benefits that technology can provide. Looking at the recent changes in the Directive (EU) 2015/719 on weights and dimensions an allowance of one additional tonne is allowed for "alternative fuels" including hybrid drivelines, but the that one tonne is not valid for an articulated vehicle. This puts innovative solutions such as those developed in TRANSFORMERS at an immediate disadvantage, as it results in loss of one tonne of payload capacity. Regulations need to be modified and developed to enable innovative technologies.

3 Potential impact & Exploitation

It is clear that the transport of goods will continue to increase with economic growth both within Europe and beyond. In particular the transport of goods by road will continue to play a key role in sustaining economic development, even if a significant modal shift occurred as an alternative option to long haul road transport (distances > 300km) in the EU, see Figure 3-1. It will become increasingly challenging to accommodate ever increasing freight flows in an efficient and sustainable way. Key issues such as sustainability, resource accessibility and scarcity, pollution and climate change, are critical challenges that the road freight transport industry will face in the coming years. For transport companies and end users, the "greening" of logistics not only has an environmental and social dimension, but is also a question of economics, efficiency and competitiveness.



SOURCE: Eurostat (rail_go_typeall) , (iww_go_atygo) and (road_go_ca_c) – 2014 EU-28 Data.. For (road_go_ta_dctg) - Averaged Data from the year 2008 to 2014 and SNIC calculations
Assumption: Modal shift does not cause increase in the total Tn-km of a journey

Figure 3-1: The TRANSFORMERS Combinations on the Public Road in Sweden

There are both direct and indirect opportunities for the exploitation of the TRANSFORMERS results which can be viewed both from the perspective of the partners and from a wider societal perspective. Societal implications to strengthen and speed up the market uptake of successful results from the project are addressed below.

TRANSFORMERS has demonstrated innovations to save energy in the transport of goods by road. Political support is a major prerequisite to further develop and commercialise these concepts, creating benefit for society in the process. However, the benefits of a TRANSFORMERS tractor and semi-trailer combination can be increased by applying the innovations to high capacity combinations. If goods get lighter there may be a need for longer vehicles with a greater cargo volume, and if goods get heavier to allow greater gross combination weights, or a combination of both. To enable these changes infrastructure regulations for existing and future highway infrastructure need to be compatible and may need to take new regulatory concepts such as the bridge formula mentioned in Section 2.4 into account.

3.1 Cooperation

By looking at the road tractor and semi-trailer combination holistically to reduce overall fuel consumption while in parallel improving load efficiency, the TRANSFORMERS innovations can provide a real world reduction of 25% or more in energy consumption per tonne.km of goods transported within the existing European regulatory framework. To exploit this potential, increased cooperation is needed across all sides of the transport industry, cooperation which could be enabled by new business models within the industry. Increased transport efficiency with lower energy use equates to both lower emissions and lower costs for the road transport industry and society as a whole.

To fully exploit the potential of the TRANSFORMERS innovations societal support is needed along with cooperation between all sides of the road transport industry. Continued cooperation between all actors in the road transport industry is necessary to:

- Further optimise the concepts and their reliability
- Apply concepts to other vehicle combinations
- Field test in real life conditions with shippers and carriers
- Test interaction with other interesting concepts such as platooning, alternative fuels, high capacity vehicles, etc.
- Optimise communication between the tractor and semi-trailer (configurable roof, HoD, load volume monitoring)
- Fine-tune the business case to create markets of sufficient scale
- Enable the concepts within the EU and national legal frameworks
- Enable the concepts within international standards
- Incentivise the concepts
    - Legislative
    - Non-legislative
- Increase the visibility of project results to underpin technical, market, and policy discussions.

3.2 Future Concepts

The potential impact of the TRANSFORMERS innovations from the perspective of future concepts including high capacity combinations is discussed in Deliverable D4.6. The input to the report was derived from specially organised workshops attended by key experts from partners within the project consortium. The results represent a vision of the future from the TRANSFORMERS perspective including longer and heavier combinations. The road transport industry can be affected by a broad spectrum of future innovations, and a high level summary is included in an annex to D4.6.

Trends are highlighted below that can impact the future of the goods supply chain, and their effect on road transport. As previously stated, despite society aiming for a modal shift for the transport of goods over long distances, the transport of goods by road will continue to be the major mode by which products will be moved in the EU. By looking into the future it also provides an opportunity to debate the technological, societal, economic and environmental risks and concerns that new concepts may pose prior to widespread adoption.

Societal changes influence the way goods and services are delivered. Some of the key changes that influence road freight transport are:

- The development of the digital economy
- Road infrastructure congestion
- An ageing population
- Automation and connectivity
- Changes in regulation supporting eco-friendly solutions

Looking into the future from a broad perspective, concepts that only a few years ago would have been dismissed as science fiction can be envisaged though it is an open question to what extent and how fast the potential could be harnessed.

Technologies such as digitisation and vehicle connectivity are already a market reality that will continue to grow, yet it is open to debate whether this growth will effectively capture the value creation opportunities offered at the interaction of value drivers of the logistics industry. The above forces will influence the logistics industry and inevitably vehicle design, but success in meeting these challenges will be determined by whether public and private stakeholders manage to successfully enable the conditions required to overcome the challenges discussed in topics below.

A high level mapping of the relationship of potential future concepts to the TRANSFORMERS innovations in terms of supporting the development of a sustainable logistics industry with road transport at its core is shown in Figure 3-2.

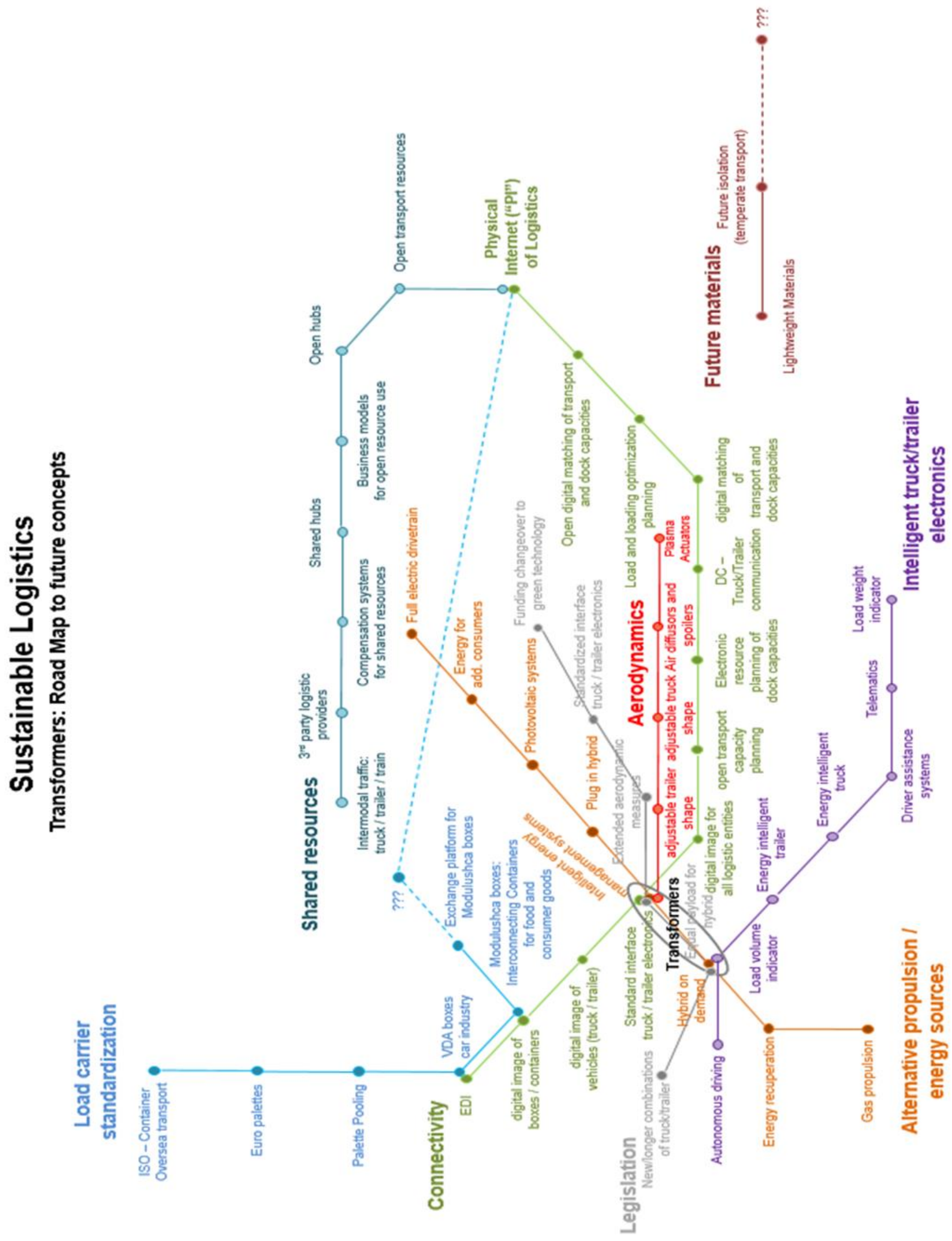


Figure 3-2: TRANSFORMERS Road Map of Future Concepts

From the perspective of industry the following issues need to be addressed to enable the development and commercialisation of future concepts to improve road transport efficiency:

- No disadvantage in terms of payload or cargo volume
  - Additional components for systems such as "Hybrid-on-Demand", and aerodynamic or load optimisation aids will add weight to the tractor and trailer combination. Under current regulations, using a trailer with such components would result in an economic disadvantage in terms of payload compared to competitors using a conventional trailer. Interaction between shippers and transport companies would also be more difficult for different payload standards.
  - The allowance of one additional tonne for "alternative fuels" including hybrid drivelines in Directive (EU) 2015/719 on weights and dimensions should be extended to the full combination.
  - Trailer manufacturers have to create a transparent display of weights for executive organisations. This should be standardised at a European level.
- Common interface between tractor and trailer
  - There is a significant potential for improvements to the HoD system by using different control strategies for different route scenarios. More investigation of the optimum system strategy is needed for different routes. The strategy should also consider the possibility of changing, for example, EMG torque limits depending on SoC especially in case of plug-in scenarios. Changing the HoD strategy dynamically during driving to suit the route offers potential. Predictive energy management systems could take actual road and traffic conditions into account and would be able to optimise fuel savings.
  - Technologies such as "Hybrid on Demand" or vehicle energy management systems can put the available energy to a more efficient use and reduce wasted energy. To enable this, a new level of communication between tractor and trailer is needed, and for electronic interfaces between the units.
  - To enable "Hybrid-on-Demand" and complete vehicle energy management, cooperation is needed between truck and trailer manufacturers and related suppliers through ISO and appropriate national mirror groups for a revised international standard based on the existing ISO Standard 11992 for the tractor-trailer communication interface. Deliverable D3.2 may form the basis of these discussions.
- Control systems on the trailer
  - Flexibility is one of the key success factors of road transport with tractor and semi-trailer combinations. Tractors can be operated with almost any trailers. Even if it has a common interface to the tractor, the future trailer should still be able to manage many of the TRANFORMERS innovations by itself. So for example, even if the truck is not equipped with appropriate systems the trailer should be able to adjust the roof or the "Hybrid on Demand" to optimal settings. Otherwise the potential for saving energy is lost as soon as non-compliant tractors are connected to the trailer. This may not be possible for the more advanced complete vehicle energy management systems that need to be closely integrated with the truck systems.
- Avoid financial disadvantages due to aerodynamic measures
  - Commercial vehicles and especially trailers are optimised to offer maximum payload and volume. Aerodynamic measures such as boat tails add length to the trailer which limits payload unless exempted in regulations for length measurements. Restrictions from a road safety and road infrastructure perspective need to be taken into account.
- Enable an easy changeover to new technology for users
  - The road transport industry is highly competitive with average profit margins of 1 to 3%, and with a significantly higher rate of insolvency proceedings than the average business. Average quotes for equity capital are around 16%, and therefore the possibilities to invest in new technologies are very limited [11]. Every financial incentive that reduces the cost or amortisation period for an investment makes the changeover to environmentally friendly technologies more feasible.
  - Concepts such as "Hybrid-on-Demand" should be enabled in national registration options and EU-harmonisation processes.
  - For transporters it is important to be sure that registration of a trailer with new concepts such as a "Hybrid-on-Demand" system is possible with their national authorities, and for international hauliers that this is recognised across Europe. It is important to create legal certainty through harmonisation of legislation across Europe to permit the use of "Hybrid on Demand" systems and other concepts, and in particular to deal with the electric brake on the trailer which is essential to recuperate energy.

3.3 High Capacity Combinations

High capacity combinations offer significant transport efficiency savings in their own right. For example the 32 m combination: the total allowed weight of the combination when loaded is 80 tonnes, and the load capacity is approximately 50 tonnes. It is used for terminal to terminal transports for consumer goods where the average total weight is 60 tonnes. The combinations rarely reach the maximum allowed weight due to the low density of the goods (on average 160 kg/m³). Tests show that compared to a tractor with a single semi-trailer, a 32m trailer combination can transport the same amount of goods using 73% of the fuel, i.e. a transport efficiency improvement of 27%. Various combinations are possible as shown in Figure 3-3.

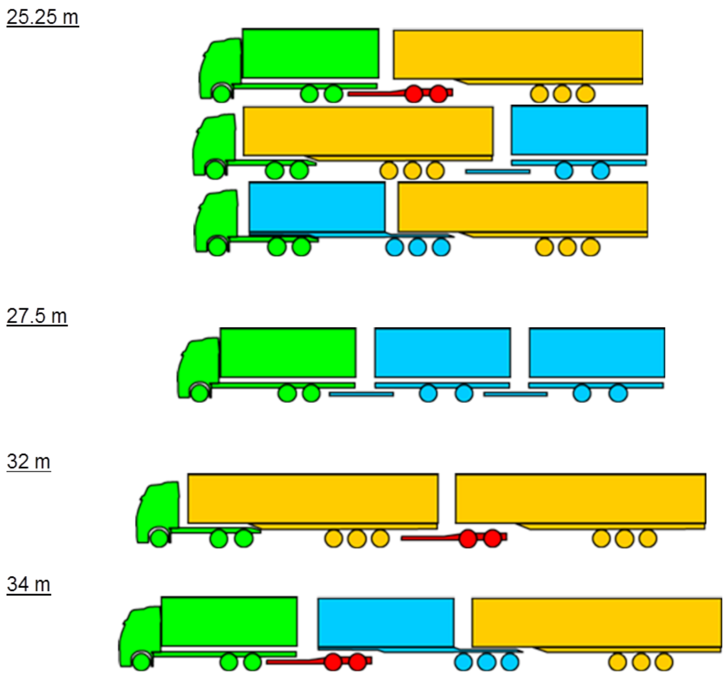


Figure 3-3: High Capacity Combinations

The TRANSFORMERS combination aims to improve the transport efficiency of tractor and semi-trailer combinations, specifically for palletised goods, by the improving load optimisation, improved aerodynamics, and by the use of a distributed "Hybrid on Demand" system. To take further steps to increase road freight efficiency, it is necessary to explore how the measures can be applied for other industry segments and vehicle combinations. The load optimisation measures designed for palletised goods can be applied to other current combinations such as a truck and trailer combination, as well as for longer and heavier vehicle combinations. In the case where a combination consists of two cargo units, additional challenges arise to manage (un)loading of both units in an efficient way. Aerodynamic features also need to be developed to handle the gap between the units. In part these challenges are addressed in the recently started AEROFLEX project (http://www.egvi.eu/projectslist/171/37/AEROFLEX).

For other industry segments such as bulk goods and container transports that are identified as interesting for longer and heavier vehicle combinations, similar challenges as for the tractor and trailer combination exist. However, the solutions will look different as the design of the units and the optimal combination design will vary. High capacity vehicle combination examples show that there are significant efficiency improvements in longer and heavier vehicle combinations, particularly when the combinations are optimised for the transport assignment. With the additional TRANSFORMERS improvements to aerodynamics and distributed drivelines, larger gains can be expected. It is clear that all vehicle combinations are not suitable for all types of transport assignments. There is also an infrastructure limit for the size and weight of vehicle combinations. To be able to use the potential efficiency improvements there is a need to match efficient vehicle combinations to the infrastructure, where the infrastructure can handle the combinations. Currently, longer and heavier vehicle combinations are not commonly used on the European road network. Sweden and Finland are the only countries where such combinations have been extensively used. However, other countries have also started to show an interest in the use of such vehicles and have started trials. The most advanced trials are taking place in the Netherlands and Denmark, with other trials in Germany, Belgium, Norway and Spain. Official evaluation reports of these trials have further illustrated the advantages of using such combinations. Further development is restricted by European legislation, and modifications could extend the scope for the use of high capacity combinations and open new opportunities for the deployment of the TRANSFORMERS solutions. Further research in this area is necessary.

3.4 Incorporating the TRANSFORMERS Innovations in VECTO

Regulation can either be a key enabler to new technologies or a barrier to them. The VECTO tool is to be used in the near future for the assessment of the CO_2 impact of heavy-duty vehicles in certification procedures. The current VECTO proposal does not allow the CO_2 reduction measures of the TRANFORMERS concept to be taken into account. This is because currently only the simulation of vehicles with non-hybrid powertrains and standard truck and semi-trailer bodywork is included. The VECTO tool itself, however, is designed to simulate CO_2 emissions based on physical and measured properties of a complete heavy duty vehicle. This means that the technical basis of the tool is suitable to simulate the achievable CO_2 emissions of innovative concepts that reduce driving resistance. Therefore, maximum achievable impacts of air drag and mass can be taken into account quite easily. The key points are summarised in Table 3-1.

Table 3-1 Modifications Necessary to VECTO to Include the TRANSFORMERS Innovations

TRANSFORMERS Innovation	Is the measure covered by the VECTO certification proposal ?	What needs to be adapted in VECTO?
Aerodynamic improvements	No, only standard bodywork and trailers allowed	The constant speed test can be used to determine CdxA of the vehicle with innovative trailer concept. Alternatively, a certified calculation method can be used to determine Cd values. Requires a utilization rate when the measure is not 100% active.
Loading efficiency	No, only fixed payload and cargo volume	Requires allowance of a different payload input and a utilization rate when the measure is not 100% active.
Hybrid-on-Demand	No	Requires development of a hybrid VECTO add-on. Complexity and development time can be significant, depending on required modelling accuracy
Weight	No, only standard bodywork and trailers	Add an input field for an alternative mass of the trailer

Another factor to be taken into account is the mission adaptability of the TRANSFORMERS innovations which may not be utilised all of the time. The TRANSFORMERS lowerable roofs may only be lowered if the cargo on a particular transport assignment allows it. Similarly the flex floor (independently adjustable double floor) feature is only beneficial when more cargo can be carried than would have been in a baseline situation using a conventional trailer. This means that the utilisation rate needs to be taken into account to determine the average CO_2 emission. Hybridisation may be harder to integrate. In theory different approaches are possible with complexity increasing as more accuracy is required.

3.5 Dissemination

TRANSFORMERS has been a very open and transparent project, openly publishing many details of the project and the key to that has been a multi-faceted dissemination strategy.

Initially a project website and related communication material were established, see http://www.transformers-project.eu/ and figure below, as well as Deliverables D7.1, 7.2 and 7.3.

Figure 3-4: Homepage of the TRANSFORMERS Website

The website contains information about the project, updates on its activities, published reports and deliverables. The website also features 4 videos prepared by the consortium members to aid dissemination of information about the project. The videos include:

- An animated video explaining the objectives of the project: https://youtu.be/ko54PneAqJw
- A video showing the TRANSFORMERS demonstrators during testing: https://youtu.be/w2wzeRS1AdA
- A video showing the revealing of the TRANSFORMERS demonstrators during the Final Conference on 29th June 2017: https://youtu.be/K_aJo0cJT-w
- A video originally created by IRU Projects to promote the project amongst their members: https://youtu.be/TOsOf3Ewen0

The project has released 15 Newsletters about progress in the project and presentation of the results at the Final Conference, see Deliverables 7.4, 7.5 and 7.6, and http://www.transformers-project.eu/downloads/#.Wd3yxFuCz3g .

TRANSFORMERS has actively disseminated information at a number of external conferences and workshops, with 11 scientific papers being published by members of the consortium and a further 3 papers submitted to the Transport Research Arena Conference in 2018, see Deliverables D7.8 and 7.9. In total 58 dissemination activities have bene undertaken in the 4 year project duration.

The major dissemination activity was the TRANSFORMERS Final Conference on the 29th June 2017, a full day event at the Volvo Trucks Experience Centre, Gothenburg, Sweden. The targeted audience were end users, road transportation companies, trucks and trailer manufacturers, and other relevant stakeholders. Instead of a workshop, the Final Conference was a complete one day conference including presentations explaining the background to the project, reveal and presentation of the TRANSFORMERS innovations and demonstrators, and project results. A panel discussion was included on future transport modes and integration in current and future regulations. Organisation started 1½ years in advance, and was considered a success with almost 120 people registering for the event with 100 of those attending. Participants represented all aspects of the road transport industry from 14 countries including South Africa, Turkey, and the USA. For more details of the event see Deliverable 7.7 and presentations can be downloaded from http://www.transformers-project.eu/downloads/#.Wd3yxFuCz3g .

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5 Published Projects Deliverables

TRANSFORMERS deliverables can be downloaded at
http://www.transformers-project.eu/downloads/#.WeD4pFuCz3g

D1.1	Report on end user requirements for a new configurable and adaptable truck
D1.2	Report on defined Key Performance Indicator (KPIs)
D1.3	Report on defined scenarios and test cases
D1.6	Report on "route selection" annex to D1.3
D3.2	Report on HoD framework including specifications of infrastructure, interfaces, and ECU functionalities
D3.4	Demonstrator of a mission adaptable Hybrid-on-Demand driveline installed in a tractor and semitrailer vehicle
D4.6	Future Concepts in Road Freight Transport: Beyond Current Regulations
D5.1	Study of the mechanical impacts of vehicle configurations on pavements (stress-strain response, fatigue, rutting) and safety barriers
D5.2	Effects on bridges of the various vehicle configurations
D5.3	Impact of new vehicle configurations on road equipment, above all safety barriers
D5.4	Compliance of vehicle configurations with infrastructure geometrical constraints, in quasi static and in dynamics
D5.5	Recommendations for EC wide regulatory framework (legislation) on dimensions and loads of vehicles
D6.3	Report on comparison results of simulation and testing
D6.4	Final report and conclusions
D7.1	Project website, public and partner restricted part
D7.2	Project templates for reports, presentations and logo, including dissemination database with relevant stakeholders, interest groups and their contact details
D7.3	Flyer publication with general project information for public project dissemination
D7.4	Newsletter (1/3) describing new developments and results from the project
D7.5	Newsletter (2/3) describing new developments and results from the project
D7.6	Newsletter (3/3) describing new developments and results from the project
D7.7	Project dissemination and stakeholders workshops/ conference
D7.8	Special sessions, mini-conferences and workshops in major international events (TRA, TRB, ITS, etc.)
D7.9	Scientific and technical publications

6 Acknowledgment

This project has received funding from the European Union's Seventh Framework Programme for research; technological development and demonstration under grant agreement no 605170.

http://cordis.europa.eu/fp7/cooperation/home_en.html

http://ec.europa.eu

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The FP7 project has been made possible by a financial contribution by the European Commission under Framework Programme 7. The Publication as provided reflects only the authors' view.

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