Impact of High Capacity Vehicles on the future developments in the Logistics sector

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Abstract:

The reduction of the carbon dioxide emission in road freight transport in the next decades is a key issue. Focussing on this challenge, we analyse the impact of high capacity road transport with longer and heavier-trucks (European Modular System: EMS some examples see Table 1) on mode choice and CO_2e emissions at the EU 28 level. The presented results are part of research done in the EU project AEROFLEX (Aerodynamic and Flexible Trucks for Next Generation of Long Distance Road Transport) funded in the H2020 programme.

AEROFLEX project aimed to increase efficiency up to 33 % in long distance road transport and logistics. For assessing the impacts of these new vehicle types, this article describes the several approaches that are used to determine the expected impacts.

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.

Conference Topic(s): *Interconnected freight transport, logistics and supply networks and Vehicles and transshipment technologies*

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1 Introduction

This article is structured into four chapters describing the impacts of high capacity vehicles of European Modular System: EMS 1 and 2 using an Advanced Energy Management Powertrain (AEMPT) with an e-dolly and aerodynamic-optimized tractors and semi-trailers (some examples, see Table 1). In the second chapter we quantify the impact from a use case perspective for selected commodities to show the improvements on logistics concepts or logistics pattern based on data collected through interviews with logistics service providers. In the third chapter, it is evaluated by freight transport modelling the impact of efficiency increases

- due to a higher average load factors (related to AEROFLEX innovations of Wabco CargoCam/Fraunhofer puzzle software). Further, it is considered already existing double-stack loading to increase cargo consolidation and cost reductions due to higher transport capacity per truck on road enabled by EMS 1 and 2 (related to tonne-kilometres due to higher weight and length limitations of EMS). The increase of efficiency on road transport is implemented in modelling parameters for these bot new vehicle configurations and shows the impact on freight transport at the EU 28 level based on several scenarios. In the last chapter, the impact on Physical Internet (PI) coming from innovations of AEROFLEX are elaborated.

2 Impact of High Capacity Vehicles on logistics

Based on the network of the AEROFLEX project partners and sounding board members several online stakeholder surveys and in-depth expert interviews amongst logistic service providers (LSP) and shippers have been conducted. Out of this, 32 different use cases have been created. The regarding tours involved 19 countries, either as origin, destination or transit country (EU countries as well as Serbia and Turkey). Combined, 171 different combinations of tours, vehicle and load variants have been analysed. 24 Prime Candidates have been chosen by interviewees from a total number of 27 Prime Candidates as possible vehicle concepts to be used.

2.1 Combined results of interviews

Interviewees were also asked to select Prime Candidates per logistics segment and route type combination, which could be used in daily business providing biggest 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_2e [kg] emissions tank-to-wheel (ttw) and well-to-wheel (wtw). About 53 % of the interviewees vote 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 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 metres semi-trailer.

Table 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 2.

Table 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	CO2e TTW	Co2e WTW
Standard average load	18.7% (10.9)	19.0% (11.2)	28.8% (17.0)	20.9% (11.3)
Maximum load; average savings for all use cases	-28.2% (16.4)	-28.1% (16.5)	-16.9% (14.4)	-25.8% (33.7)

2.2 Results of two selected uses cases

To show the overall benefit in an exemplary way, the following two use cases are selected. Each use case shows the potential efficiency gain by shifting reference vehicles to EMS 1 or EMS 2 for a specific todays transport. The first use case reflects an intermodal logistics chain on road and water ways and involves multiple countries (Netherlands, Germany and Finland). Using Prime Candidate 6.1 (i.e. EMS 2) enables 74 tons instead of 40 tons Gross Combination Weight (GCW) and results in a CO_2e emission reduction potential of -129.6 kg or -25.8 % on one tour. The second use case distinguishes from the first use case and gives an explanation about 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 an emission reduction potential of only -72.0 kg CO_2e could be achieved. Nevertheless, this is equivalent to a CO_2e potential of -32.4 % on one tour.

In relation to these two use cases table 3 shows the theoretical benefit of EMS 2 and EMS 1. Only 1 instead of 2 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: 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	45ft	6.1	45ft 45ft
1.1	45ft		(saved)
No.	**Reference vehicles (similar to 2nd use case)**	**No.**	**Re-allocation w.r.t. EMS 1 (e.g. PC 4.3):**
1.1	45ft	4.3	20ft 45ft
1.1	45ft	1.1	45ft
2.3	20ft 20ft	2.3	20ft 20ft
2.3	20ft 20ft		(saved) 20ft (saved)

But beside these very positive theoretical effects of EMS 1 and 2, there are much more complex decisions to be taken on fleet level, which is factored in by the results from the overall sample (cf. Table 2). 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 Impact of High Capacity Vehicles on freight transport of EU

3.1 Methodology approach

This chapter describes a freight modelling approach to calculate the impact of EMS 1 and 2 related to EU freight transport in 2040 by considered impacts like (i) the possible shift in mode choice, (ii) the change road transport mileage, and (iii) expectations on CO_2e emissions. The two topics of access policy and infrastructure requirements for EMS 1 and 2 are not addressed. The project AEROFLEX elaborated these two topics in a special approach and the impact assessment gives input to the argumentation. Thus, the described scenarios do not consider existing regulations for High Capacity Vehicles in several EU countries as well as current EU regulation on the maximum authorised dimensions in national and international traffic and the maximum authorised weights in international traffic (Directive 2015/719/EC, 2015) or other restrictions.

3.1.1 Freight modelling

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 transport modes: 'rail', 'road' and 'inland waterways' and indicate the transport modal split. The goods transport on road can be realized by seven road-vehicle types (GCW: Gross Combination Weight):

Table 4: Table: truck types used in modelling approach

(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 with 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. 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 for every vehicle-type. Due to EMS 1 and 2 configurations: there are reduced costs per tonne-kilometres based on a higher available transport volume and GCW as well as a higher average load factor (by using AEROFLEX innovations like the Wabco CargoCam/Fraunhofer puzzle software as well as already existing double-stack loading to increase cargo consolidation, which help to optimize the ratio of transport volume and weight).

The input parameters for cost calculations (e.g. average fuel consumption) were fixed bases on exchange with AEROFLEX project partners, who give input from the results of their testing and simulations. The relevant transport costs distinguish time and distance related costs of different transport modes and vehicle types.

3.1.2 Upscaling the results for EU 28

The modal split and the means split on the road of 'DEMO-GV' have to be upscaled to the EU level. First, we calculate the freight transport in tonne-kilometres (transport performance) 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]:

$$tp = tv \cdot d_{Germnany} \tag{1}$$

The next step is an extension on the freight transport performance tp which exists at EU 28 level. For this reason, we assume:

$$\frac{tp_{German,c,i}}{total\ tp_{German}} = \frac{tp_{EU-28,c,i}}{total\ tp_{EU-28}} \tag{2}$$

- $tp_{German,c,i}$ = 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]

The assumption (2) is the result of the same mode ratios in Germany and the EU 28 (EUREF projection, 2016). Based on equation (2) 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 maritime transport as well as short see shipping were not considered due to the assumption that this transport mode would not be influenced by use of EMS 1 and EMS 2 in land-based transport.

Based on the freight modelling output in tonne-kilometre by vehicle type, we derive the annual mileage using the average load factors for selected vehicle types in table 4: (V), (VI) and (VII). The CO_{2e} emissions are calculated based on emission factors of JEC (JEC, 2013, 2014).

3.1.3 Scenarios

The projection of EMS 1 and 2 is separated into 5 scenarios [short name in brackets]:

(1) baseline scenario 2040 (without EMS 1 and EMS 2) ['Baseline']
(2) implementation of EMS 1 without any restrictions 2040 ['EMS 1']
(3) implementation of EMS 1 and EMS 2 without any restrictions 2040 ['EMS 1+2']
(4) 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']
(5) consideration of external costs of transport e.g. study (Biehler, C., Sutter,D. 2019) from September 2019 ['EMS 1+2 + external costs']

Using these scenario projections, we are able to conclude the impact by comparison of the results of the different scenarios for EU 28.

3.1.4 Results

Corresponding to Figure 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.

The combined transport (CT) is disproportionately growing in the baseline scenario between 2010 and 2040 by 78 % for inland water way (IWW) transport and for rail freight transport by 56 %.

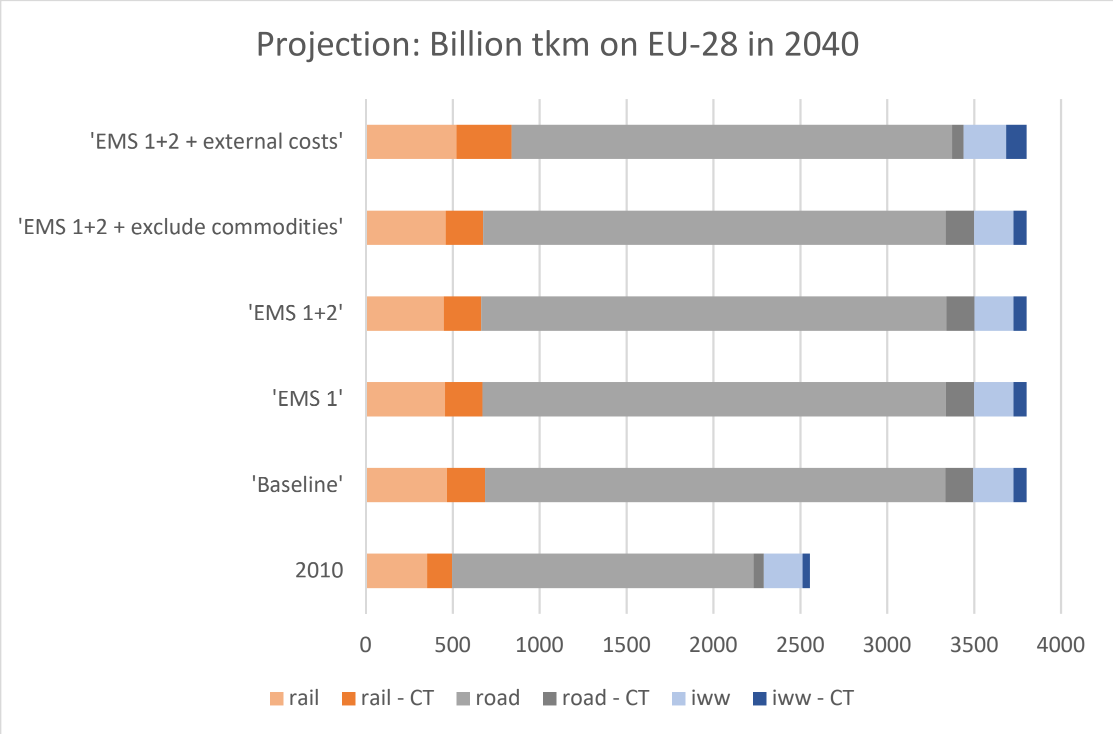

Figure 1: Projected transport performance for all scenarios

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

- in in scenario 'EMS 1': There are an increase of 0.7 % on road and a reduction of 2 % on rail including CT and 1.7 % on IWW including CT.
- in scenario 'EMS 1+2': There are an increase of 1.1 % on road and a reduction of 3.2 % on rail including CT and 2.6 % on IWW including CT.
- in scenario 'EMS 1+2 + exclude commodities': There are an increase of 0.6 % on road and reduction of 1.5 % on rail including CT and 1.7 % on IWW including CT.

In scenario 'EMS 1+2 +external cost' the picture is different related to the other scenarios. There is a reduction of 7.4 % on road and rail including CT is growing by 22 % and IWW including CT by 18 %.

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_2e emission costs in the whole transport sector).

Figure 2 distinguishes the travelled road kilometres of the three heaviest vehicle types in all scenarios. The total travelled road kilometres grow up from 293.2 billion km ('baseline') to 298.5 billion km ('EMS 1+2'). The implementation of external costs leads to 228.8 billion km, nearly 22 % less road kilometres as in baseline scenario. If there is assumed the exclusion of several commodities, we achieve the maximum: 301.7 billion kilometres. The strong increase of mileage in this scenario is determined by the shift of heavy commodities from EMS 1 and 2 back to the standard truck with up to 40 tonnes GCW.

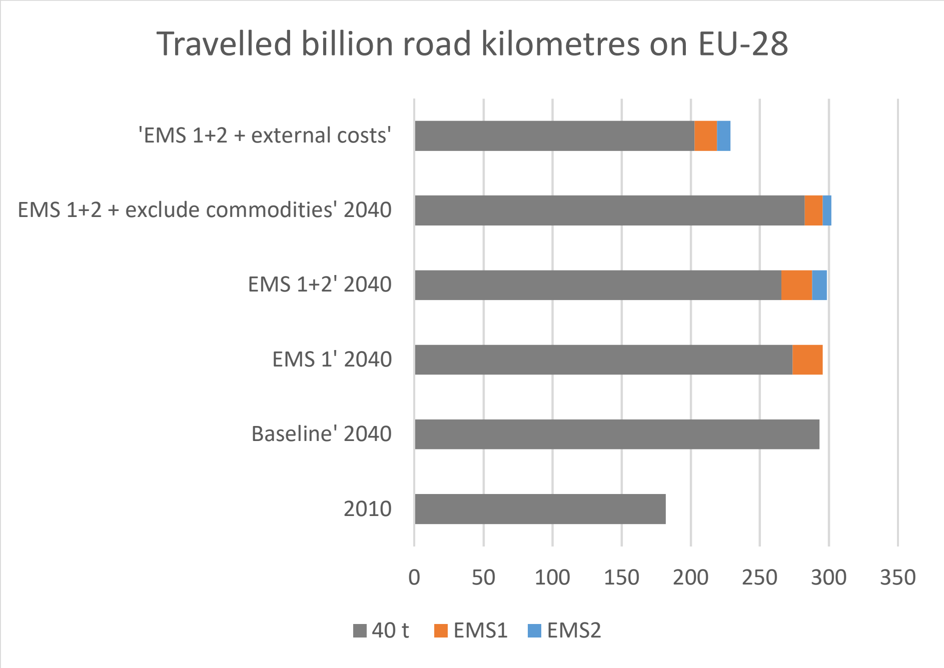

Figure 2: Travelled road kilometres of heavy trucks (40 t GCW , EMS 1, EMS 2) for all scenarios

The final step in the methodology is the calculation of CO_2e emissions of road freight transport in EU 28. The CO_2e emissions could be reduced by about 39 Mio. tonnes per year or about 18 % compared with the baseline in EU 28 (see figure 3) in the best case scenario 'EMS 1+2 + external costs'. This scenario does not assign the efficiency improvements of road freight transport to a reduction of transport costs (€/tkm) in comparison with the other modes.

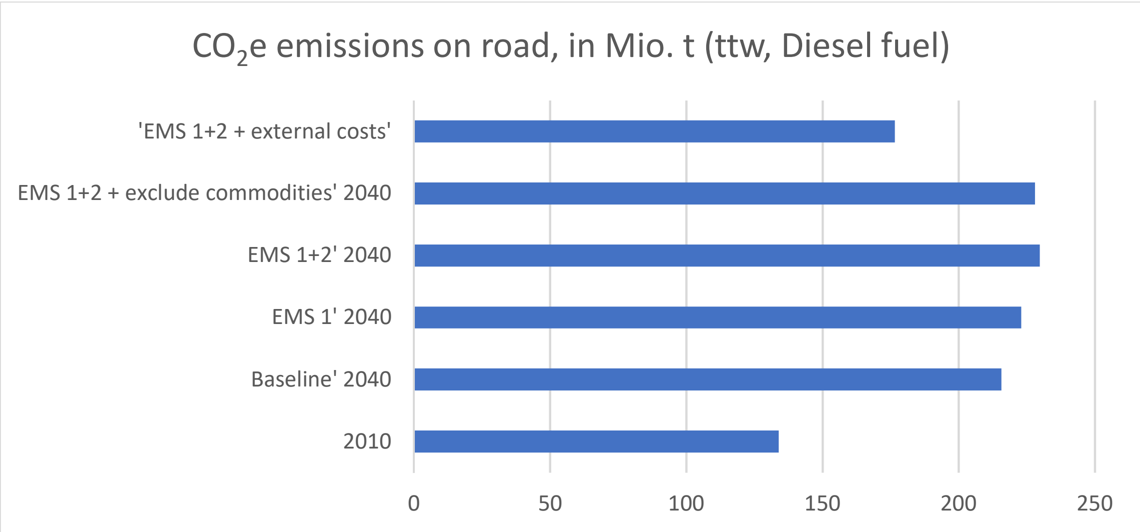

Figure 3: Impact on CO_2e emissions on road transport (ttw: tank-to-wheel)

In contrast, the modelling results of all other scenarios show that CO_2e emissions will increase due to mode shift from rail and inland water way to road. Based on these results, the policy regulation framework or the access policy for EMS should address on one hand side the realization of the possible improvements in road freight transport. On the other hand, the cost of road freight transport (in €/tkm) should be influenced by regulations in a way, that the cost advantages of the use of EMS would be compensated by measures to improve rail or inland water way (e.g. by including increased CO_2e emission costs in transport, internalisation of external cost, cost reduction on rail and IWW).

4 Application of AEROFLEX innovations in PI operations

The AEROFLEX project innovations can bring progress in the evolution towards the physical internet (PI) 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 (of AEROFLEX trailer and/or dolly)
- high capacity transport for high volume major connections (e.g.: hub-to-hub transport with full truck load)

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

- Advanced Energy Management Powertrain (AEMPT)
- Aerodynamic Features for the Complete Vehicle (AFCV)
- Smart loading units (SML)

Furthermore, the work 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.

The rest of this section discusses some of these innovations in more detail.

4.1 Advanced Energy Management Powertrain (AEMPT)

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 rigid or a tractor and a semi-trailer, through electrification and built in communication equipment, the e-dolly can be operated remotely and without a towing vehicle. This allows the driver to split the whole EMS 1/2 in separate units for easy maneuvering and parking. 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 (maneuvering, high degree of start/stop driving).
- Physical Internet nodes are large or small logistics yards where autonomous maneuvering 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 specialization. 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 maximize their productivity.

4.2 Aerodynamic Features for the Complete Vehicle (AFCV)

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 maximizing 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” (as defined in the VECTO tool (European Commission DG CLIMA, 2021).

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.

4.3 Smart Loading Units (SML)

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 optimization,
- 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. 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. Another example of increased flexibility and load factor optimization called for by the PI concept is the use of double floor trailers and the CargoCam of project partner WABCO and the puzzle software of project partner Fraunhofer IML, a software tool based on the use of 3D sensors built into the trailer. Tests have shown, this can improve fill rate up to 38 %. These concepts are demonstrated in the project through practical use cases.

4.4 Other considerations

In addition to technological development, AEROFLEX work on the regulatory framework can be a stepping stone for further innovative legislative design to accommodate other PI-related advances.

5 Conclusion

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 centers 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 EU projects such as MODULUSHCA and CLUSTERS 2.0.
Use cases show, that on a transport related level transport costs (per €/tkm) and CO_2e emissions per ton-kilometres could significantly be reduced. Macroscopic freight modelling compares different scenarios and shows that a positive impact on whole EU freight transport need an intelligent access policy to scaling up the existing benefits of use cases to the EU road transport level. More detailed information about AEROFLEX innovations and findings are available at the website www.AEROFLEX-project.eu.

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