AEROFLEX - TRANSPORT EFFICIENCY POTENTIAL OF EMS VEHICLES USING LOGISTIC USE-CASES




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Abstract

This paper describes the assessment framework of the AEROFLEX project and the first results obtained with this framework. Within the AEROFLEX project, new vehicle concepts are being developed and demonstrated utilizing technological innovations including improved aerodynamics, a distributed powertrain and flexible, and adaptive loading units. The assessment framework has been developed in order to compare the fuel-efficiency of the innovations on different vehicle concepts used in a variety of real-world logistic use-cases. The assessments in this paper show the comparison of current vehicles with longer and/or heavier vehicle concepts. The results show that considerable fuel savings (up to 30% in l/t-km) can be gained by increasing the size and weight of the vehicle on a use-case, where the savings depend strongly on the specifics of the cargo (mass, volume, loading unit) and the route (elevation, length, average speed). The future steps to include the AEROFLEX innovations into the analysis and to look at the effect of the savings on the costs and benefits for each use-case, are highlighted.

Keywords: vehicle simulation, heavy-duty transport, fuel efficiency, EMS.

1. Introduction - the AEROFLEX Project

The vision of the AEROFLEX project [Kraaijenhagen *et al.* 2018] is to support vehicle manufacturers and the logistics industry to meet the future challenges for road transport. The goal of the AEROFLEX project is to develop and demonstrate new technologies, new concepts and new architectures for complete vehicles with optimised aerodynamics, powertrains and safety systems as well as flexible and adaptable loading units with advanced interconnectedness contributing to the vision of a “physical internet” [Lischke *et al*. 2021]. These new vehicle concepts and innovations need to be assessed in terms of their impact on transport efficiency and CO_2 emissions. In the AEROFLEX project, an assessment framework is developed and used to calculate the impact of the demonstrator vehicles and a variety of other combinations of vehicle configurations and innovations.

EMS (European Modular Systems) or HCV (High Capacity Vehicles) play an important role achieving the goals of the AEROFLEX project. The philosophy of the AEROFLEX project is that optimized aerodynamics, distributed powertrains and adaptable loading units enable the EMS pulling units to be relatively simple, cheap and fuel efficient. In this way, transport efficiency could benefit most and the best cost-benefit ratio should be reached. In the project both EMS1 (25.25 m) and EMS2 (32 m) are tested and evaluated. At the moment of writing this paper, all reference vehicles are tested and evaluated and the EMS1 and EMS2 demonstrator vehicles including the AEROFLEX innovations are subject to various on-road tests. Since the project will end in September 2021, this paper will show the potential impact of EMS1 and EMS2 vehicles, excluding the AEROFLEX innovations. The final results of the project will be reported and presented during the AEROFLEX final event end of September 2021.

A unique factor in this project is the use of so-called “customer use-cases”. In the project, more than 50 companies in the logistic sector were interviewed and a selection of these companies were used to describe actual use-cases [Lobig *et al*. 2018]. This selection will be used in the evaluation phase of the AEROFLEX project, to make sure that the potential of the vehicle configurations and innovations are based on realistic and actual situations in logistics. For this evaluations phase, an assessment framework is developed to accommodate both customer use-cases and the AEROFLEX vehicle configurations and innovations. Using this framework, the impact on transport efficiency, CO_2 emissions and cost-benefit can be calculated, using exactly the same routes the owners of the use-cases perform, including elevation profiles and traffic conditions. Furthermore, the assessment framework allows the finetuning of the vehicle configurations and specifications, as well as the combination and specifications of the AEROFLEX innovations, according to the specific needs of each use-case. The assessment framework described in this paper focusses on transport efficiency of vehicle concepts in logistic use-cases. Other impacts of high capacity vehicles, such as infrastructure wear, bridge capacity and safety performance are not part of the assessment framework and this paper.

2. Assessment Methodology

In this section the assessment framework used in the AEROFLEX project is described. The role of the final technical assessment within the project is to build on the results of the reference and demonstrator tests, being performed with actual vehicles on the road. These tests are the most realistic means to measure the fuel efficiency of the vehicles. However, the fuel efficiency of a vehicle concept is affected by numerous factors such as the logistic application (e.g. length of the route, payload, number of stops, multimodality), the location (temperature, weather conditions, regulations) and the routes (route profile, speed limit, elevation, traffic conditions) in which the vehicle concept is being deployed. It is clear that it is not feasible to test all possible combinations of factors within the limited time and resources of the project. The simulation studies performed within the final technical assessment are meant to identify those factors that influence the performance of the vehicle combinations and to assess them if they have not been assessed by the on-road tests.

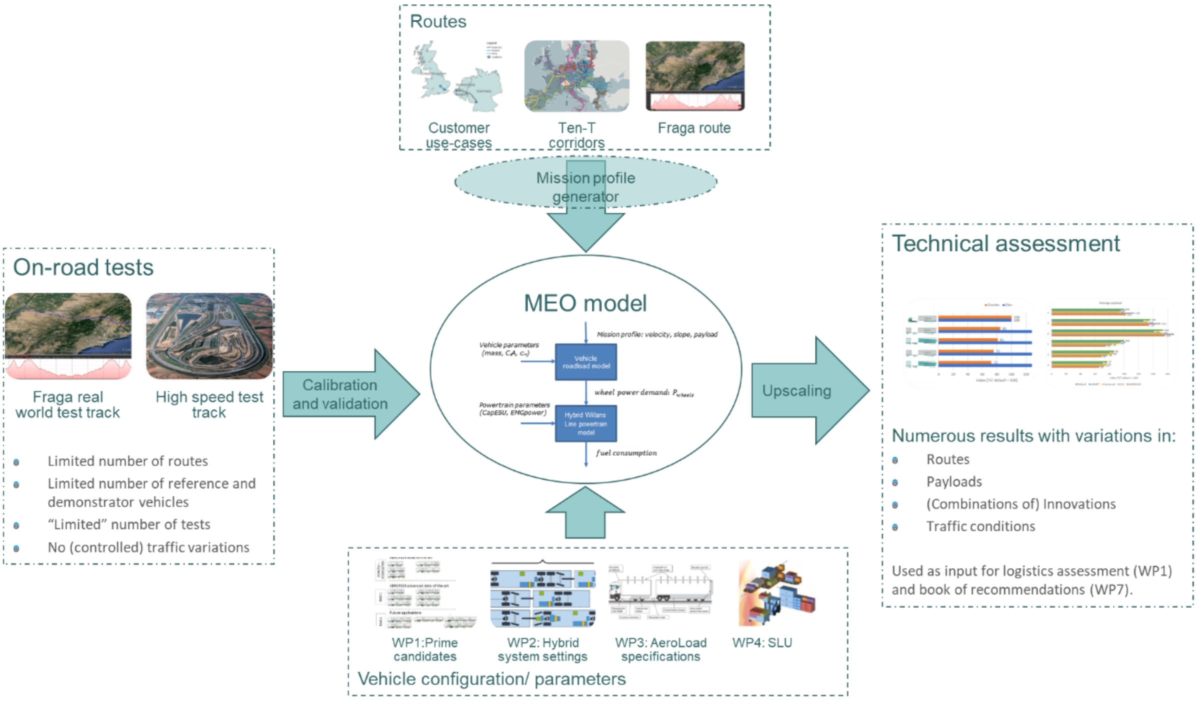

Figure 1 - Schematic overview of the assessment framework used for AEROFLEX

Figure 1 summarizes the assessment framework and its relation to other work packages (WP) and tasks within the project. In essence, the functional description of the assessment framework is to assess the efficiency performance of AEROFLEX innovations in common European long haul operations, building on the reference and demonstrator test results, using realistic simulations and providing input to the logistics assessment and book of recommendations.

The simulation framework that is used in the technical assessment is designed in a way that it enables calculating the energy efficiency for any given vehicle, equipped with any given AEROFLEX innovation or combination of innovations, used in any given transport application.

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

One of the biggest challenges of the final technical assessment is the planning; the assessment largely depends on the measurement data from the vehicles but the final tests are only performed months before the end of the project. This leads to a very short period in which the assessment can be performed, thus thorough preparation is key. Early in the project the assessment framework was presented to all project partners in a pilot assessment. This helped in getting them acquainted with the models and results. The on-road measurement data is directly used for the calibration and validation of the models to ensure a proper fit to the measured vehicles. Sensitivity analyses are performed to study the bias of the test route (warm weather, no congestion, only hilly roads) and correct for this when performing simulations on other routes.

The final technical assessment consists of two parts. First, the demonstrator vehicles (vehicles that are developed and tested within the project) are tested on different missions and compared to the reference vehicles (also tested in the project). Second, the customer use-cases are simulated. These are carefully selected logistic use-cases based on the daily operations of logistic parties throughout Europe (see section 3). In these analyses, real logistic missions are used to compare the currently used vehicles to future prime candidates with and without AEROFLEX innovations applied. The selected customer use-cases provide a large variation in logistic applications and routes. This allows for an assessment of the AEROFLEX innovations in various situations including e.g. flat and hilly routes, free flowing and congested roads, fully loaded and empty vehicles, motorways and urban roads.

3. Logistic Customer Use-Cases

From over 50 interviews with Logistic Service Providers (LSP) and shippers, information is obtained about their typical logistics operation in terms of current and future desired vehicle type, route, payload, cargo type/volume/meters and frequency of operation over the year. From this, a sub-set is chosen to be assessed in detail for the AEROFLEX innovations on fuel consumption (l/100km) and fuel efficiency (l/t-km) improvements. The subset that has been chosen is summarized in Table 1 and the routes of the use-cases can be seen in Figure 2. The criteria to make this subset of use-cases is to get a large variety among them in terms of:

- **Goods category** (based on the EU Standard Goods Classification for Transport Statistics (NST): focus is to include at least the NST categories covering the top three of most transported goods (t-km) in trips over 150km, being NST categories:
    - NST category 4: (food, beverages and tobacco);
    - NST category 18: grouped goods and;
    - NST category 1: products of agricultures, hunting, and forestry; fish and other fishing products
- **Trip length**: various total length and individual legs (composed to total use-case trip length)
- **Geographic regions** in Europe: different countries and headings (see Figure 2)
- **Elevation profiles**: routes containing predominantly flat, hilly and mountainous roads
- **Prime Candidates (PC):** different types of vehicles according to [Saxe de, *et al*., 2019]. In total six different PCs are involved and when also differentiated by trailer type, fourteen different vehicle types are included in the selected use-cases
- **Multi-modality**: truck-train-truck and truck-ferry-truck missions
- **Handling units**: includes palletized goods, goods on another standardized handling unit, bulk goods and piece goods (no standardized handling unit)
- **Logistics concept**: Full Truck Load (FTL) with height and low cargo density, and Less than Truck Load (LTL) with less than maximum cargo volume/weight and consolidation type use-case
- **Potential for Smart Loading Units** (SLU): within the project, also innovations are researched not only changing the vehicle, but also the logistics operation, such as multimodal loading unit clusters [EU project Clusters2.0, 2021], horizontal collaboration in EMS vehicles, combined heavy and light weight palletized goods and multimodal transport (e.g. alternative for road by train or ferry)

Table 1 – Overview of the eight selected customer use-cases

Name	Origin-Destination (modality)	NST Goods categorie	Total distance (# of legs)	Total elevation change	Potential for SLU innovations	Current Prime Candidate	Desired future Prime Candidates
UC1	Germany (road)	3: Metal ores and other mining and quarrying products; peat; uranium and thorium ores	115 km (2)	780 m			
UC2	Germany (road)	4: Food, beverages and tobacco	500 km (1)	5400 m	Shift to train		
UC3	Germany – Spain (road)	12: Transport equipment	1300 km (1)	8000 m	Shift to train	Euro-Mega	Mega, Mega
UC4	Turkey - Sweden (road, shortsea)	4: Food, beverages and tobacco (conditioned)	3040 km (3)	18700 m	3. Horizontal Collaboration, Shift to train	Frigo	Frigo, Frigo; Euro-Frigo; Frigo, Frigo
UC5	Germany - England (road, shortsea)	18: Grouped goods: a mixture of types of goods which are transported together	1340 km (6)	7200 m		Mega	Mega, Mega; Mega, Mega
UC6	Netherlands-Sweden (road-ferry)	18: Grouped goods: a mixture of types of goods which are transported together	2995 km (26)	8970 m		Mega	Mega, Mega
UC7	Netherlands -Sweden (road,rail)	18: Grouped goods: a mixture of types of goods which are transported together	852 km (8)	4280 m	1. Multimodal Clusters2.0	Mega	Mega, Mega
UC8	Germany (road)	18: Grouped goods: a mixture of types of goods which are transported together	720 km (2)	5900 m	2. Heavy and light weight palletized goods		

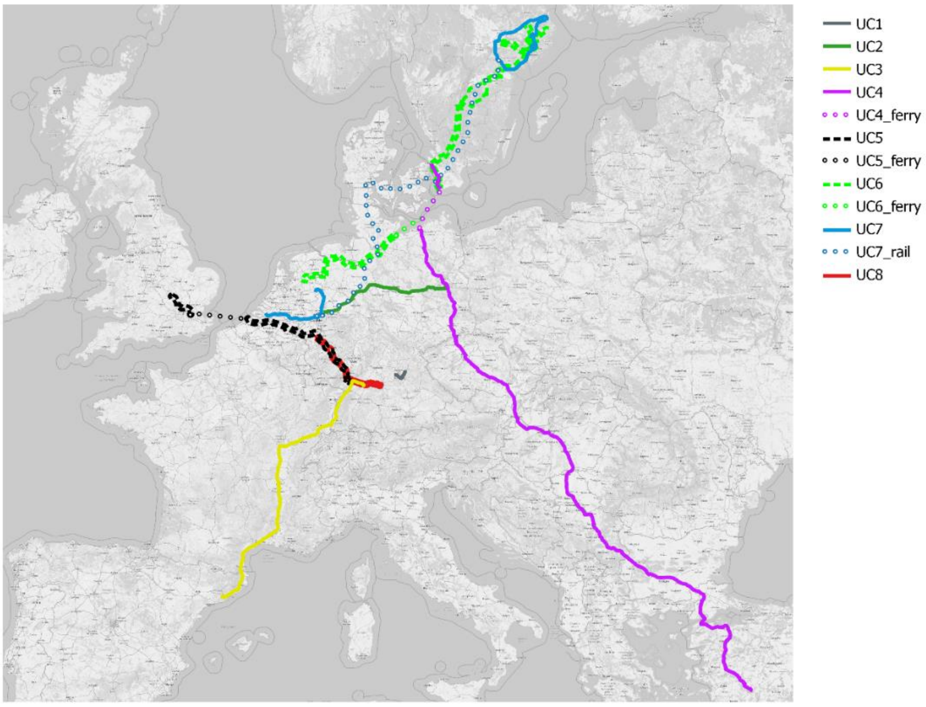

Figure 2 – European map with the eight selected customer use-cases

4. The Impact of EMS Vehicles on Transport Efficiency

This chapter discusses the results of the impact assessment, using the customer use-cases as described above. For each of the use-cases, the following input was used:

- Desired versus current vehicle configurations (see Table 1);
- payload according to the actual situation of the customer; in case the resulting GCW (gross combination weight, total mass of the vehicle combination including payload) exceeds current limits, a second variant is added without limits on GCW;
- route according to the actual situation of the customer;
- traffic conditions based on freeflow traffic and the actual situation on a typical day in the week during morning rush hour.

The output of the calculations is the fuel efficiency in l/km and l/t-km, which is summarized in Table 2. The table shows the fuel consumption savings for each use-case when the current vehicle is replaced by another Prime Candidate, where a positive saving means that the new vehicle uses less fuel. The GCW shown in the table is the average GCW of the vehicle, weighted over the kilometres driven per leg.

Table 2 - Fuel savings for each use-case and different prime candidates (a positive saving means a reduction in fuel consumption)

Use-case	Current	GCW [ton]	Future	GCW [ton]	saving [l/km]	saving [l/tkm]
UC01: Heavy mining		29		26	10%	26%
				35	-4%	43%
UC02: FTL		38		67	-44%	28%
UC03: Long distance car-parts	Euro-Mega	39	Mega, Mega	58	-30%	10%
			Euro-Mega, Euro-Mega	76	-54%	23%
UC04: Long distace Frigo	Frigo	40	Frigo, Frigo	60	-33%	10%
UC05: UK ferry	Mega	30	Mega, Mega	60	-50%	25%
UC06: LTL ferry	Mega	27	Mega, Mega	49	-40%	30%
UC07: Rail	Mega	37	Mega, Mega	68	-47%	25%
UC08: Lightweight volume transport		19		36	-44%	28%

As can be clearly identified, in most use-cases the fuel consumption in l/km increases when implementing the new vehicle concepts, due to the higher GCW. However, when looking at the fuel consumption impact in l/t-km, significant savings become visible. The difference in savings per use-case are explained below.

1. **UC01** is not an average use-case. The mining products are transported over relatively short distance. The desired future prime candidate is therefore only aimed at a higher payload. A tractor-trailer combination at a comparable GCW already saves fuel due to the lower empty weight of the combination. Ideally, the customer would like to increase the payload until the technical maximum of the combination, 56 ton, which would consequently save fuel up to 43% on a l/t-km basis. Note that the GCW in the table includes an empty return trip.
2. **UC02** is also Germany based and is 92% loaded in terms of volume. The customer desires to use an EMS2 combination, which is possible within a 74 ton GCW limit without changing the cargo per trailer. On the relatively hilly route, the fuel saving on a l/t-km basis is 28%, which seems to be pretty average looking at the other results using an EMS2 combination.
3. In **UC03** automotive parts are transported over a long distance across Europe. Here two prime candidates are calculated: both EMS1 and EMS2. Compared to other use-cases the savings for the EMS2 vehicle are relatively low (23%). This can be explained by the very heavy weight of the combination, including two euro combi mega trailers.

4. **UC04** is ultra-long-distance transport of cooled products from Turkey to Sweden. The cooled trailer and the specific route are the reasons why this transport is not done by train. The fuel saving is 10% in l/t-km, which equals in absolute numbers around 30 litres of fuel on a one-way trip.
5. **UC05** is the transport of automotive parts from Germany to the UK by road and ferry. The trailers sail to the UK without the tractor unit, which is one of the key reasons why the customer desires an EMS2 and not EMS1 with a truck as pulling vehicle. The saving is 25% in l/t-km. The route in Germany is partly quite hilly.
6. **UC06** is a LTL route between the Netherlands and Sweden. The overall saving is 30% in l/t-km but the savings per leg vary largely which will be shown later on.
7. In **UC07** most part of the route is done by rail. In the Netherlands the route includes an FTL trip from a distribution centre to the train station and vice versa. In Sweden the route includes a milk-run for delivery and pickup starting and ending at the train station. The saving is 25% in l/t-km.
8. In **UC08** lightweight consumer goods are transported on a two-way route within Germany. The light weight of the goods makes that this route is specifically suitable for logistic innovations. These will be analysed in a later stage. Without logistic innovations the saving already is 28% in l/t-km.

The above analysis shows that there are large differences on the efficiency gain of EMS vehicles between use-cases (ranging from 23-30% savings for EMS2 vehicles compared to TST vehicles) but even more can be shown when comparing different legs of the same use-case. Figure 3 shows a comparison of all legs in UC06. Note that the payload of the EMS2 vehicle is twice the payload of the TST vehicle on all legs of the use-case. This might not be a realistic scenario logistically but it does show the relation between fuel consumption reduction and payload.

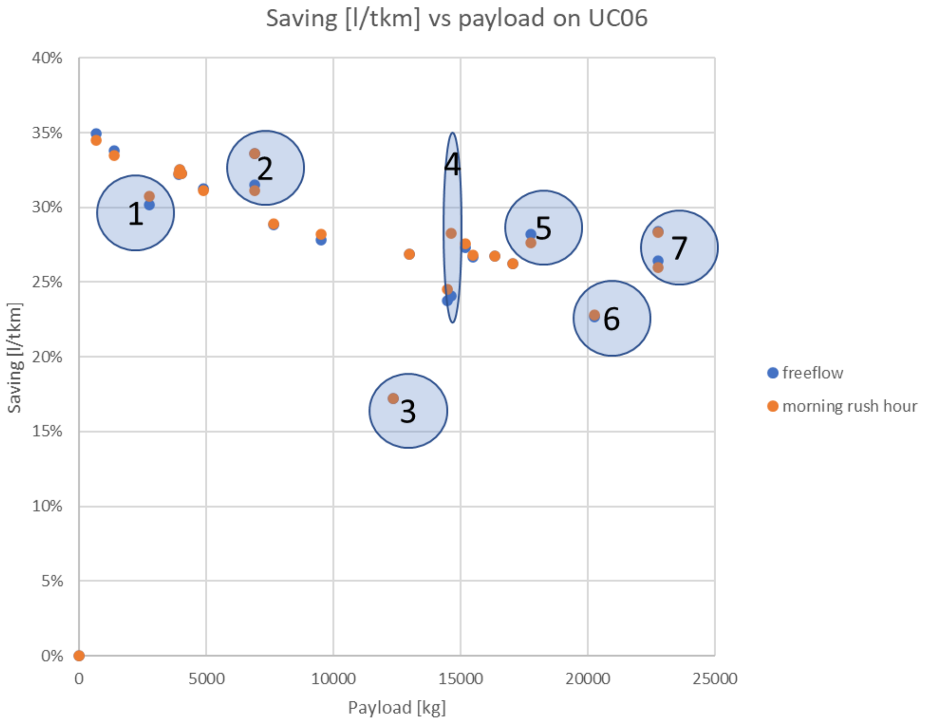

Figure 3 - Fuel consumption savings (l/t-km) between a TST and and EMS2 vehicle on the different legs of UC06 (the x-axis shows the payload on the TST, the payload on the EMS2 is twice as high)

The figure shows that the relative fuel reduction (in l/t-km) decreases with increasing payload (and mass) of the vehicle. This means that the efficiency gain for high volume, low mass goods will be higher than for low volume, high mass goods. There are some legs that stand out in this picture. Either because they show higher or lower savings than legs with similar payload or because they show a large difference between freeflow and rush hour traffic. These highlighted legs are analysed shortly below.

1. This leg consists of a fairly short route of 20 km with about half of the route in an urban area with sharp turns, roundabouts and lots of accelerating and decelerating which explains why the heavy EMS2 vehicle performs slightly less.
2. These are the last leg of the Sweden roundtrip and the return trip from the train station to the Netherlands. They are of comparable length (~400 km) and with the same payload. However, the Swedish part includes more elevation changes and more acceleration and deceleration due to a couple of roundabouts. Therefore, the EMS2 vehicle uses more fuel.
3. This leg is a very short leg of <2km and therefore only consists of accelerating and decelerating.
4. On this short leg (2.5 km) there is a large difference between the freeflow speed and the rush hour speed. The freeflow speed on the leg is on average 31 km/h but the morning rush hour speed at the moment of sampling was only 19 km/h.

5. Although there is a large difference between freeflow and rush hour traffic it doesn't affect the efficiency that much. This is because the speed is still around 60 km/h and because the traffic is only on about a quarter of the total route. This leg is further analysed below.
6. Leg 4 is again a short urban leg with low speeds and lots of accelerating and decelerating.
7. These two legs are the part from the Netherlands to the train and the first part of the Swedish route. Although the payload is the same, the route differ in elevation profile and average speed.

A particular part of a single leg from UC6 is selected to further analyse the results of congestion to the fuel consumption and fuel efficiency for the current and future prime candidates. At the time of routing and consulting the traffic information database for this leg, road maintenance was conducted and congestion was present due to the morning rush hour (8:00AM). At several locations on the E4 in Sweden in Northern direction this was the case over a distance of approximately 160 km.

Figure 4 shows the differences in vehicle speed for the freeflow (no congestion nor road maintenance) and congestion situation for the two different PCs. Since the route is highway, the majority of the reference vehicle speed is 85 km/h. However, in case of the traffic scenario, the reference speed fluctuates a lot. The difference in time due to congestion over this part is about 31 min.

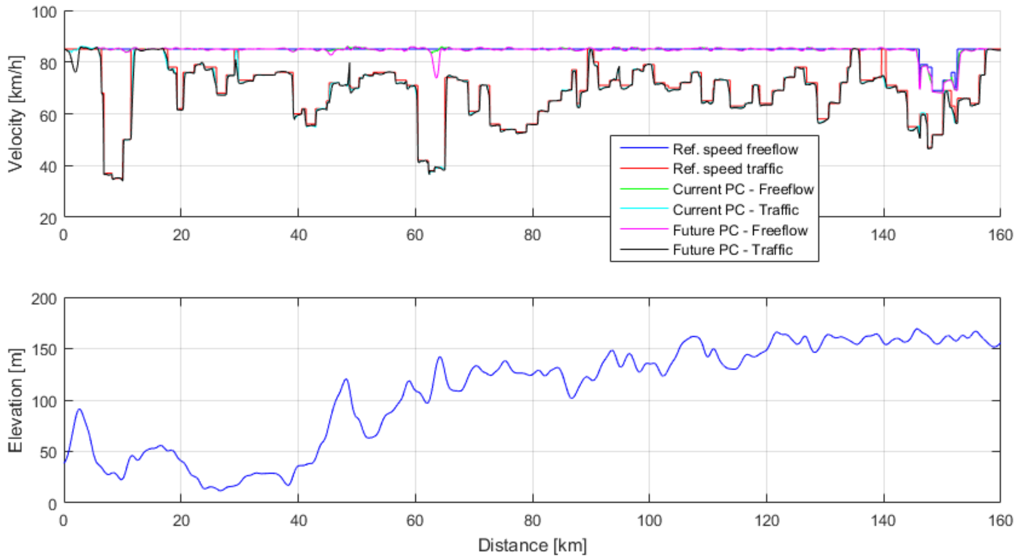

Figure 4: Overview of the different target and realized vehicles speeds for two traffic conditions and two PCs

In Figure 5, the differences are seen in accumulated fuel consumption relative to the current PC at freeflow conditions for traffic conditions and the future PC. Due to the averaged lower vehicle speed in traffic conditions, the (road load) resistance forces are lower, resulting in reduced fuel consumption of about 4.4% for the current PC, while for the future PC this reduced to 3.4%. However, as concluded earlier, the time needed for this part of the leg is increased with 31min under traffic conditions.

Looking at the additional fuel consumption needed for the future PC compared to the current PC results in 45.2% and 46.2% under free-flow and traffic conditions respectively. This is mainly caused by the higher vehicle weight and increased aerodynamic drag for the future PC. However, twice the amount of cargo is transported in the future PC. Although the effect of the rush hour traffic is considerable on the travel time and fuel consumption, this only slightly affecting the efficiency gain of the PC (see area '5' on Figure 3). This shows that the effect of congestion is larger on short routes in urban areas.

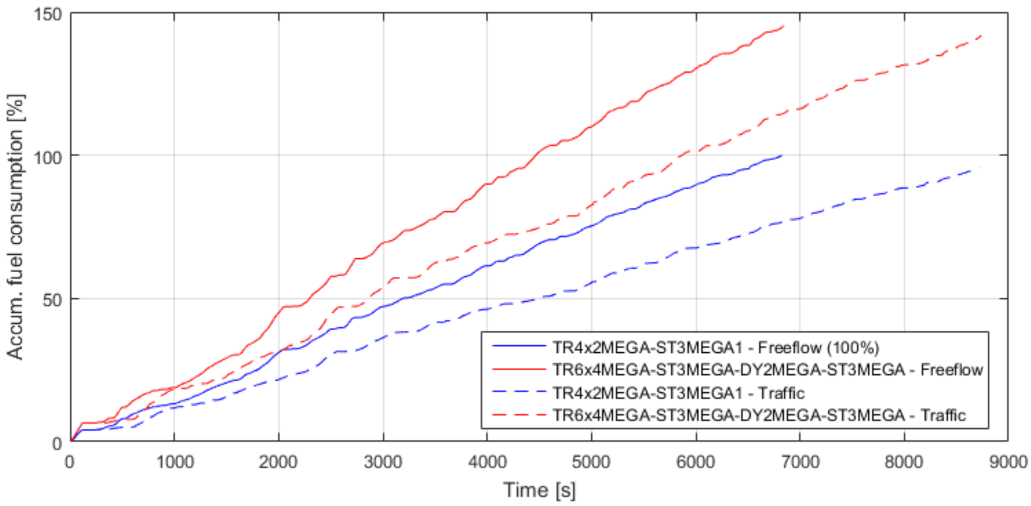

Figure 5 – accumulated fuel consumption under various traffic conditions for two PCs relative to current PC at freeflow

The results of the assessment of customer use-cases show that the possible fuel consumption savings depend on the type, mass and volume of the cargo and the specifics of the route that is travelled (elevation, length, average speed, traffic conditions). The next steps are to include the AEROFLEX innovations (improved aerodynamics, a distributed powertrain and logistic innovations) and to look at the costs and benefits of the vehicle concepts.

5. Conclusions and Outlook

Significant improvements in transport efficiency can be achieved by introducing new vehicle concepts and allowing higher masses, up to 30% in l/t-km using EMS2 vehicle configurations. Using the assessment framework, developed in the AEROFLEX project, the impact of specific desired vehicle concepts and innovations has been assessed on a wide range of actual logistic use-cases. Furthermore, the sensitivity of the results can be validated by adjusting key parameters in the model, based on real world data.

In the remainder of the AEROFLEX project, measurement data will become available of the demonstrator vehicles including the AEROFLEX innovations, which were not taken into account in this paper. The impact will be assessed using the described assessment framework and translated to the selected customer use-cases. A cost-benefit analysis from logistics perspective will be added for some customer use-cases.

To harvest the benefits of the new vehicle concepts, more is needed than just an analysis of the costs versus benefits. Road access needs to be controlled in a smart way, learning from practical experiences around the world. The view on Intelligent Access is discussed in a parallel paper by L. Aarts *et al.* within the HVTT16 conference.

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