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

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Publishable Executive Summary

The mission of the AEROFLEX project is to support vehicle manufacturers and the logistics industry to become prepared for future challenges in road transport. The main objective of the AEROFLEX project is to develop and demonstrate new technologies, concepts and architectures for complete vehicles that are energy-efficient, safe, comfortable, configurable and cost-effective.

The reduction of the carbon dioxide (CO_2) emissions in road freight transport in the next decades is a key issue. Focussing on this challenge, AEROFLEX WP1 analyses the impact of high-capacity road transport with longer and heavier-trucks (European Modular System: EMS examples see Figure 1-1) on mode choice and CO_2 emissions at the EU level. For assessing the impacts of these new vehicle types, aimed to increase efficiency up to 33 % in long distance road transport and logistics, this deliverable describes the several approaches that are used to determine the impact e.g. on transport logistics, on modal split on CO_2 emissions in road freight transport, and on combined transport.

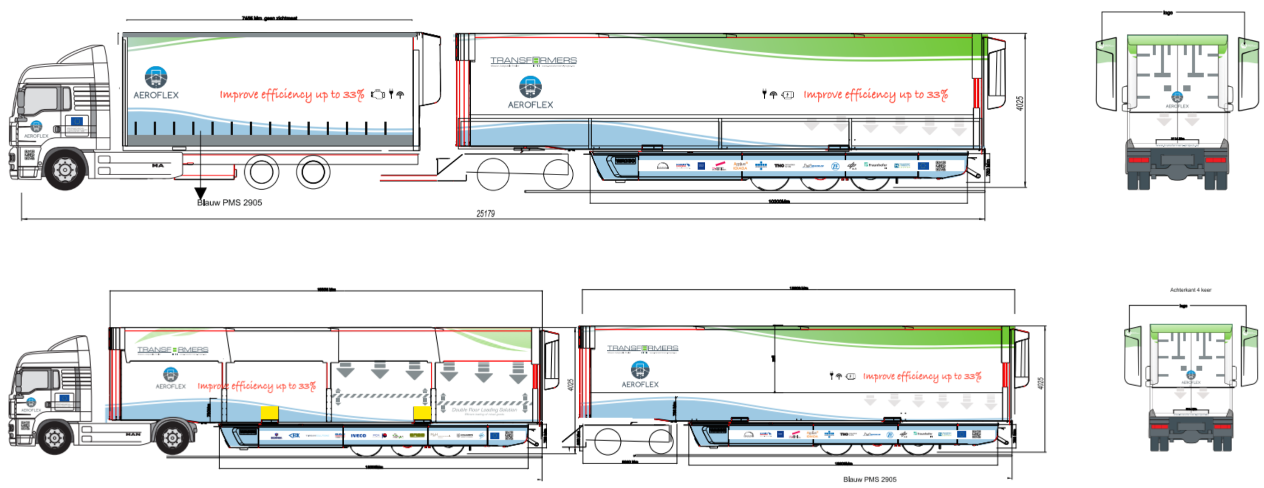


Figure 1-1: European Modular System; EMS1 (above) and EMS 2 (below)

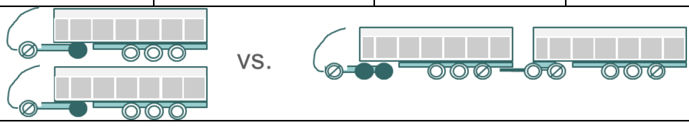
WP1 has the task to map and quantify load in EU and potential for configurable truck. The objectives of this deliverable are:

- to describe the benefits of AEROFLEX innovations for selected use cases that were based on expert interviews
- to calculate the impact of EMS on CO_2 emissions on the EU freight transport market
- to describe the potential for AEROFLEX innovations on the physical internet (PI) as one of the identified trends in future logistics
- to derive recommendations as input for a book of recommendations.

In addition, standard average loads by reference vehicles are compared to the maximum load for European Modular System to calculate average mean values and standard deviations of each KPI. These mean savings potentials in percentage values for different KPIs for the overall sample are displayed in Table 3-2.

EMS will have a positive impact on company logistics. There will be more optimisation opportunities in trip and route planning for long road haulage, as well as for pre- and post-haulage in combined transport, due to both the increase of load capacity and the flexibility of EMS. The use of EMS in hub and spoke concepts of logistics service providers, especially for good classes with high tonne-kilometres and growing market segments (e.g. food products, courier/parcel/express cargo and general cargo) in combination with long daily transport distances per truck, EMS will significantly reduce mileage, transport costs, and CO_2 emission.

Table 1-1: Mean saving potential for overall sample in % for different KPI. Standard deviation in parenthesis. Negative values indicate advantages for the Prime Candidates.

KPI	€/tkm	Cost/tour	CO_2 TTW	CO_2 WTW[1]
Standard average load	18.7 % (10.9)	19.0 % (11.2)	28.8% (17.0)	20.9 % (11.3)
(exemplary visualization)				
Maximum load for Prime Candidate	-28.2 % (16.4)	-28.1 % (16.5)	-16.9 % (14.4)	-25.8 % (33.7)
(exemplary visualization)				

Further, based on an impact assessment by a macroscopic freight model, we can conclude that the modal shift changes in scenarios by using EMS 1 and EMS 2 without compensation of the higher efficiency in road transport and derived cost reduction on road freight transport, lead to a slight increase of freight transport on road on the one hand, and a decrease of rail and IWW in the range up to 3 % on the other hand. If this shift to road transport should be avoided, transport policy regulation or the access policy for EMS 1 and EMS 2 should provide a level playing field for all transport modes and should be accompanied by measures to improve efficiency of rail and inland waterway transport.

Further, WP1 project partners could conclude that the deployment of EMS is expected to have a major impact on the CO_2 emissions of whole EU road freight transport, due to a decrease of mileage in road freight transport in a scenario which external transport costs are considered. An adjusted EU regulation for integration of EMS in freight transport should be aimed to avoid 'rebound effects' like shifting transport volume from rail and inland waterway transport to road transport.

Finally, we address that AEROFLEX road transport innovations can take a role in the physical internet that is similar to that of broadband wireless connections in the digital internet: ultra-flexible, capable of moving high volumes at high speeds, with the best possible coverage at much greater efficiency than past technologies.

[1] For TTW and WWT calculations emission factors from DSLV Guide on Calculating GHG emissions for freight forwarding and logistics services (2012) have been used.

Contents

Figures

Tables

1 Purpose of the document

This document is the AEROFLEX deliverable D1.3 containing the final results of WP 1 in the AEROFLEX project. It covers the impact assessment of High-Capacity Vehicles (European Modular System EMS 1 and 2) on the following topics:

- the freight transport logistics, based on selected use cases (chapter 3.1)
- the freight transport on EU-27 level including projections of modal split and CO_2 emissions of road transport in year 2040 (chapter 3.2)
- the chance to reduce post- and pre-haulage costs in intermodal transport chains (chapter 3.3)
- the application of AEROFLEX innovations in Physical Internet (PI) operations (chapter 3.4).

The achieved results are based on the realized expert interviews to get information about real use cases for using the prime candidates as well as a macroscopic freight modelling, data evaluation and literature review. The document describes the relevant conclusions that have to be considered to evaluate the impact on the freight market in the EU-27. The derived recommendations (chapter 4) are based on our quantitative and qualitative impact assessment and the results that were published in WP1 deliverables D1.1 and D1.2 (AEROFLEX 2018a, 2018b). It gives an input to WP7 of AEROFLEX.

These outputs give a first appraisal of the market potential and impact on CO_2 emission in EU freight transport market by new vehicle concepts (EMS 1 and 2).

Abbreviation

AEROFLEX	project acronym for 'Aerodynamic and Flexible Trucks for Next Generation of Long Distance Road Transport'
CO_2	Carbon dioxide equivalent
EMS	European Modular System
EU	European Union
ft	feet
FTL	Full Truck Load
GHG	Greenhouse Gas
KPI	Key Performance Indicator
IWW	Inland waterway transport
ILU	intermodal standard loading units (containers 20ft, 40 ft, 45 ft, swap bodies and semitrailers approved for combined transports)
LHCV	Long heavy commercial vehicles
LTL	Less than Full Truck Load
LSP	Logistics service provider
NST 2007	Standard goods classification for transport statistics (see References)
PI/π	physical internet
TEU	twenty food equivalent unit
tkm	tonne-kilometres
ttw	tank-to-wheel
WP	Work Package
wtw	well-to-wheel

2 Introduction

2.1 Overall objective of project AEROFLEX and of WP1

The mission of the AEROFLEX project is to support vehicle manufacturers and the logistics industry to prepare for future challenges in road transport. The main objective of the AEROFLEX project is to develop and demonstrate new technologies, concepts and architectures for complete vehicles that are energy-efficient, safe, comfortable, configurable and cost-effective. Work package 1 (WP 1) contributes to the overall project objective by describing the needs of the European logistics market in order to enable a vehicle development in line with the market requirements. The present report represents deliverable 1.3. The objectives of this deliverable are:

- to describe the benefits of AEROFLEX innovations for selected use cases that were based on expert interviews
- to calculate the impact of EMS on CO_2 emissions on the EU freight transport market
- to describe the potential for AEROFLEX innovations on the physical internet (PI) as one of the identified trends in future logistics
- to derive recommendations as input for a book of recommendations.

The results of the deliverable 1.3 are used in work package 7 to give an input to the transport policy regulation and to show the potential of AEROFLEX innovations. A first stakeholder workshop has shown that it is difficult to translate the requirements of the logistics service providers directly into technical details of new vehicle concepts. Therefore, the results of WP 1 were discussed in two online webinars (in September 2020 and in March 2021) organised with the help of European Technology Platform ALICE. These two online webinars have given us the chance to disseminate our results and to get a feedback from the participants. Furthermore, a special AEROFLEX session at the IPIC 2021 conference was held to disseminate the AEROFLEX results in June 2021.

2.2 Preliminary notes

Research carried out prior to the UK's withdrawal from the European Union on 31 January 2020, and published subsequently, may include data relating to the 28 EU Member States (EU-28). Following this date, our research results take into account the 27 EU Member States (EU-28 minus the UK), unless specified otherwise.

This report presents the results of research conducted prior to the outbreak of COVID-19 in Europe in February 2020. For this reason, the results do not take account of the outbreak.

The projections of freight transport until 2040 are calculated with the assumption that only diesel fuel is used by trucks. Alternative fuels such as CNG/LNG, biofuels, e-fuels, pure electric drive-train trucks, and hydrogen trucks that will be available in year 2040 are not taken into account. Therefore, it should be considered that due to a mix of efficient internal combustion engine driven trucks using a fuel mix (fossil, bio, and synthetic) besides new technologies like electric drives (fuel cell and/or battery) in trucks, the CO_2 emissions will be significantly lower in the EU freight transport market. Our approach was designed to highlight the impact of AEROFLEX innovations to EU freight transport, but all conclusions are equally valid when considering energy consumption instead of fuel consumption and CO_2 emissions. Therefore, we do not consider any other technical and technological transformations that could be expected but it is not the scope of AEROFLEX to quantify the impact of this transformation process in EU road freight transport.

2.3 Overview of results of the previous deliverables of WP1

2.3.1 Market potential by new vehicle concepts

The deliverable D1.1 describes the relevant trends of transport related to new vehicle concepts.

Logistics and the supply chain development cause the demand for long road haulage. Figure 2-1 shows some future trends and drivers of logistics that will influence the long road haulage in the future.

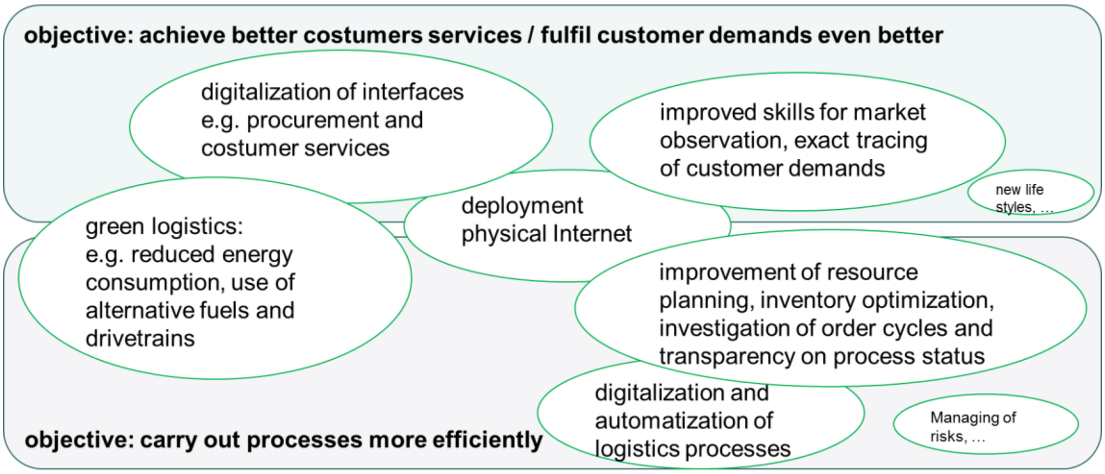


Figure 2-1: Future drivers of logistics (own figure based on Schwemmer 2017)

The conclusions for the development of new vehicle concepts are as follows:

Increase of efficiency for freight transport

First of all, the improvement of efficiency is one important driver of European freight transport market. Co-modality and synchromodality are key elements to improve the efficiency. Freight transport should be organized by the consideration of the strengths and weaknesses of the transport modes that are relevant to fulfil the requirements of the shipper: (i) lead and transport time, (i) weight and volume of the order /the shipment, (iii) and further specific costumer or good related characteristics. The transport by only one transport mode could be the most efficient way in case the strengths of this mode fulfils the given constraints, e.g. (i) to carry goods due to time constraints, (ii) to realize a direct transport between shipper and receiver without detours, (iii) and the availability of infrastructure and specialised transport equipment. Furthermore, it is necessary to fulfil the customer related expectations regarding transport costs and related to the increased influence of green logistics solutions.

The available European data shows that in terms of tonne-kilometres, about 57 % of all freight transport is realised on long haul (300 km and over, Figure 2-2). Freight transport services up to 150 km are also relevant for new vehicle concepts in combination with smart loading units in order to support more efficient transport services at the interface between long and short distance transports i.e., in terminals (for combined transport) and logistics hubs. From the perspective of tonne-kilometres, new vehicle concepts could address all goods classes and not only selected ones due to the objective to develop a configurable and cost-efficient vehicle concept that is not dedicated for only some commodities.

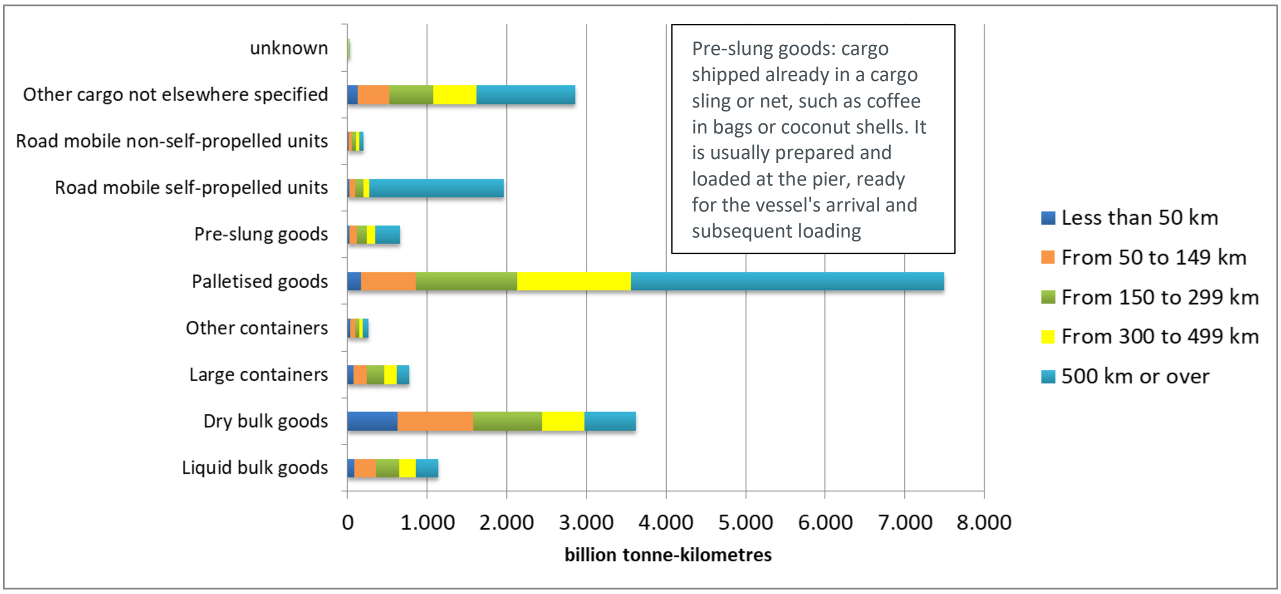


Figure 2-2: Characterisation of transported cargo in EU-28 in 2016 (EUROSTAT 2018)

Vehicle concepts should be developed for low density goods, long transport distances and high revenue logistics segments

New vehicle concepts should address good classes with high transport performance measured in tonne-kilometres (e.g. food products, beverages and tobacco, agricultural products) in combination with long transport distances. Furthermore, the potential revenues in logistics segments (e.g. contract logistics, full and less than truck load with palletized goods and courier/express/parcel) should be considered. These segments should be addressed, because the balance between market size, expected revenues and small order sizes expect a high demand for advanced vehicle concepts using modular loading units. Finally, it is recommended to realize an optimum trade-off between payloads and transport volumes in order to maximize the use of the loading capacities - combine different types of goods so that the maximum filling rate both in terms of weight and volume could be achieved, i.e. cargo that is stackable or use of double deck trailers.

Fast and frequent road transport between hubs and industrial sites become important

Due to the increasing amount of courier/parcel/express cargo and general or mixed cargo, hub and spoke transport concepts are increasingly used to consolidate the shipments and thus, to increase transport efficiency. Therefore, an already promising and further growing segment for new truck concepts can be identified in transports between hubs (e.g. terminals, ports, large warehouses) as well as between industrial sites and hubs/large warehouses/terminals. Here, it is essential that loading units can be optimally loaded and unloaded, manoeuvred, and placed at the gateways in cross-docking stations or in warehouses, even if there exists a limited space on yards and terminals for manoeuvring of trucks. Further, the organisation of a fast exchange of loading units between different vehicles or between transport modes is important.

New vehicle concepts have to be compatible with the existing infrastructure

Infrastructure conditions and constraints of the existing road infrastructure – road, bridges, yards, driveways, roundabouts, parking areas and docks – are key issues for new vehicle concepts. Currently, most parking areas and docks are not suitable for long commercial vehicles above 18.65 metres. The new vehicle concept of European Modular System (EMS) is compatible with the existing road infrastructure to avoid an extensive need for enhancement of the European road infrastructure or sophisticated technical solutions supporting manoeuvring in confined spaces on motorways and inter-urban roads.

2.3.2 CO_2 emission changes by new vehicle concepts

The deliverable D1.2 describes the findings that high-capacity vehicles are a promising concept on the way to optimizing logistics operations is supported by the fact that 62 % of the survey's participants state that they already engaged with high capacity vehicles. 46 % expect to benefit from the use of longer vehicles and 39 % expect to benefit from heavier vehicles than are currently permitted by EU regulation (EU Directive 2015/719).

In order to quantify possible savings for the different Key Performance Indicators (KPIs), use cases are analysed that are collected during expert interviews. The calculations are based on real world tours that are specified by logistics companies, including descriptions of currently used vehicles. This information is combined with characteristics of prime candidates the experts select to be potentially useful in the according use cases and fuel consumption simulations, as well as total cost of ownership (TCO) and transport cost calculations.

3 Methods and results

3.1 Impact the freight transport logistics, based on selected use cases

This first chapter presents the results of using EMS for selected use cases that were collected by interviews with logistic operators in transport companies and logistics service providers. Results are based on the quantification of benefits of EMS if they will be in operation and will replace other standard vehicles in road freight transport.

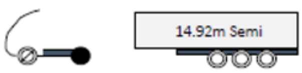
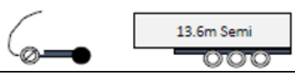
3.1.1 Methods

Following the Global Logistics Emissions Council (GLEC) Framework, two sound tools for delivery tour simulation and total cost of ownership (TCO) calculation are used to calculate the KPI values of selected prime candidates and related future increase in transport efficiency by European Modular System (EMS) vehicles in the use cases (see below). As input values for the logistics tour simulation we use, on the one hand the vehicle configurations such as weight, engine and gearbox type and rear axle ratios, and on the other hand, the cycle characteristics i.e. slope and speed. In a second step, we process the simulation results of fuel consumption and average speed to calculate the TCO using further cost factors like driver's costs, purchase and maintenance.
Furthermore, the CO_2 emissions of the reference tour (based on the expert interviews) as well as for the potential tour with an EMS are based on the simulated fuel consumptions of a MAN tool.

3.1.2 Results of use case implementation

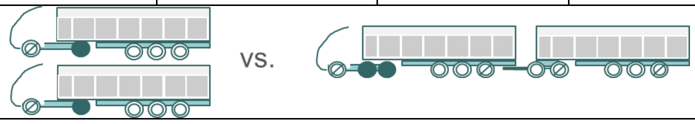
Interviewees were asked to select prime candidates per logistics segment and route type combination, which could be used in daily business providing the largest potential for economical and logistical benefits from their perspectives. The approach to use European Modular System (EMS) vehicles to improve efficiency is based on load consolidation as a crucial factor to realize the expected benefits. Thus, the impact of the use of the prime candidates is analysed with regard to the KPIs €/tkm, €/tour and CO_2 [kg] emissions tank-to-wheel (TTW) and well-to-wheel (WTW). About 53 % of the interviewee's votes were given for the following six most relevant prime candidates (in descending order of vote share): 6.1, 2.1, 3.1, 1.4, 2.2 and 4.7 (see Table 3-1). The shares ranged from 11.7 % to 6.2 %. An additional 10.1 % was achieved by Prime Candidate 1.3, which is a standard 4x2 tractor unit with a 13,62 m long semi-trailer.

Table 3-1: Share of votes by interviewees of preferred Prime Candidates

No.	Prime Candidate	Share of votes
6.1		11.7 %
2.1		9.7 %
3.1		9.7 %
1.4		9.3 %
2.2		6.6 %
4.7		6,2 %
1.3		10.1 %

In addition, standard average loads by reference vehicles are compared to the maximum load for prime candidates to calculate average mean values and standard deviations of each KPI (see above). These mean savings potentials in percentage values for different KPIs for the overall sample are displayed in Table 3-2.

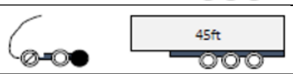
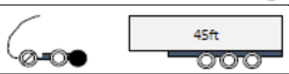
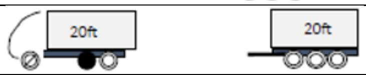
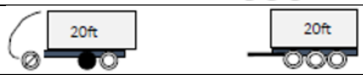
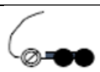
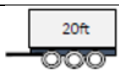
Table 3-2: Mean saving potential for overall sample in % for different KPI. Standard deviation in parenthesis. Negative values indicate advantages for the Prime Candidates.

KPI	€/tkm	Cost/tour	CO_2 TTW	CO_2 WTW[2]
Standard average load	18.7 % (10.9)	19.0 % (11.2)	28.8% (17.0)	20.9 % (11.3)
(exemplary visualization)				
Maximum load for Prime Candidate	-28.2 % (16.4)	-28.1 % (16.5)	-16.9 % (14.4)	-25.8 % (33.7)
(exemplary visualization)				

3.1.3 Results of two selected uses cases

To show the overall benefit, we select two use cases as an example. Each use case shows the potential efficiency gain by shifting reference vehicles to EMS 1 or EMS 2 for a specific current transport and maximizing the cargo volume to maximum GCW. The first use case reflects an intermodal transport chain on road and waterways and involves multiple countries (Netherlands, Germany and Finland). Using Prime Candidate 6.1 (i.e. EMS 2) makes it possible to carry 74 tons instead of 40 tons Gross Combination Weight (GCW) and results in a CO_2 emission reduction potential of -129.6 kg or -25.81 % per tour. The second use case distinguishes from the first one and gives the potential to increase transport efficiency of EMS 1. In this case a single mode logistics chain (only road) is reflected by a tour between Germany and Austria using Prime Candidate 3.2 (i.e. EMS 1) with a maximum of 60 tons instead of 40 tons GCW permissible. Due to the lower transport distance between origin and destination the emission reduction potential is limited to -72.0 kg CO_2. Nevertheless, this is equivalent to a CO_2 potential of -32.44 % on one tour.
In relation to these two use cases, Table 3-2 shows the theoretical benefits of EMS 2 and EMS 1. Only one instead of two vehicles (EMS 2) and only 3 instead of 4 vehicles (EMS 1) would be needed to transport (nearly) the same load as the reference vehicles.

Table 3-3: Prime candidates and re-allocations in selected use cases

No.	Reference vehicles (similar to 1st use case)	No.	Re-allocation w.r.t. EMS 2 (e.g. PC 6.1):	
1.1		6.1		
1.1			 (saved)	
No.	**Reference vehicles (similar to 2nd use case)**	**No.**	**Re-allocation w.r.t. EMS 1 (e.g. PC 4.3):**	
1.1		4.3		
1.1		1.1		
2.3		2.3		
2.3			 (saved)	 (saved)

2 For TTW and WWT calculations emission factors from DSLV Guide on Calculating GHG emissions for freight forwarding and logistics services (2012) have been used.

But beside this very positive theoretical effects of EMS 1 and 2, there are much more complex decisions to be taken on fleet level management, which is factored in by the results from the overall sample (cf. Table 3-3). Thus, on fleet level up to 30 % of tractors and drivers in suitable use cases could be saved by using EMS 1 and 2.

3.2 Impact on freight transport on EU-28 level including projections of modal split and CO_2 emissions of road transport in year 2040

In the following sections, we describe the two steps of calculating the impact of EMS 1 and 2 on European transport in 2040. The steps are: (I) application of a macroscopic freight model DEMO-GV for German transport, (II) upscaling the results for EU-28 (including the UK). Our approach is aimed to show the impact, based on assumptions for:

- average payload per cargo group,
- average fuel consumption, and
- transport costs (distinguishing between time and distance related transport costs.

These are developed for a baseline and four other scenarios. Our main interest is to calculate and assess the differences between these different scenarios compared with the baseline scenario. This should show the impact of using EMS 1 and EMS 2 on European road freight transport in year 2040.

3.2.1 Methods

For our projection we use the macroscopic freight model 'DEMO-GV' (Burgschweiger et al. 2017). It calculates the transported goods between c. 400 German an c. 200 other European traffic cells. The goods will be transported via three modes: 'rail', 'road' and 'inland waterways': This is the modal split. The goods transport on road can be realized by seven road-vehicle types. Five are current vehicles:

(I) Truck 3.5 ≤ 7.5 t GCW	(II) Truck 7.5 ≤ 12 t GCW	(III) Truck 12 ≤ 18 t GCW
(IV) Truck 18 ≤ 26 t GCW	(V) Truck 26 ≤ 40 t GCW	

and two are new European Modular System (EMS) vehicles:

(VI) Truck 40 ≤ 60 t GCW (EMS 1)	(VII)Truck 60 ≤ 74 t GCW (EMS 2)

The share between all truck types is the mean split in the freight transport modelling. Modal split and mean split are calculated separately for every NST-2007 commodity class (NST 2007) and the combined transport (CT). The model DEMO-GV imports the data of average load factors and average transport costs (distinguishing between time and distance related costs) for every vehicle-type. Given the higher capacity of EMS 1 and EMS 2 vehicles, there are reduced costs per transported ton and a higher average load factor.
DEMO-GV is a six-step model, including the following steps:

(I) freight generation,
(II) distribution,
(III) transport costs,
(IV) utility,
(V) modal split related to transport modes (except air transport, pipeline, maritime and short sea shipping), and
(VI) mean split on road.

3.2.1.1 Freight Modell description of DEMO-GV

(I) Freight Generation
In the first step of DEMO-GV, there is the production of supply and demand in every traffic cell: the produced goods in the sources and the needed goods in the sinks. The goods are calculated based on to the gross value added (GVA) in each traffic cell. The relation between GVA and transported goods has been described by Müller (Müller et. al 2015).

(II) Distribution
The distribution step calculates the goods (in tons) which are transported from a traffic cell (source) to another traffic cell (sink). This source-sink-relation corresponds to the following gravitation approach:

$$\exp\left(\beta_c \cdot EMU_{ij}\right) \cdot m_i^q \cdot m_j^s \quad (1)$$

$$EMU_{ij} = \ln\left(e^{u_{rail}} + e^{u_{road}} + e^{u_{iww}}\right) \quad (2)$$

β_c: fading rate of commodity c between source and sink

m_i^q: total mass of a commodity c which is transported from a source i

m_j^s: total mass of a commodity c which is transported to a sink j

u_m: Utility between source i and sink j for a commodity c and a mode m

EMU_{ij}: "estimated maximum utility" between source i and sink j

The gravitation approach and the total mass in the sources and sink are used in the 'iterative proportional fitting'. This leads to the transported mass for every source-sink-relation (distribution).

(III) Transport Cost

The third step calculates the transport cost for every source-sink-relation. Hereby, we calculate the costs for every mode separately. Each cost value represents the cost for a standard delivery order that contains average time and distance related costs of each mode. The implementation of EMS 1 and EMS 2 leads to a reduction of the average transport cost in mode road.

(IV) Utility

The utility describes the "positive value" of a shipper if goods are transported via a specific mode (between source and sink) by him. The calculation of the utilities corresponds to BVU et al. (2012).

$$u_{y,i,j,c,s,m} = \beta_s^C BC(c_{y,i,j,c,s,m}, \lambda_s^C) + \beta_s^T BC(t_{i,j,c,s,m}, \lambda_s^C) + \beta_s^P p_{y,type,m} + \beta_s^D BC(d_{y,type,m}, \lambda_s^D) \quad (3)$$

$$BC(x, \lambda) = \begin{cases} \frac{x^{\lambda}-1}{\lambda}, \text{wenn } 0 < \lambda \leq 1 \\ \ln(x), \text{wenn } \lambda = 0 \end{cases} \quad (4)$$

$u_{y,i,j,c,s,m}$: utility of source i, sink j and commodity c or (maritime/continental) combined transport

$BC(x, \lambda)$: box-cox-transformation

$c_{y,i,j,c,s,m}$: cost for a standard delivery order between i and j for commodity c or (maritime/continental) combined transport via mode m, in the year y [€]

$t_{i,j,c,s,m}$: transport time from i to j for commodity c or (maritime/continental) combined transport via mode m [min]

$p_{y,type,m} | d_{y,type,m}$: punctuality [%] and delay [min]via mode m, in year y, and via traffic type 'type' (CT or no CT)

$\beta_s^C, \beta_s^T, \beta_s^P, \beta_s^D$: weighting parameters each segment

$\lambda_s^C, \lambda_s^T, \lambda_s^D$: parameter for box-cox-transformation (each segment)

'Segments' are classification of commodity classes which behave similar in transport.

All utilities have to be calibrated by a variable summand α. This summand guarantees the modal split which has been observed in 2010. The calculation of α uses the distribution matrix of 2010 (PTV Group, TCI Röhling, Mann, H. 2016). The calibration is necessary for a reliable projection.

(V) Modal Split

The modal split for the three modes 'rail', road' and 'inland waterways' for a source-sink-relation is calculated by the probability $p_{i,j,c,s,m}$ for a specific mode (McFadden 1973):

$$p_{i,j,c,s,m} = \frac{\exp\left(u_{i,j,c,s,m}^{calibrated}\right)}{\sum_{mode} \exp\left(u_{i,j,c,s,mode}^{calibrated}\right)} \quad (5)$$

$p_{i,j,c,s,m}$: probability for a delivery order of a commodity c or (maritime/continental) combined transport from source i to sink j via mode m [1]

$u_{i,j,c,s,m}^{calibrated}$: calibrated utility for a standard delivery order of a commodity c or (maritime/continental) combined transport from i to j via mode m [1]

$\sum_{mode} \exp\left(u_{i,j,c,s,mode}^{calibrated}\right)$: sum over all modes 'mode' [1]

The modal split for a source-sink-relation with mass $m_{i,j,c,s}$ is calculated by $p_{i,j,c,s,m}$:

$$m_{i,j,c,s,m} = p_{i,j,c,s,m} \cdot m_{i,j,c,s} \quad (6)$$

$m_{i,j,c,s,m}$: tons of a commodity c or (maritime/continental) combined transport which are transported from source i to sink j via mode m (modal split) [t]

$m_{i,j,c,s}$: tons of a commodity c or (maritime/continental) combined transport which are transported from source i to sink j (source-sink-relation from distribution) [t]

(VI) Mean split on road

After calculating the modal split for all three modes, we calculate the mean split on road. Hereby, the tons which are transported on road are split on several road-vehicle types *tm*, including EMS 1 and EMS 2. We use the parameters α and γ which are calibrated by a maximum likelihood estimation. This estimation uses a sufficiently large sample for a reliable projection. The sample is Eurostat data from the year 2011 [Eurostat 2011]. The parameters α and γ distinguish between regional (≤ 150 km) and long-distance traffic (> 150 km).

$$u_{i,j,c,s,m=road,tm} =$$

$$\left(\alpha_{regional,cl} \cdot c^{ton}_{i,j,c,s,tm} + \gamma_{regional,cl,tm}\right) \cdot \delta^{regional}_{ij} + \left(\alpha_{longDistance,cl} \cdot \ln\left(c^{ton}_{i,j,c,s,tm}\right) + \gamma_{longDistance,cl,tm}\right) \cdot \delta^{longDistance}_{ij}$$

$$p_{i,j,c,s,m=road,tm} = \frac{\exp\left(u_{i,j,c,s,m=road,tm}\right)}{\sum_{tmR}\exp\left(u_{i,j,c,s,mode=road,tmR}\right)} m_{i,j,c,s,m=road,tmRoad} = p_{i,j,c,s,m=road,tmRoad} \cdot m_{i,j,c,s,m=road} \quad (7)$$

$u_{i,j,c,s,m=road,tm}$: utility for road-vehicle on road from i to j for commodity c and segment s

$c^{ton}_{i,j,c,s,tm}$: costs each ton of payload of a standard delivery order for tm between i and j, commodity c and segment s [€]

$\alpha_{regional,cl}$: generic parameter for ‘commodity cluster’ cl in regional traffic

$\alpha_{longDistance,cl}$: generic parameter for „commodityCluster“ cl in long-distance traffic

$\gamma_{regional,cl,tm}$: alternative-specific constant for tm and „commodityCluster“ cl in regional traffic

$\gamma_{longDistance,cl,tm}$: alternative-specific constant for tm and „commodityCluster“ cl in long-distance traffic

$\delta^{regional}_{ij}$: 1 if regional traffic between ij; 0 if long-distance traffic between ij

$\delta^{longDistance}_{ij}$: 1 if long-distance traffic between ij; 0 if regional traffic between ij

$p_{i,j,c,s,m=road,tm}$: probability of transporting a mass via road-vehicle type tm from i to j for commodity c ≠ 0 und segment s ≠ 1; 2 (no combined transport); qualified probability after mode ‘road’ [1]

$m_{i,j,c,s,m=road,tm}$: mass which is transported from i to j via road-vehicle type tm [t]

$m_{i,j,c,s,m=road}$: mass which is transported from i to j on road: commodity c ≠ 0 und segment s ≠ 1; 2 (no combined transport)

The upper variables are valid for commodities $c \neq 0$ and segments $s \neq 1;\ 2$ (no CT).

In general, the mean split for every road-truck type, including EMS 1 and 2, is defined by its individual costs per ton [€/t]. The calibrated parameters α and γ lead to the mean split for each road-vehicle type.

3.2.1.2 Upscaling the results for EU-28

The modal split and the means split on the road of ‘DEMO-GV’ have to be upscaled to European level. First, we calculate the freight transport in tonne-kilometres tp at German level, multiplying the transport volume tv by the distance d between the cells at German level. The unit is tonne-kilometre [tkm]:

$$tp = tv \cdot d_{Germnany} \quad (8)$$

The next step is an extension on the freight transport performance tp which exists at European level. For this reason, we assume:

$$\frac{tp_{German,c,i}}{total\ tp_{German}} = \frac{tp_{EU-28,c,i}}{total\ tp_{EU-28}} \quad (9)$$

$tp_{German,c,i} =$ Freight transport performance at German level for commodity c with mode i [tkm]
$total\ tp_{German} =$ Total freight transport performance at German level [tkm]
$tp_{EU-28,c,i} =$ Freight transport performance at European level for commodity c with mode i [tkm]
$total\ tp_{EU-28} =$ Total freight transport performance at European level [tkm]

We assume the European territory as the territory of the EU-28. The assumption (8) is the result of the same mode ratios in Germany and the EU-28 EUREF 2016 projection (EUREF 2016) Based on equation (8) and the total projected freight transport performance in EU-28 of EUREF in 2016, a disaggregated freight transport performance

in EU-28 in 2040 is derived. The freight transport performance is disaggregated by NST-2007-classification and the three modes.
The calculation of impact is realised by projections for the five scenarios.
The projection of EMS1 and EMS2 is separated into 5 scenarios [short name in brackets]:

a. baseline scenario 2040 (without EMS 1 and EMS 2) [‘Baseline’]
b. implementation of EMS 1 without any restrictions 2040 [‘EMS 1’] in modelling step (III)+(VI)
c. implementation of EMS 1 and EMS2 without any restrictions 2040 [‘EMS 1+2’] in modelling step (III)+(VI)
d. no EMS 1 and EMS 2 for ‘heavy commodities’: avoiding heavy cargo (e.g. bulk) will be shifted from rail to road [‘EMS 1+2 + exclude commodities’]: DEMO-GV distinguishes between cargo groups in all modelling step, including cost calculation (III) and modal split (V)
e. consideration of average external costs of transport e.g. study (Biehler, C., Sutter,D. 2019) from September 2019[‘EMS 1+2 + external costs’] by including them as transport costs in modelling step (III). The externals costs are allocated unbalanced to the several vehicles classes.

The focus of this assessment of the modelling exercise by a calibrated freight model is on relative variations between scenarios, all absolute figures are based on model assumptions and construction for validated projections in 2040. These projections do not show the real EU freight transport volumes in the sense of validated forecasts in 2040. This result shows the impact assessed by the modelling of different scenarios.

The share of travelled kilometres by EMS 1 and 2 in all scenarios is not limited (e.g. by a parameter that indicates a penetration grade, the availability of semitrailers or e-dollies), in comparison to all travelled kilometres on road. The individual truck-type costs define the travelled kilometre-costs for each truck-type (i.e. mean split) in every scenario. Therefore, our modelling algorithm select a truck configuration, depending on the cost per ton (related to distances and commodities) for the generated freight transport in the model. If the price [€/t] is cheaper, the percentage of the truck configuration is higher.

3.2.2 Freight modelling results

On Figure 3-1 we observe the same increase of total transport tonne-kilometres from 2010 to 2040 in all scenarios and all modes will profit by increase of tonne-kilometres, that grows up from 2,556 billion tkm in 2010 to 3,801 billion tkm (+49 %) in 2040 for all modes. As mentioned in the introduction this research was carried out prior to the UK’s withdrawal from the European Union on 31 January 2020. Further, these results present data of research conducted prior to the outbreak of COVID-19 in Europe in February 2020. For this reason, the results do not take account of the outbreak.
The combined transport (CT) is growing above average in the baseline scenario between 2010 and 2040 by 56 % for inland water way (IWW) transport and for rail freight transport by 65 %.

Related to the adjusted cost parameters, we see that the modal shift (in tkm) changes slightly:

- in the scenarios in scenario ‘EMS 1’: There is an increase of 0.7 % in road, and reductions of 2 % in rail (including CT), and 1.7 % in IWW (including CT).
- in scenario ‘EMS 1+2’: There is an increase of 1.1 % in road, and reductions of 3.2 % in rail (including CT) and 2.6 % in IWW (including CT).
- in scenario ‘EMS 1+2 + exclude commodities’: There is an increase of 0.6 % in road, and reductions of 1.5 % in rail (including CT) and 1.7 % in IWW (including CT)

In scenario ‘EMA 1+2 +external cost’ the picture is completely different compared to the other scenarios. There is a reduction of 7.4 % on road tonne-kilometers, while rail (including CT) is growing by 22 % and IWW (including CT) by 18 %. This scenario shows the significant impact of transport costs of mode split on our freight modelling results.

In general, we can conclude that the modal shift changes in scenarios by using EMS 1 and EMS 2 without compensation of the cost savings on road freight transport, lead to a slight increase of freight transport on road on the one hand, and a decrease of rail and IWW in the range up to 3 % on the other hand. If this shift to road transport is to be avoided, it is necessary to increase costs of road transport to compensate the advantage of an increased efficiency due to use of EMS 1 and 2. Therefore, the external costs of transport in scenario [‘EMS 1+2 + external costs’] were included in transport costs (for all modes) and the figure shows a directly opposed impact by shifting transports on rail and IWW.

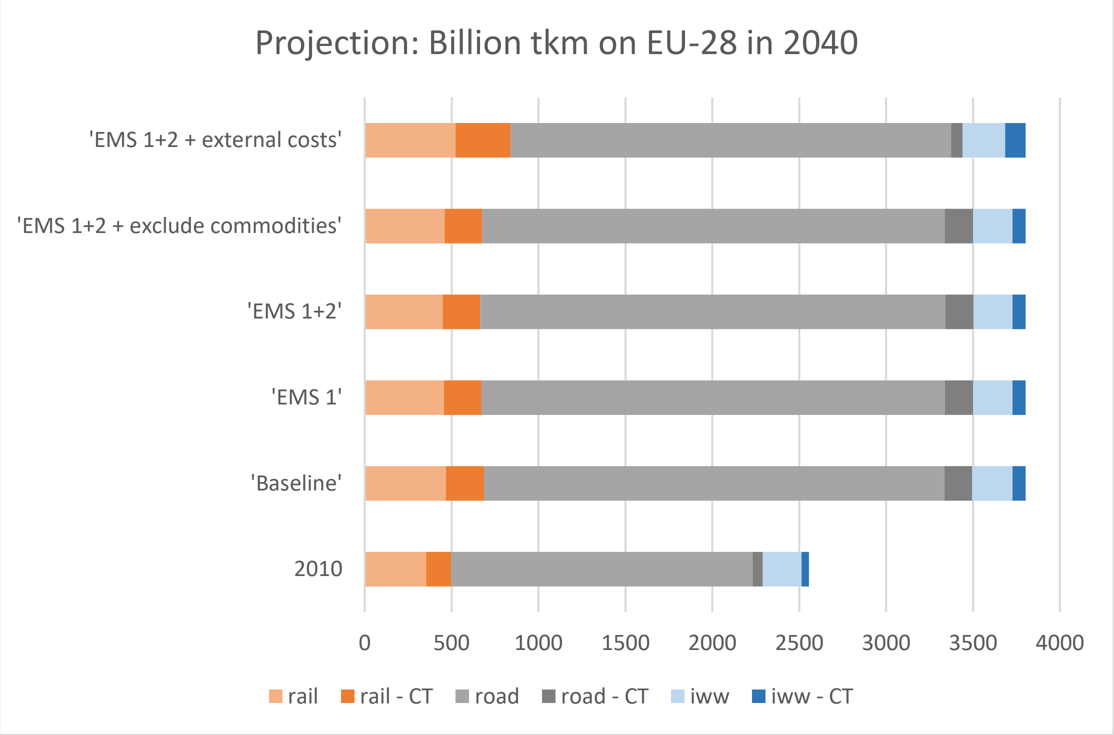


Figure 3-1: Projected transport performance (tonne-kilometres) for all scenarios

Figure 3-2 distinguishes the travelled road kilometres of the three heaviest vehicle types in all scenarios. The total travelled road kilometres grow from 293.2 billion km ('baseline') to 298.5 billion km ('EMS 1+2') in 2040. The scenario with the internalisation of external costs shows a road volume of 270.4 billion km, 7.8 % less than in the baseline scenario. The scenario with the exclusion of several commodities shows the maximum value: 301.8 billion kilometres. The strong increase of mileage in this scenario is caused by the shift of heavy commodities from EMS 1 and EMS 2 back to the standard truck with up to 40 tonnes GCW.

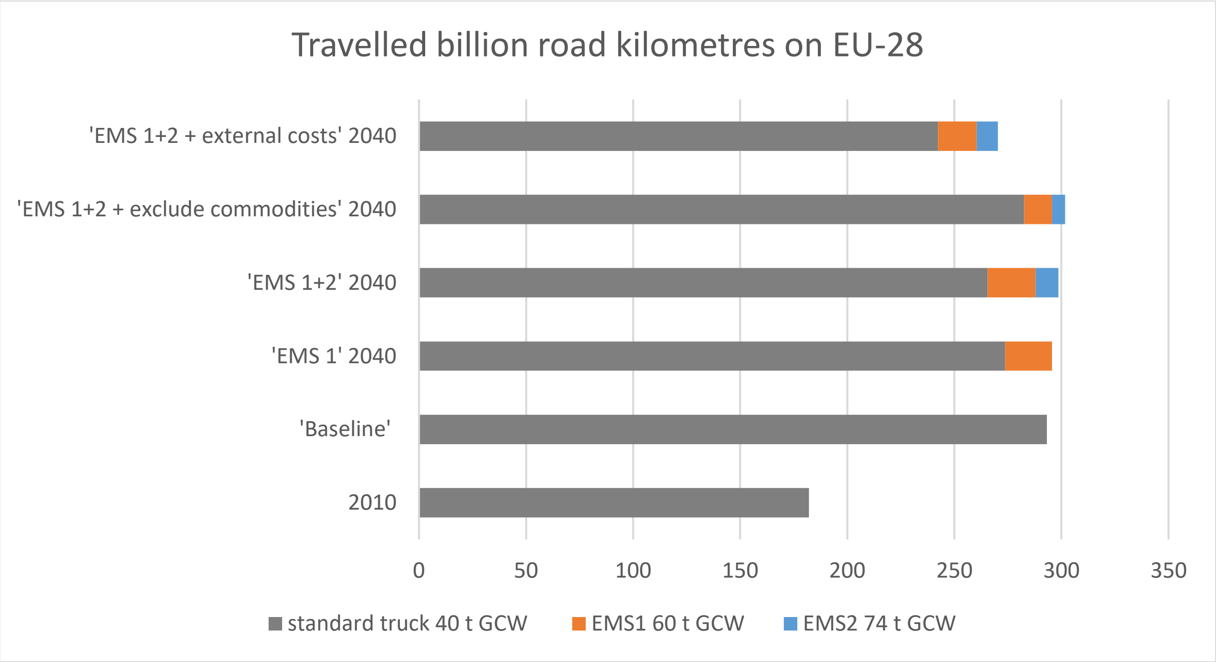


Figure 3-2: Travelled road kilometres of heavy trucks (40 t GCW, EMS 1, EMS 2) for all scenarios

The Figure 3-2 also shows the market share of EMS 1 and EMS 2 vehicles in the scenarios in 2040. In the scenario with EMS 1 the freight transport model calculates a market share of 7.4 % in road freight transport based on road mileage. In the other scenarios EMS 1 vehicles could reach a market share in road mileage between 4.3 % and 7.5 % and EMS 2 vehicles between 2.0 % and 3.7 % in 2040.

The final step in our approach is to show the impact on CO_2 emissions from road freight transport in EU-28. We calculated an average CO_2 emissions factor per vehicle-kilometre based on JEC 2020 and assumptions of the AEROFLEX project related to average fuel consumptions. These parameters were discussed in a separate with project partners and are based on the realized tests (e.g. in WP 6) and shared experiences of AEROFLEX project partners.

Table 3-4: Main assumptions for calculation of average CO_2 emissions of the vehicle with GCW 40 tons and above EU -28

vehicle type	average fuel consumption in litre per vehicle-kilometres in 2040
standard rigid 4x2 + trailer (vehicle group 4), standard tractor 4x2 + 3 axle standard semitrailer vehicle group 5), GCW 40 tons	0.28
EMS 1: rigid 6x2 + e-dolly (incl. battery package) + 3 axle AEROFLEX semitrailer with an e-axle (vehicle group 9) GCW 60 tons	0.376
EMS 2: tractor 4x2 + e-dolly (incl. battery package) + 3 axle AEROFLEX semitrailer with an e-axle + 3 axle AEROFLEX semitrailer (vehicle group 5) GCW 74 tons	0.443

The following values for CO_2 emissions are calculated with the general assumption that only diesel fuel is used by trucks. CNG/LNG, biofuels, pure electric trucks, and hydrogen trucks that will be available in year 2040 from the current perspective are not considered. Therefore, it should be considered that due to a mix of efficient internal combustion engine driven trucks using a fuel mix (fossil, bio, and synthetic) besides new technologies like electric drives (fuel cell and/or battery) in trucks the CO_2 emissions of road transport will be significant lower. The CO_2 emissions of total road freight transport could be reduced by 7.9 Mio. tonnes per year or 3.7 % compared with the baseline in EU-28 (see Figure 3-3) in the best case scenario 'EMS 1+2 + external costs'. This is due to a combination of improved fuel efficiency in road transport (from EMS 1 and 2) and the internalisation of external costs leading to modal shift.

In contrast, the freight modelling results of all other scenarios show that CO_2 emissions will increase between 3.4 % to 6.5 %, due to modal shift from rail and inland waterway to road. Our approach was designed to highlight the impact of AEROFLEX project results to EU freight transport. Therefore, we do not consider other technical transformations that could be expected.

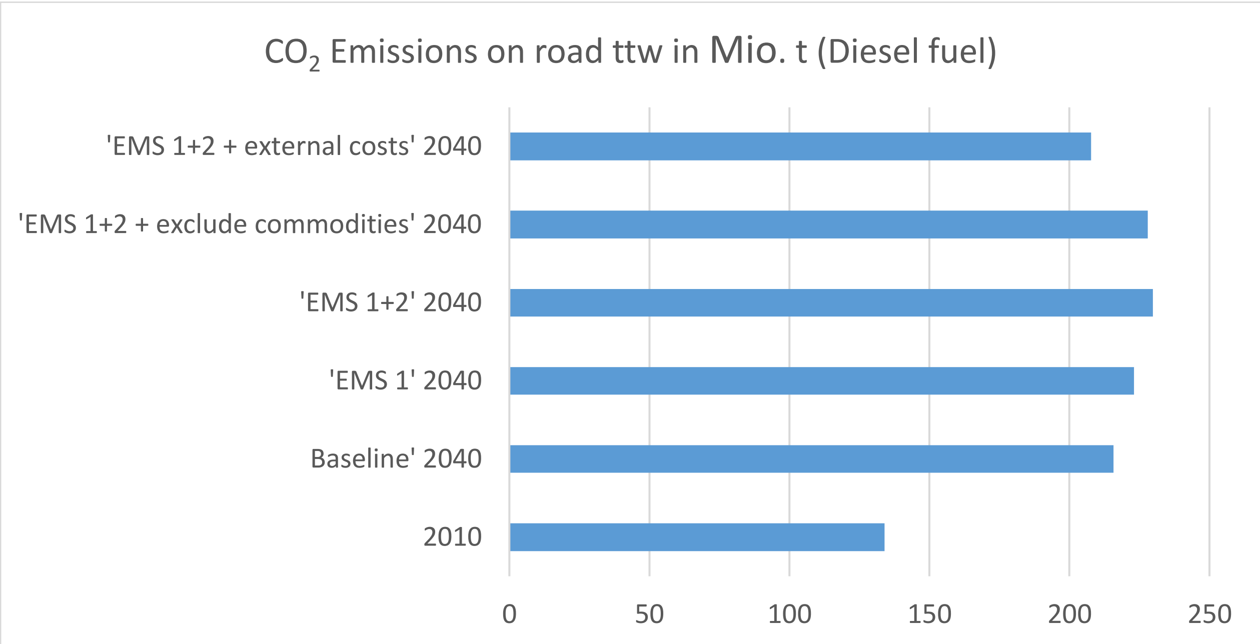


Figure 3-3: Impact on CO2 emissions on road transport (ttw: tank-to-wheel)

Based on these results, the policy regulation of transport and the access policy for EMS 1 and EMS 2 should address on the one hand the realization of the possible improvements in road freight transport. On the other hand, the future policy should be aimed to realize a level playing field in EU freight transport, so that the cost advantages of the use of EMS 1 and 2 would be compensated by measures to improve rail or inland waterway or to compensating these cost advantages by addressing measures for more sustainable transport (e.g. by use of hybrid or full electric drives or by including increased CO_2 emission costs in the whole transport sector).

3.3 Chance to reduce post- and pre-haulage costs in combined transport

Year 2021 is the European year of rail. If the objectives of the European Green Deal are met, rail will have to take up a bigger share of passenger and freight transport. Addressing this part of the EU transport policy, this chapter will discuss how EMS could help to improve combined transport by higher efficiency of pre- and post-haulage to intermodal hubs and terminals.

3.3.1 Methods

Based on the modelling results, it can be concluded that EMS could help to improve the combined transport chain by more efficient pre- and post-haulage transport between intermodal terminals and shippers. We use a qualitative approach to show the potential benefits that will be able to reduce the transport time and the transport costs for first and last mile transport.

3.3.2 Results related to combined transport

The objective of this chapter is to identify potential more efficient tours for pre- and post-haulage on road by standard equipment and by using EMS 1 and EMS 2 vehicle configurations, following a general approach that is also implemented into the freight modelling (see chapter 3.2.2). Different studies (TML et al, 2008; Fraunhofer et.al. 2009; Christidis, P., Leduc, G., 2009; K+P Transport Consultants, 2009) have investigated to the impacts of longer and heavier vehicles in long road haulage related to the volumes of combined transport and single wagon load on rail transport. These studies have not given emphasis to the possible cost saving in combined transport and benefits in logistics that could be realised by using longer and heavier vehicles. The freight modelling in AEROFLEX addresses both aspects related to assumptions of average costs,

(i) the cost savings in long-road haulage as well as
(ii) the cost savings in pre- and post-haulage on road in combined transport by using EMS 1 and EMS 2.

Due to that approach, we want to describe possible cost savings in the following description.

The following intermodal use case describes the current standard situation with intermodal standard units (ILU). It has to be acknowledged that the terminals and shipper's infrastructure to manage EMS vehicle configurations is necessary to realize the benefits.

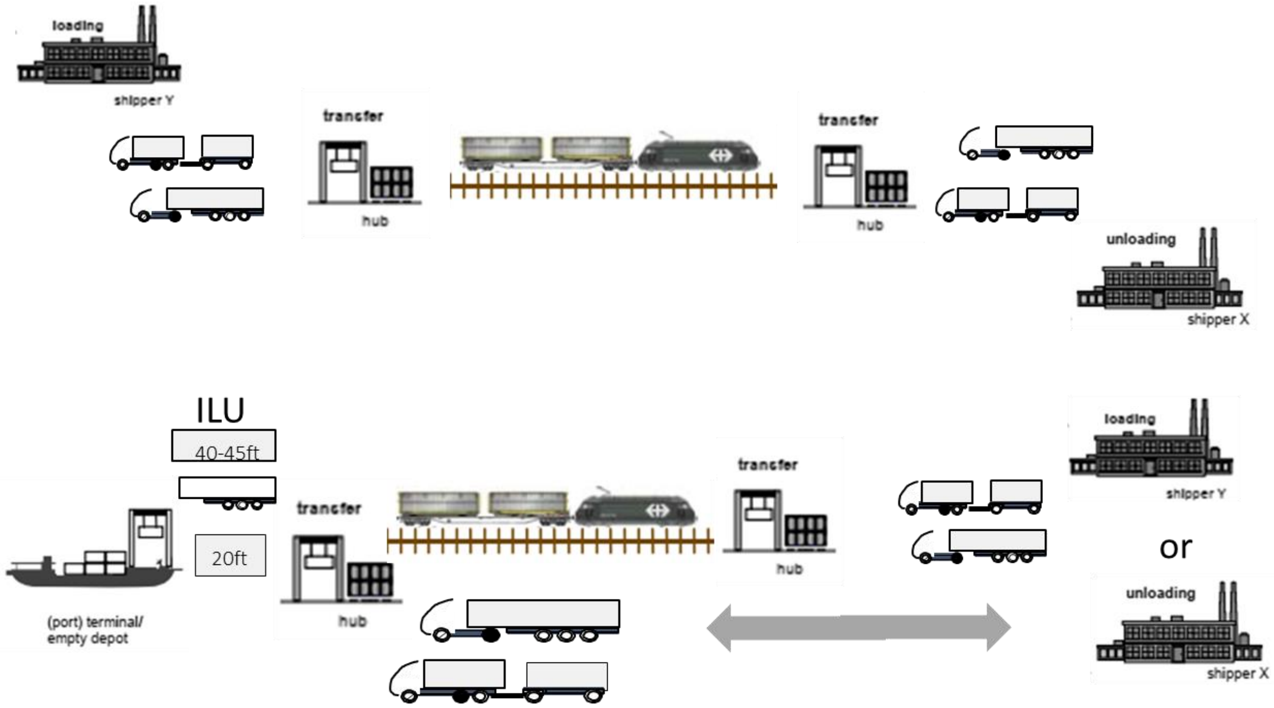


Figure 3-4: Intermodal transport chain – current standard for national and international transports

Figure 3-4 shows the use of tractor-semitrailer or rigid with container chassis and container trailer transport between shippers in an intermodal transport road/rail and between shipper and maritime or ferry-terminals.

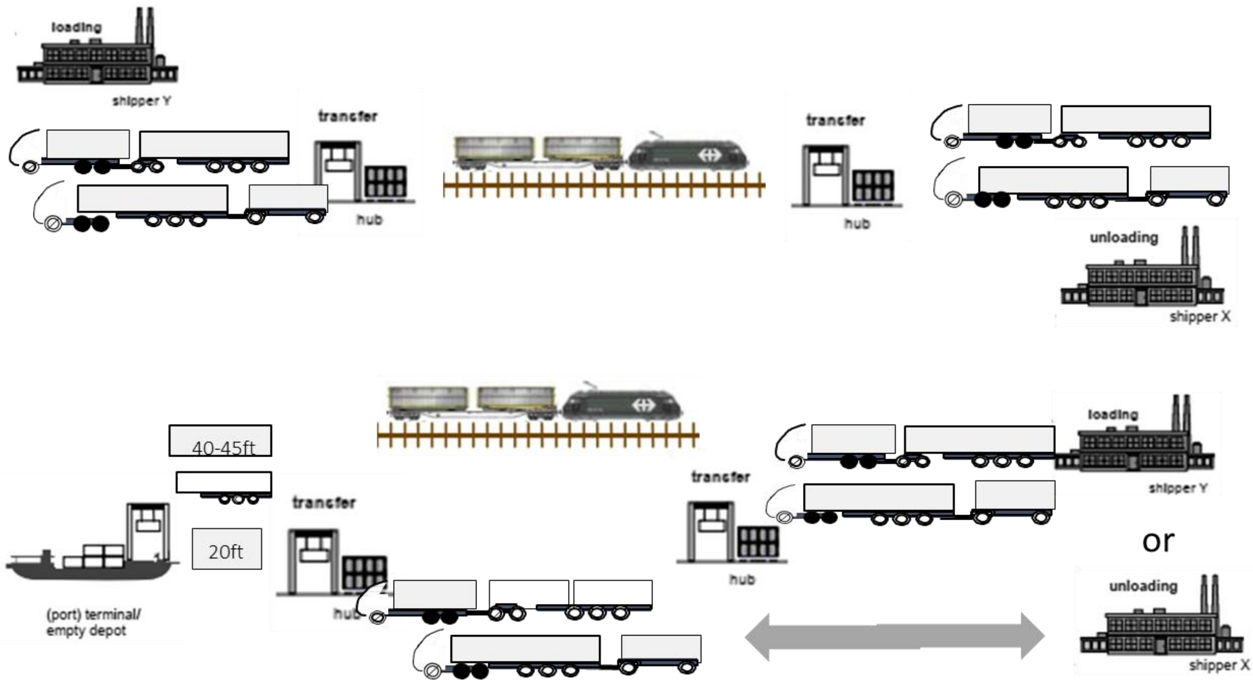


Figure 3-5: Intermodal transport chain – use of EMS 1 for national and international transports

The use of EMS 1 is shown in the next figure 3 5. The efficiency of pre- and post-haulage on road could be increased and the cost will be reduced. Based on the cost component data and the general assumption that the number of round trips from intermodal terminal to shippers and vice versa has the same frequency, we have calculated average cost savings of about 13 % per TEU (twenty food equivalent unit) – average transport volume 6 TEU per day instead of 4 TEU for a standard vehicle combination.

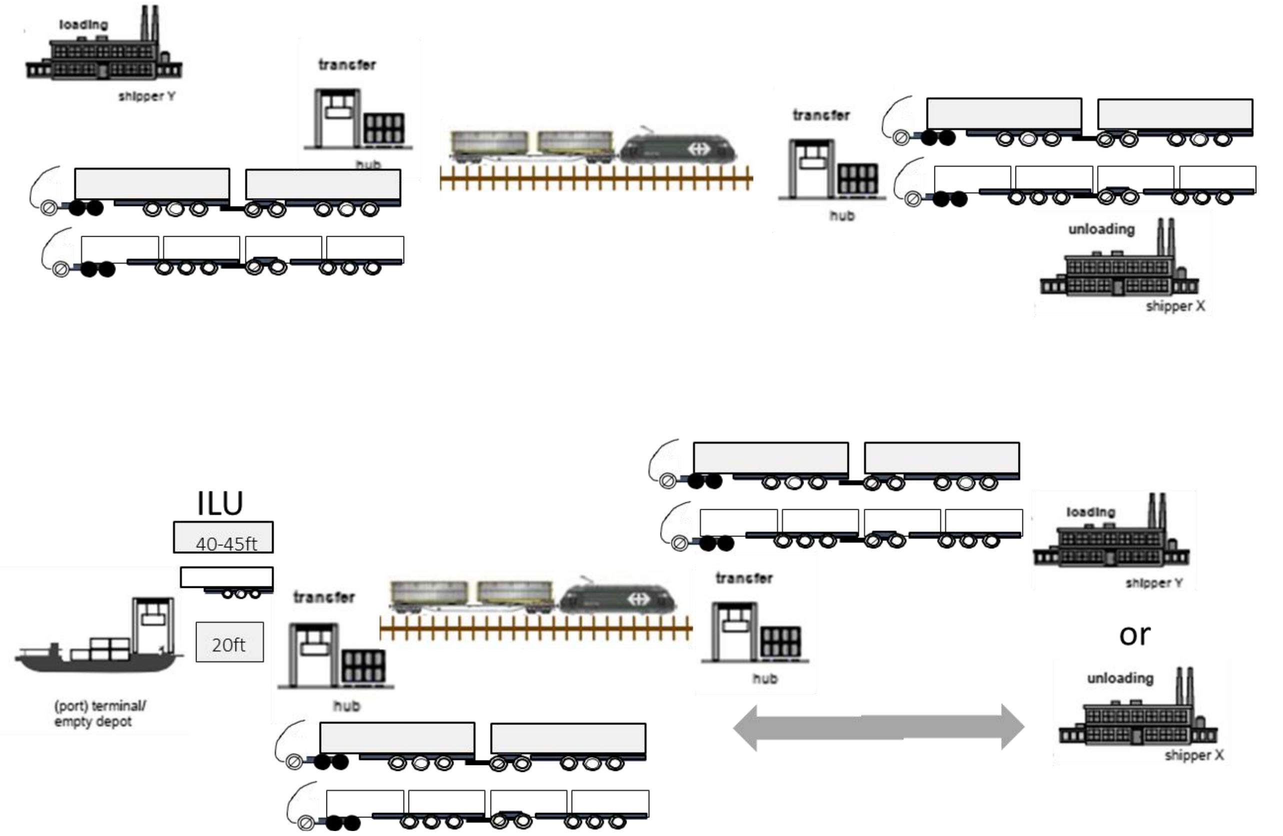


Figure 3-6: Intermodal transport chain – use of EMS 2 for national and international transports

Finally, Figure 3-6 shows the use of EMS 2 in intermodal transport. Per round trip, the number transported ILU could be doubled. The calculated cost saving per TEU is on average about 21 % compared with a standard vehicle configuration – average transport volume of 8 TEU per day instead of 4 TEU with the same number of drivers and hauling tractors. For both EMS 1 and EMS 2, the number of round trips per day to transport the same number of ILU or transport more ILU by one EMS 2 vehicle between shippers and intermodal terminals can be reduced. The shown round trip configurations in the figures 3-5 to 3-6 are not possible by using only standard HDV that have a limited capacity of only two TEU and need more round trips to carry the same numbers of ILU. EMS 1 and EMS 2 will therefore support to realised new round trip configuration that are more cost efficient. Figure 3-7 should describe one option to flexible use of EMS 2 for pre- and post-haulage in combined transport.

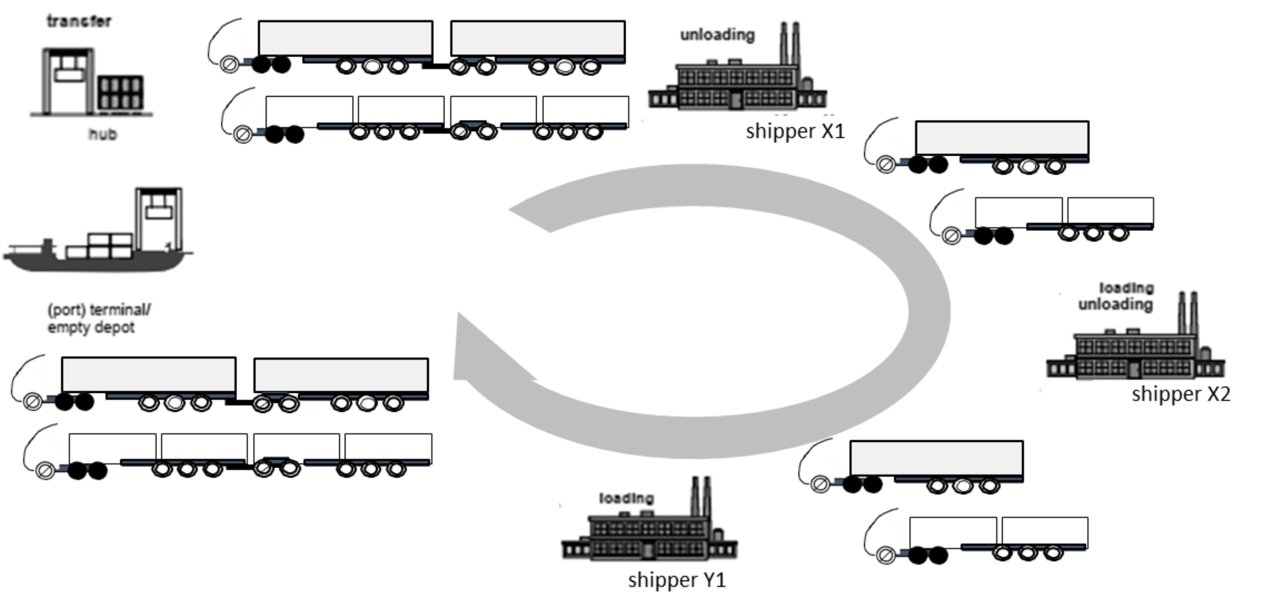


Figure 3-7: Intermodal transport chain – use of EMS 2 and the opportunity to extend the trip planning and reduce of daily circles

3.4 Contribution of AEROFLEX vehicle innovations to PI progress

The AEROFLEX project innovations can bring progress in the evolution towards the physical internet for three main areas of physical/digital/operational connectivity:

- encapsulation: standardized π containers: world-standard, smart, eco-friendly and modular
- flexible vehicles able to operate in diverse cycles, including (semi-)autonomously in logistic hubs using the electric drive train
- high capacity transport for high volume major connections

These aspects can be fitted in the physical internet roadmap. Each can be matched with innovative concepts developed in AEROFLEX:

- the Advanced Energy Management Powertrain (AEMPT) of WP2 with the ability to remote control of manoeuvring
- the Aerodynamic Features for the Complete Vehicle (AFCV) of WP3
- the Smart loading units (SML) of WP4

Furthermore, the work of WP7 regarding the regulatory framework should be of great help to facilitate the implementation of these concepts in homologation and standardisation processes that need to be set in motion if the concept is to find large scale adoption.

WP5 on the Innovative Front End Design for more Safety (IFEDS) will benefit the entire road freight transport sector and society as a whole by improving the interactions between freight vehicles and other road users. Since there is no direct link to PI concepts, this AEROFLEX innovation, while significant, is not discussed further.

3.4.1 Methods

The "Physical Internet" concept is defined as "an open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols. It is a perpetually evolving system driven by technological, infrastructural and business innovation." The parallels with the digital internet are found in these two principles:

a. standard sized packets switched and transported from host to host
b. connection of independent networks operating based on independent concepts connected through routers and switches

In physical internet (PI, or π) terms, it is the cargo that is packaged in standardised containers of many different sizes, and flows through transport networks from hub to hub on vehicles or vessels with the appropriate capacity. In the nodes that connect the hubs, intelligent systems ensure that packages are moved automatically from one vehicle to the next until the final destination is reached. This leads to better use of scarce resources including vehicles, drivers, warehouse space and transport infrastructure, greater transparency of the logistics process and reduced external costs of logistics (emissions, congestion, accidents, road damage, …).

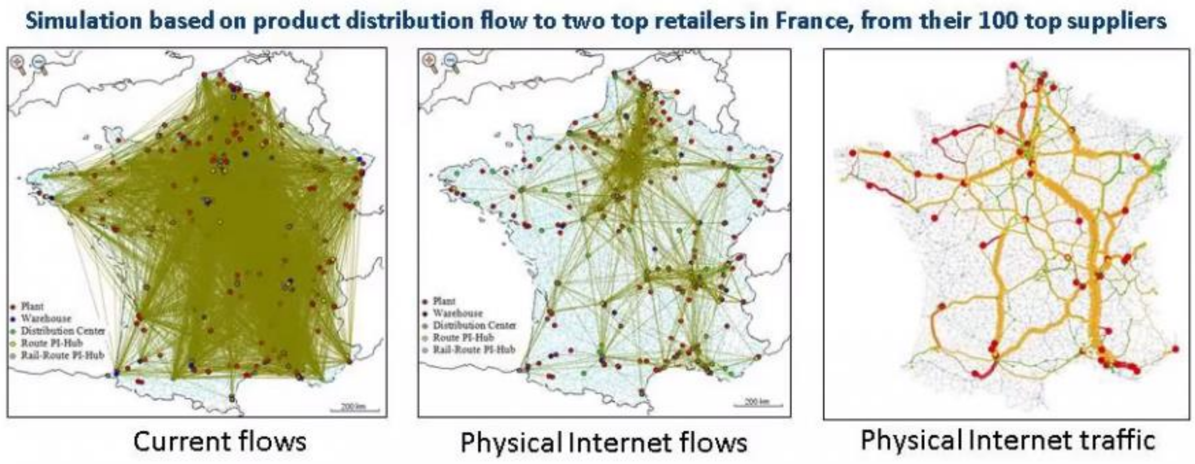


Figure 3-8: Current freight transport flows versus physical internet flows (Benoît Montreuil 2011; professor of Material Handling and Distribution at the Georgia institute of Technology)

For a more detailed description of the PI concept and its different elements and development trajectories, we refer to (Montreuil, 2011) and the large literature base on this topic.

3.4.2 Results PI concepts and AEROFLEX - Relevant aspects of vehicle innovations in PI operations

(I) Advanced Energy Management Powertrain (AEMPT) (WP2)

The AEMPT is conceptually a distributed hybrid electric powertrain. In addition to its environmental savings potential (through a more optimal power management), the functional exponent of the AEMPT is an e-dolly. While a dolly is a vehicle component that is typically used to couple a truck and a semi-trailer, through electrification and built-in communication equipment, the e-dolly can be operated remotely and without a towing vehicle. The contributions of the AEMPT to the progress of the PI development are:

- hybrid electric, distributed powertrains can help the environmental performance (fuel consumption/climate change and local pollutants) of the vehicles in the first and last mile (manoeuvring, high degree of start/stop driving).
- physical internet nodes are large or small logistics yards where autonomous manoeuvring of loading units using the e-dolly can contribute greatly to the streamlined functioning of the yard.
- this also helps mitigate the issue of driver shortage and specialisation. Drivers can focus on driving instead of loading and unloading, administration, etc. They can drop off their trailer at a gate and immediately pick up a new one to maximise their productivity.

(II) Aerodynamic Features for the Complete Vehicle (AFCV) (WP3)

The physical internet calls for high-capacity vehicles (road, rail or ship, depending on the availability of infrastructure and the service requirements for the cargo) for the transport flows between the primary nodes of the network, in the most sustainable manner. In the case of road transport, this implies maximising the energy efficiency of the largest vehicles travelling over motorways at high speeds in operational profiles that correspond to either “long haul” or “regional delivery”.

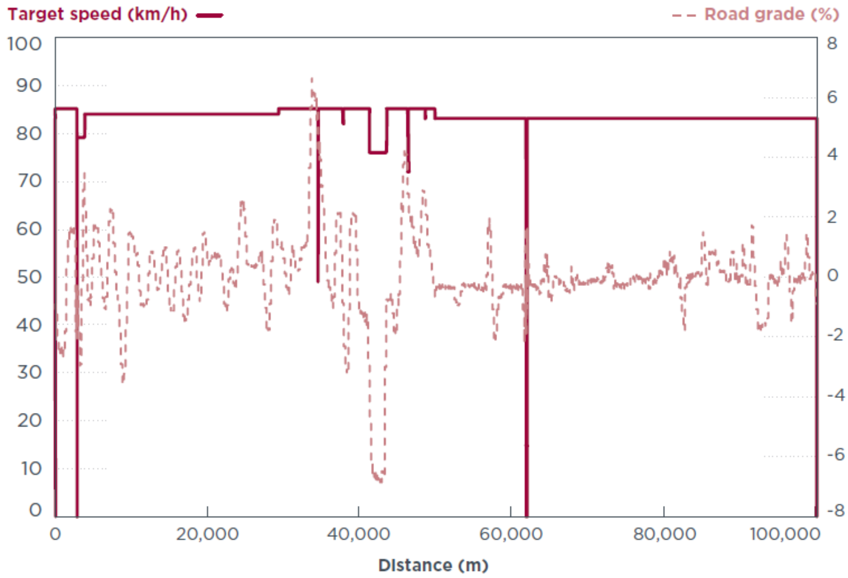


Figure 3-9: VECTO Long Haul Cycle (Delgado, Rodriguez, & Muncrief, 2017)

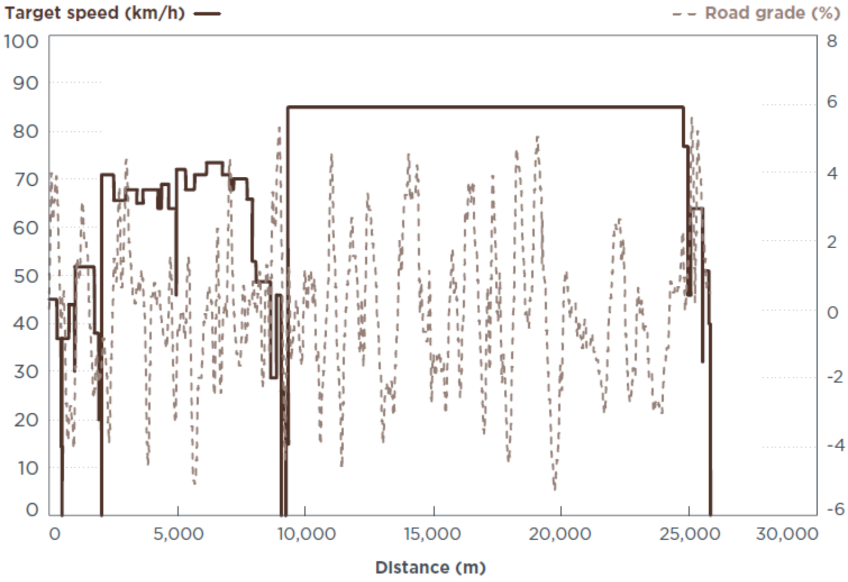


Figure 3-10: VECTO Regional Delivery Cycle (Delgado, Rodriguez, & Muncrief, 2017)

These cycles particularly lend themselves to the deployment of trucks that are aerodynamically optimized from front to back, and from top to bottom, so as to improve their fuel efficiency. The application is mainly in hub-to-hub transport, with high loads but essentially irrespective of distance. So long as there is an important part of driving under circumstances where the aerodynamic improvements developed in AEROFLEX achieve their maximal effectiveness (such as high speed driving on motorways), the deployment of AEROFLEX vehicles is useful.

(III) Smart loading units (WP4)

One of the most distinguishing features of the physical internet is the use of modular loading units that can be combined in an infinite amount of ways; from shoebox size to TEU container size. AEROFLEX works on 'Smart Loading Units' (SMLs), which cover the following features and functions:

- intelligent and safe,
- full access security,
- load optimisation,
- fast interoperability,
- aerodynamic design,
- telematics-friendly,
- fit for intermodal.

Many of the design features of AEROFLEX SMLs translate seamlessly to the PI concept's requirements.

In case road transport is not the optimal choice, the standardized loading units studied in AEROFLEX are developed with the explicit objective to be suitable for intermodal transport, with e.g. specific elements to improve the craneability of the loading unit. This is perfectly in line with the physical internet principle (and also with the synchromodality concept) to transport the cargo (or the loading unit to be exact) in the transport mode that maximizes efficiency while still meeting the customer's requirements for delivery time. This is demonstrated in the use case with UIRR/CFL as described in AEROFLEX deliverable D4.2 (https://aeroflex-project.eu/downloads-2).

Another example of increased flexibility and load factor optimisation called for by the PI concept is the use of double floor trailers (as developed in the P&G use case in D4.2 as well) and Wabco CargoCam/Fraunhofer Puzzle software (D4.3), a software tool based on the use of 3D sensors built into the trailer. Coupled with other innovations of WP4 pertaining to the accessibility and modularity of the loading space, e.g. by providing additional fixing equipment, cargo access via different sliding elements, tests have shown this can improve fill rate by 38 %.

For more details, we refer to AEROFLEX deliverable 4.2 and 4.3 (see www.aeroflex-project.eu).

4 Recommendations

The main objective of WP1 is to figure out the impact and derive requirements of potential users of EMS in relation to the future developments of the European road transport market. This section is a summary of some relevant outputs of WP1 that should be considered in the ongoing development and discussion for EMS.

Selected use cases show that transport costs (per €/tkm) and CO_2 emissions per ton-kilometres could significantly be reduced by deploying EMS. Macroscopic freight modelling compares different scenarios and shows that a positive impact on the whole EU freight transport need a regulation to scaling up the existing benefits of use cases to the whole EU road transport level.

Several projects are currently running or have run over the past decade to prepare the logistics industry for the transition to the physical internet concept. Some worked on the loading units, others worked on the organisational setup of package flows or on the Information Communication Technologies (ICT) as a backbone required to support the exchange of information between all parties involved in the logistic process. In the physical internet's analogy with the digital internet, AEROFLEX road transport innovations can take a role in the physical internet that is similar to broadband wireless connections in the digital internet: ultra-flexible, capable of moving high volumes at high speeds, with the best possible coverage at much greater efficiency than past technologies. While able to operate on its own, this new and improved characteristic of road freight transport is best supported by a strong wired network (rail, inland waterway and maritime transport) that is able to achieve even greater efficiency at higher volumes, between the main nodes, i.e. consolidation centres of the network. The process towards the uniform modularity that is required for all data/cargo transfers is advanced by the work on the smart, intermodal and fully modular loading units, which can be an inspiration for the physical internet containers and build upon initiatives of other projects such as MODULUSHCA and CLUSTERS 2.0.

4.1 EMS

The biggest and most relevant potential for EMS in road freight transport exists for full truck load transports (FTL) and less than full truck load (LTL) with a tour length of 150 km or longer (generally defined as long haul transport). About 36 % (150-300 km) and 40 % (300 km and more) of all transports that cover this long haulage distance are fully loaded (more than 90 % load factor by in terms of maximum volume or space used during the journey).

NST-2007 good groups 01, 04, 06, 08, 09, 10, 18 (Table 4-1) have the highest tonne-kilometres. Therefore, EMS should address the shippers and logistics service providers which are active in these good markets to gain a high impact of CO_2 emission reduction in European road freight transport. Temperature guided transports are a relevant part in NST-2007 good group 04. Commodities with the strongest expected growth are grouped and miscellaneous goods, representing e.g. containers and groupage activities. Metals and metal products are also projected to see increased transport volumes. Lower or negative growth is to be expected from commodity groups coal and lignite, and petroleum products, but these are hardly relevant applications for EMS.

Table 4-1: Selected standard goods classification for transport statistics (NST 2007)

NST number	Short description of goods classes
01	Products of agriculture, hunting, and forestry; fish and other fishing products
04	Food products, beverages and tobacco
06	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials; pulp, paper and paper products; printed matter and recorded media
08	Chemicals, chemical products, and man-made fibres; rubber and plastic products; nuclear fuel
09	Other non-metallic mineral products
10	Basic metals; fabricated metal products, except machinery and equipment
18	Grouped goods: a mixture of types of goods which are transported together

There is a high share of palletized goods in these relevant transport groups. The use of standardised loading units is an important pre-condition for maximisation of the use potential. This includes a harmonisation of the length of the transport equipment and loading units with the pallet's dimensions, so that it can be efficiently used by a maximum number of pallets in road transport. The overall transport volume of non-palletized cargo is less important for EMS.

There are also chances for EMS in combined transport. One special market is container haulage between container terminals i.e. in a port and for pre- and post-haulage for transports road/rail and road/IWW transport chains. This could improve the efficiency of the whole transport chain and generate benefits also for rail and IWW transports.

Another interesting market is the transport between the hubs of courier, express and parcel transporting companies. This market has been increasing strongly over the last two decades and it is expected that its growth will continue.

The main output of the online survey was that about 60 % of the stakeholders have answered that they engage vehicles with a length of more than 18.75 metres and a laden weight of more than 44 tons in their business. Nearly 50 % of the stakeholders have indicated that they expect to make economic use of vehicles with more loading meters than are currently possible. Finally, about 40 % of the stakeholders expect that they are able to make economic use – at their company – of vehicles with a higher tonnage (above 44 tonnes) than is currently permitted by EU regulation.

Projections with regard to average trip distance from four Western European countries indicate that this parameter will increase slightly, with tonne-kilometres growth outpacing tonnage growth. International transports are expected to experience a stronger increase than domestic transports.

The integration of EMS into the European road freight transport market will be possible based on existing loading units like semitrailer, ISO containers and swap bodies. For certain specialised road freight market players, e.g. logistics segments like LTL or Courier/Express/Parcel the quick exchange of swap bodies between different vehicles is very relevant. Further, in the ISO container transport segment, there is a trend that the number of 20ft containers decreases and the number of 40ft and 45ft containers will increase. Based on these findings it can be concluded that the best chance for EMS is to focus on semitrailers for the big market of palletized goods and flat chassis up to 45ft that could carry containers and swap bodies. Based on our interviews, it seems that the EMS 2 configuration is more accepted by users due to loading processes and flexibility in operation processes.

4.2 Regulations

EMS should be regulated in such a way that the maximum benefits for the whole transport sector and the CO_2 emissions can be realised. The freight modelling approach of WP1 has highlighted the expected impact of EMS in European freight transport using a 5 scenarios approach. The integration of EMS in combined transport chains should also be addressed by the transport regulation to strengthen the efficiency in pre- and post-haulage on road between intermodal terminals and shippers. Based on efficiency benefits by using EMS vehicle configurations, reverse modal shift from rail and IWW to road is a real possibility, which would increase the whole CO_2 emissions of EU freight transport. In parallel, relevant UN and EU regulations related to the approval of the vehicle shall be modified in order to allow the deployment of the proposed solution of each WP (aerodynamic devices, powered e-dolly, and front-end design).

Therefore, the transport policy regulation or the access policy for EMS 1 and EMS 2 should consider on the one hand the realization of the possible improvements in road freight transport. On the other hand, the future policy should be aimed to realize a level playing field in EU freight transport, so that the cost advantages of the use of EMS 1 and 2 would be compensated by measures to improve rail or inland waterway or to compensating these cost advantages by addressing measures for more sustainable transport (e.g. by use of hybrid or full electric drives or by including increased CO2 emission costs in the whole transport sector). Establishing a level playing field between transport modes through appropriate internalisation measures should benefit the transport system as a whole and preserve the markets of rail and inland waterway transport.

AEROFLEX innovations and EMS could also play a role in the preparatory process for the settings of standards of the PI containers and optimised vehicles. These standards would be global and thus require a different procedure what is usual in the European context only, though global collaborations on these topics occurs frequently (e.g. in the OECD-ITF). But it is of paramount importance that all existing information stemming from trials and pilots is harmonised if the process to come to such standards is to be successful, e.g. with the International Standardisation Organisation.

Routinely deploying EMS 1 and EMS 2 vehicles for transport between nodes or hub means that more cargo can be stored on the road, thus limiting the space needed at warehouses to store containers, leaving more for the processing of goods, which can help achieving a faster turnaround and reduction of transport times, while also saving time and costs for intra-warehouse cargo moves.

4.3 Conclusions

Our realized work in AEROFLEX WP1 are concluded based on our results.

- The deployment of EMS is expected to have a major impact on the CO_2 emissions of EU road freight transport, due to a decrease of mileage in road freight transport in scenario if external transport costs are considered.
- Reduced average transport costs for long haul road transport will likely decrease the share of rail and IWW in some markets, leading to more CO_2 emissions in our modelling for whole road freight transport in the year 2040. This is a modelling result but should be considered in the EU regulation for EMS to avoid such 'rebound effects'. Policy measures for EMS regulation should partly compensate cost advantages of road from using EMS - e.g. by including increased CO_2 emission costs in transport, other internalisations of external cost, cost reduction on rail and IWW.
- EMS should have a positive impact on company logistics. There will be more optimisation opportunities in trip and route planning for long road haulage, as well as for pre- and post-haulage in combined transport, due to both the increased load capacity and the flexibility of EMS. The use of EMS in hub and spoke concepts of logistics service providers, especially for good classes with high tonne-kilometres and growing market segments (e.g. food products, courier/parcel/express cargo and general cargo) in combination with long daily transport distances per truck, EMS 1 and EMS 2 will significantly reduce mileage, transport costs, and CO_2 emission.
- AEROFLEX innovations contribute to logistics optimization to increase load factors and provide more flexibility to support the development of the physical internet.
- The role of EMS 1 and 2 in pre- and post-haulage in combined transport (e.g. flexibility of loading units) should be closely examined. It is expected that the usage of EMS in combined transport (reduced costs for pre- and post-haulage) will help to reduce transport costs but it should be further investigated by demonstration in a real terminal processes if this savings could be realised by daily practice.

5 Risk and quality assurance

5.1 Risk Register

Risk No.	What is the risk	Probability of risk occurrence[3]	Effect of risk[4]	Solutions to overcome the risk

5.2 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 Cor van der Zweep (UNR)	Peer reviewer 1 Jose Campos (MAN)		Technical Coordinator Ben Kraaijenhagen (MAN)
1. Do you accept this deliverable as it is?				
2. Is the deliverable completely ready (or are any changes required)?				
3. Does this deliverable correspond to the DoW?				
4. Is the Deliverable in line with the AEROFLEX objectives?				
a. WP Objectives?				
b. Task Objectives?				
5. Is the technical quality sufficient?				

[3] Probability risk will occur: 1 = high, 2 = medium, 3 = Low
[4] Effect when risk occurs: 1 = high, 2 = medium, 3 = Low

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Project partners:

#	Partner	Partner Full Name
1	MAN	MAN TRUCK & BUS SE
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
10	TIRSAN	TIRSAN TREYLER SANAYI VE TICARET A.S.
11	CREO	CREO DYNAMICS AB
12	MICH	MANUFACTURE FRANCAISE DES PNEUMATIQUES MICHELIN
13	WABCO	WABCO Automotive
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
25	ZF	ZF CV Systems Hannover GmbH
26	VET	Van Eck Trailers

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8 Appendix A – Risk table

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

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