VEL-Wagon

Versatile, Efficient and Longer Wagon for European Transportation

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– DELIVERABLE REPORT –

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Document Information

Document Name: D3.1 Study on railway business for VEL-Wagon and target costs

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SECTION I –SUMMARY

Title: **Study on railway business for VEL-Wagon and target costs**	
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Abstract

This deliverable monetizes the hypothetical consequences of using VEL-Wagon in European rail freight transportation. The most remarkable case is a potential saving of 500.000 € per year in a typical container shuttle service between Rotterdam and Milan.

The business case dedicated to conventional traffic does not yield a remarkable benefit for VEL-Wagon, which would perform at slightly higher level than typical rolling stock.

Finally a variation of the business and technical parameters intends to give an overview of the sensitivity.

VEL-wagons competitiveness compared with existing wagons has been tested both with data from specific business cases as well as with a more general cost model. The result of the both analysis is the same: VEL wagon is competitive for inter modal but has not big advantages in wagon load traffic.

Disposition of the report

This report consists of two parts. **The first part** is the cost analysis of TUB and deals with a detailed cost analysis of VEL-wagon where the economic calculations have been based of the NEA-et.al Report *“Costs and performance of European rail freight transportation”.* Detailed calculations have been done according to wagon costs, energy costs and track access costs which have been implemented in some specific business cases both for inter modal and wagon load traffic. Part one also includes sensitivity analysis according to load factor, wagon length, heavy and tall containers.

The second part is the cost analysis of KTH. In this KTH cost model has been used which is a more general cost model in which different wagon types can be tested, both existing and hypothetical. Detailed data in the calculations from part 1 i.e. data for energy consumption has been used also in part 2 and the results have been calibrated to the results in part 1. Also here VEL-wagon both for inter modal and wagon load has been calculated and compared with other wagons.

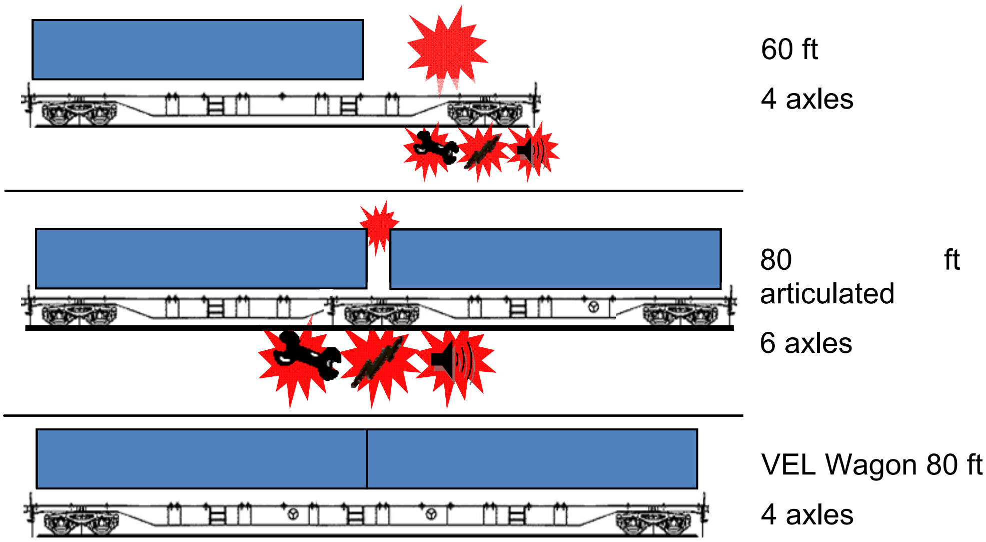
Contents:

FIRST PART (COST ANALYSIS TUB)

Author: Armando Carrillo Zanuy

1 Background

The project VEL-Wagon strives for longer wagons with fewer wheels and longer and uninterrupted surfaces. This reduces the deadweight of the rolling stock, leads to energy savings, reduces the noise and brings about a better arrangement of cargo by covering a larger scope of loading cases.



VEL-Wagon 80 ft compared to conventional intermodal wagons.

The previous work has addressed diverse aspects of the European intermodal system that are relevant for the future implementation of VEL-Wagon, namely:

- intermodal traffic (continental and maritime),
- train capacity,
- loading gauges,
- axle loads,
- infrastructure and operational characteristics relevant for energy consumption,
- infrastructure capacity and
- terminal capacity.

Accompanying this analysis, few models for calculating the capacity of trains and infrastructures were employed to ascertain the benefits and challenges of having a longer wagon for intermodal transports. The models were also employed to obtain the optimal physical dimensions and characteristics of the VEL-Wagon, which in principle should stand for an 80 ft long container wagon with ca. 18 m distance between pivots and 1040 mm (provisional) of loading height.

The advantages obtained from a simulation of an 80 ft VEL-Wagon for intermodal transports are:

- Better loading factor of trains (10% more TEU per length (vs. REF due to better arrangement of units)
- Fewer axles per length which implies:
    - Less energy consumption (decreased rolling resistance, less deadweight)
    - Less maintenance
- Less noise (fewer axles with increased axle load)
- Better aerodynamics (fewer bogies and fewer gaps between containers)

The conventional rail freight traffic was as well analyzed obtaining some conclusions for the applications of such longer wagons, namely:

- Industries having high demand fluctuations: Construction industry, large projects, forestry.
- Commodities needing long non-articulated wagons: Long pipes, plates, poles, masts, beams, house sections.
- Palletized cargo, volume-oriented transports, machine parts, automotive parts, etc.

To enable the VEL Wagon to flexibly serve these markets, it is recommended that the wagon be designed:

- without a floor;
- with side sill top flanges flat and level and suited to bolting of standard log bunks;
- with end sill pockets for installation of end stakes or bulkheads.

2 Introduction

During the last years there has been clear dominance of the shuttle production system in intermodal transportation. The shuttle represents the simplest form of exploitation in transport systems. In many cases it may be the only feasible production system for operators, especially when considering small companies and startup companies. Yet, the shuttles have the risk of not being filled up by the demand, in this way the demand may vary from one day to another whereas a shuttle may be designed for a semester of for a year. Furthermore the cost elements of the shuttle, such as locomotive and wagons, track path and indirect costs are long-term bounded, which increases the risk of the whole entrepreneurship. Other productions systems such as linear trains, direct trains (with changing wagon composition), multi-block trains, hub-and-spoke systems or the like need shunting and / or marshaling procedures which are only at the reach of big companies and have an important impact on the final costs of the service.

In the previous activities of VEL-Wagon a study of the European intermodal traffic was produced. By this, the typical and most frequent intermodal loading units were identified, providing as well their weight distribution based on real statistical data. Furthermore a simulation of probable cases showed that longer wagons -like VEL-Wagon- behaved better under averaged conditions of traffic. These averaged conditions refer mainly to mainstream traffic corridors e.g. services along the Rhine Corridor, between Italy and Scandinavia, Austria, Czech Republic, Poland etc. which represent nowadays the backbone of the European intermodal transport.

On the other hand the conventional railway freight transportation offers good possibilities for VEL-Wagon too. The typical application for long or extra-long cargo e.g. beams, pipes, masts, rails, long plates, profiles, trunks, etc., is very interesting for VEL-wagon, however these longer surfaces with lower loading heights would be also very adequate for weather-sensitive voluminous cargo. This includes for example: grouped goods in pallets, food and consumer goods, bottled and packed beverages, paper rolls, white goods, brown goods, textiles, rubber parts, plastics and machine parts (also auto parts). In European freight railways the wagons addressing such cargo types are categorized as “H” wagons (covered wagons). To emulate an H wagon, VEL-Wagon should be equipped with a detachable superstructure consisting of a removable floor and a cover with lateral sliding walls.

Provided that the shuttle production system is widely employed in European railways, not only in combined transportation but also in conventional transportation in form of regular unit trains, the VEL-Wagon team proposes to evaluate the economics of the shuttle with a particular case referred to VEL-Wagon. In so doing, the shuttle case will have several advantages:

A number of variables can be kept fixed, especially when it comes to operational parameters such as:

- Train length and wagon composition
- Circulations and mileage of wagons / trains
- Locomotive type and personnel employed
- Use of infrastructure, railway facilities, terminals etc.

The sensible parameters under study can be more easily isolated qualified and quantified, namely:

- Wagon investment breakeven
- Wagon maintenance costs
- Energy consumption
- Capacity efficiency
- Averaged axle load
- Payload efficiency
- Other

The shuttle production system is as well easier (than other productions systems) to simulate and to obtain useful results from, which may lead to a better validation and comparison with existing cases in the literature and in the praxis

The ultimate objective is to compare the economic terms of VEL-Wagon against the current best possible market solutions. These market solutions include a freight railway option and a pure-road option.

3 Business cases

The railway shuttles will be defined according to the most frequent operational parameters found in the praxis and in the literature. According to this, an important source of operational data is the report *"Costs and performance of European rail freight transportation"* published by Panteia/NEA, Railistics and Raillogix in 2008–henceforth NEA-et.al-report-. NEA has given specific authorization to TUB for using its contents in VEL-Wagon project; this will help to focus on the specific wagon-dependent parameters rather than to focus on the definition and validation of the production systems themselves.

The train services that will be taken in account for the calculations are:

i. 5 intermodal shuttles a week between Rotterdam and Busto Arsizio (25km north of Milan) with maritime containers or continental units or both of them.

ii. 5 unit trains a week with covered wagons (H-type) between Cologne and Lyon carrying palletized cargo.

3.1 Business case 1 Rotterdam-Busto Arsizio maritime intermodal shuttle

Background (KTH)

Route:

(NL) **Rotterdam**

Zevenaar (Betuwe)

(D) Emmerich

Oberhausen

Cologne

Mainz

Manheim

(CH) Basel

Bern

(Lötschbergbasistunnel)

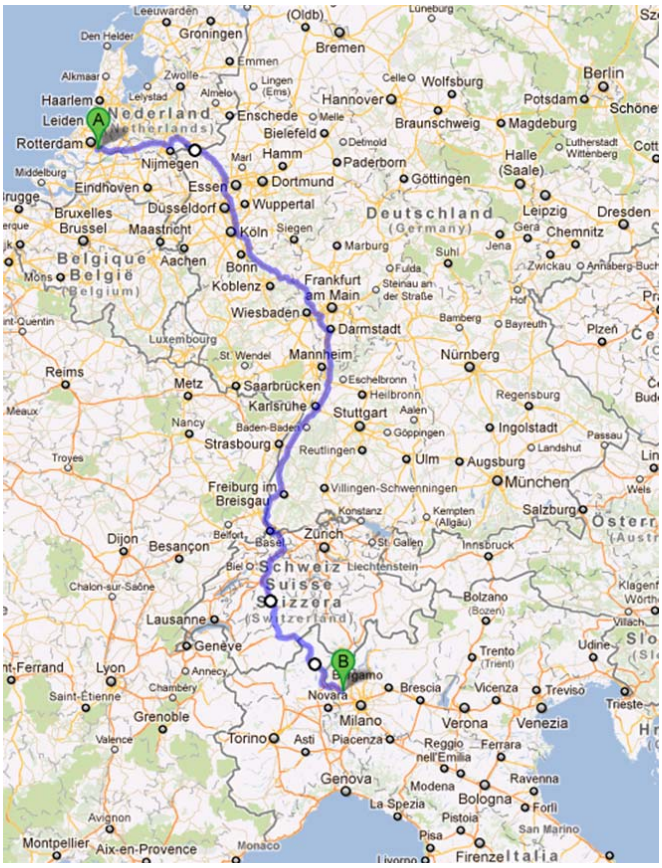
(IT) Domosdosola

Gallarate

Busto Arsizio

Distance (one way):

1.100,71 km



Route 1: Rotterdam-Busto Arsizio. Source: Googlemaps 2012 (approximation).

Train characteristics:

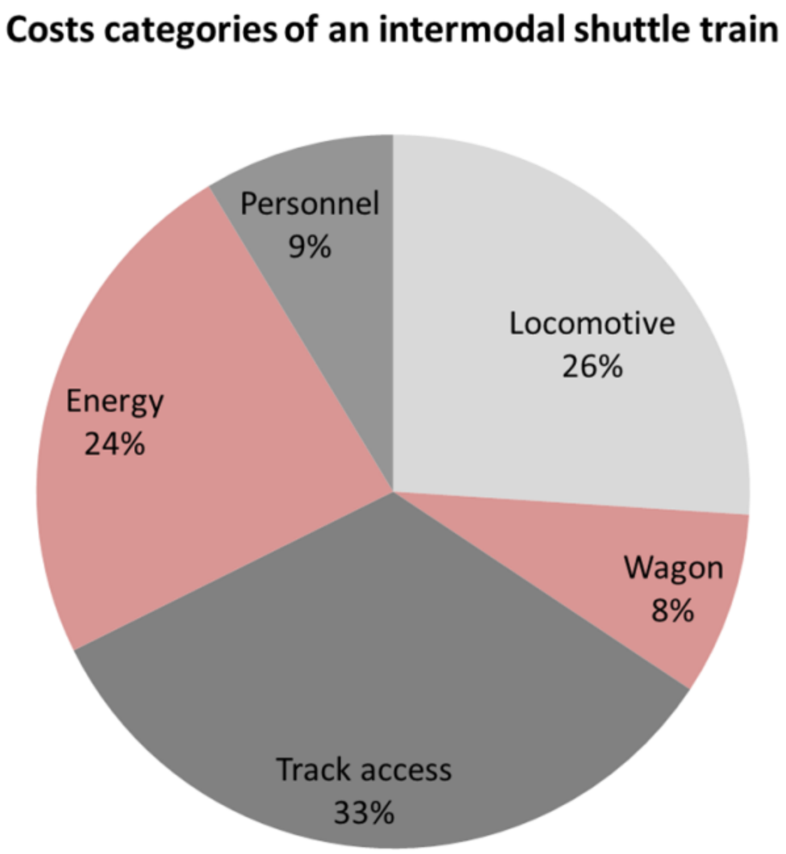
	Train length	Train g. weight	Train tare	Train payload	No. wagons	Wagons Sgns 60 ft	Wagons Sggmrss 80 ft	No. axles	No. TEUS	TEUs / Container	Axle load
Train NEA report	520 m	1385 t	635 t	750 t	20	5	15	114	75	1,6	12,15 t

The incurred costs of a complete turnaround intermodal train (two-way) are depicted on the following table (NEA-et.al-Report):

Country	Locomotive	Wagon	Access	Energy	Personnel	Overall
Netherlands	1.811,54	277,05	250,16	742,10	236,46	3.317,31
Germany	2.380,84	1.199,49	5.408,96	3.745,50	821,03	13.555,82
Switzerland	945,32	476,26	2.436,01	1.155,15	857,04	5.869,78
Italy	1.509,62	169,82	413,68	404,51	294,81	2.792,44
Overall	6.647,32	2.122,62	8.508,81	6.047,26	2.209,34	25.535,35

Overall incl. 30% overhead						33.195,96

Red figures indicate costs items that will be modified by the use of VEL-Wagon, overhead is calculated as 30% of overall costs. Figures in Euros.



Cost categories of an intermodal shuttle train between Rotterdam and Busto Arsizio. Red sectors indicate VEL-Wagon-affected items. Data source: NEA-et.al Report.

Recalculation of the cost items affected by the utilization of VEL-Wagon

This section will analyze and re-calculate the costs chapters that may be affected by the use of VEL-Wagon.

3.1.1 Wagon costs

The wagon costs are taken directly from the NEA publication; VEL-Wagon costs have been estimated.

Wagon	Units	Depreciation per wagon and year	Interest per wagon and year	Insurance per wagon and year	Maintenance per wagon and year	Total per wagon and year	Total costs per year	Cost per turn (260 turns/ year)
Sgns 60ft	15	2.400	1.650	720	1.800	6.570	98.550	379,04
Sggmrss 80ft	45	3.680	2.530	1.104	2.760	10.074	453.330	1.743,58
60ft + 80ft (train)	*60*	*3.360*	*2.310*	*1.008*	*2.520*	*9.198*	**551.880**	**2.122,62**
VEL	57	3.040	2.090	912	2.300	7.882	**449.274**	**1.828,82**

Estimation of VEL-Wagon costs in Euros.

A first estimation of the VEL-Wagon costs has been done taking in account the amount of bogies it has, which is 2.

It can be assumed that the cost of a VEL-Wagon will be slightly superior to the cost of a regular 60 ft wagon (2 bogies) and clearly inferior to the cost of an articulated 80 ft wagon (3 bogies and an articulation). According to this, if VEL-Wagon assumes the averaged cost between a 60 ft wagon and an articulated 80 ft wagon this assumption will be on the pessimistic side.

Then:

$$\text{VEL-Wagon cost (pessimistic)} = \frac{(\text{Cost of a 60 ft wagon} + \text{Cost of an articulated 80 ft wagon})}{2}$$

The interest and insurance costs are calculated following the same principle as they depend majorly on the investment costs.

The maintenance costs are much related to the amount of bogies that a wagon has, for this reason it is assumed that the maintenance costs of VEL-Wagon will be higher than the costs of a 2-bogie wagon because although it has the same amount of axles, these axles have a higher axleoad on average. In concrete the axles will be loaded a 25% more, which entails more wear and tear of the wheels and thus more maintenance costs.

To be conservative it has been assumed that the maintenance costs of a VEL-Wagon will be equal to the maintenance costs of an 80 ft wagon divided by 6 (amount of axles) multiplied by 4 (amount of axles VEL-Wagon) and multiplied by 1,25.

The necessary amount of VEL-Wagons for the service, 57, has been calculated as follows:

According to NEA-et.al report it is necessary to have 3 complete trains in order to complete the 260 turnaround circulations a year that result from a 5-time weekly shuttle service.

According to NEA-et.al a train unit is formed by:

Train= 1 x Locomotive + 5 x Sgns (60 ft) + 15 x Sggmrss (80 ft art). It has a length of 500 m (locomotive excluded).

Since a VEL-Wagon has an approximated length of 26 m, the necessary amount of VEL-Wagons for making a 500 m train is 19. Then so, 3 complete trains need 57 VEL-Wagons.

Summarizing, the total cost per circulation imputable to the wagons is 2.122,62 € in the reference case and 1.727,98 for the VEL-Wagon.

VEL-Wagon would represent a 13,84% save on wagon cost against the reference case.

A variation of the wagon costs for VEL-Wagon and a breakeven cost will be discussed in the sensitivity analysis chapter.

3.1.2 Energy costs

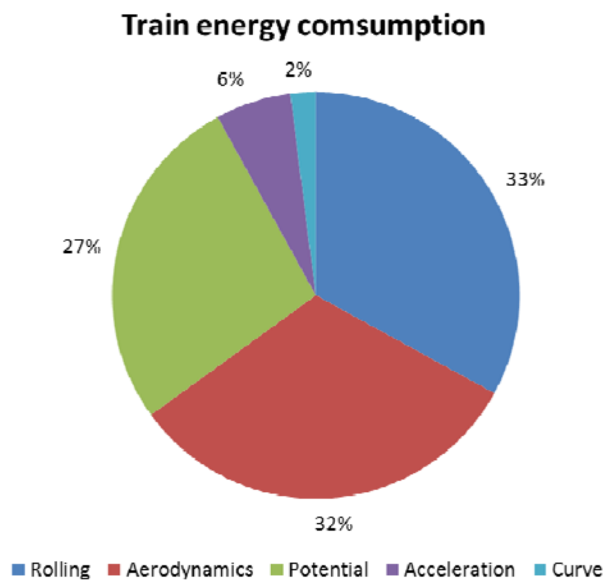
A calculation is presented here utilizing the values published in the NEA-et.al report.

The NEA-et.al report employs the following train parameters, blue figures are calculations done for VEL-Wagon:

								Train energy consumption in kWh per km				
	Train length	Train g. weight	Train tare	Train payload	No. wagons	No. axles	Axle load	Total (100%)	Rolling (33%)	Aero (32%)	Potential (27%)	Rest (8%)
NEA report	520 m	1385 t	635 t	750 t	20	114	12,15 t	26,00	8,58	8,32	7,02	2,08
VEL-Wagon	520 m	1253 t	503 t	750 t	19	80	15,66 t	22,52	7,19	6,90	6,35	2,08

A first appraisal of the energy consumption of a VEL-Wagon train was undertaken in a previous chapter of VEL-Wagon project (See D2.2, pages 83 to 101).

The energy consumption is subdivided in 5 categories:



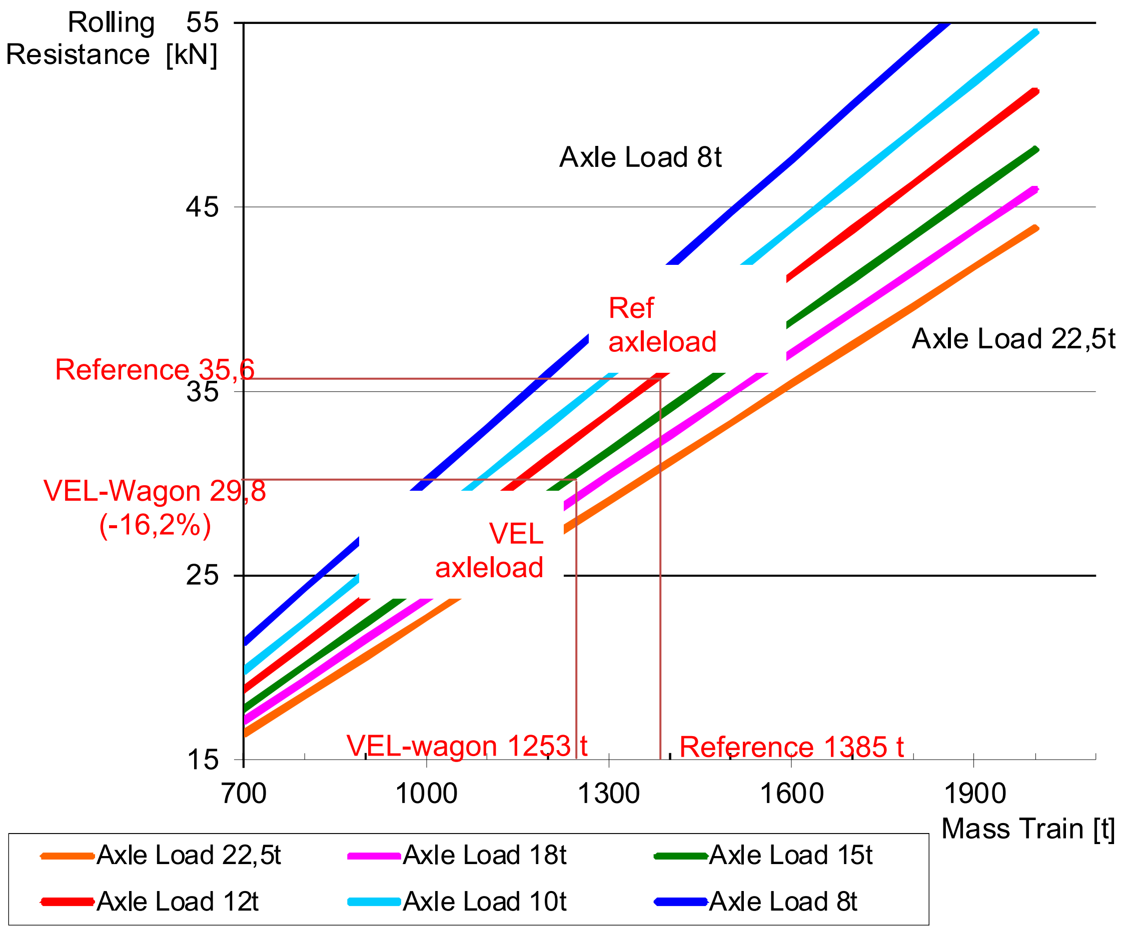
- Rolling resistance: Due to the wheels rolling on the rails. (33% of total energy consumption)
- Aerodynamic resistance: Due to the air friction against the train body. (32% of total energy consumption)
- Potential energy: Due to a change on the potential energy on ramps and slopes. (27% of total energy consumption)
- Acceleration resistance: Due to the acceleration to increase speed. (6% of total energy consumption)
- Curve resistance: transverse, rotating and longitudinal movements due to runs on curves. (2% of total energy consumption)

Energy consumption categories of a typical intermodal train in Europe. Source: Vergleichende Berechnungen zum Energiebedarf von zwei Güterzügen des KV im Rahmen des Forschungsprojekts VEL-Wagon, Simon Stolz, TU-Berlin.

According to the results presented in the previous figure, it is possible to break down the energy consumption item in 4 categories. By this it is possible to recalculate each category in respect to the VEL-Wagon characteristics.

The rolling resistance is directly proportional to the train weight and the amount of axles (or the axle load). In exhibit 51 of Deliverable 2.1 is portrayed a chart that establishes the relation between these parameters.

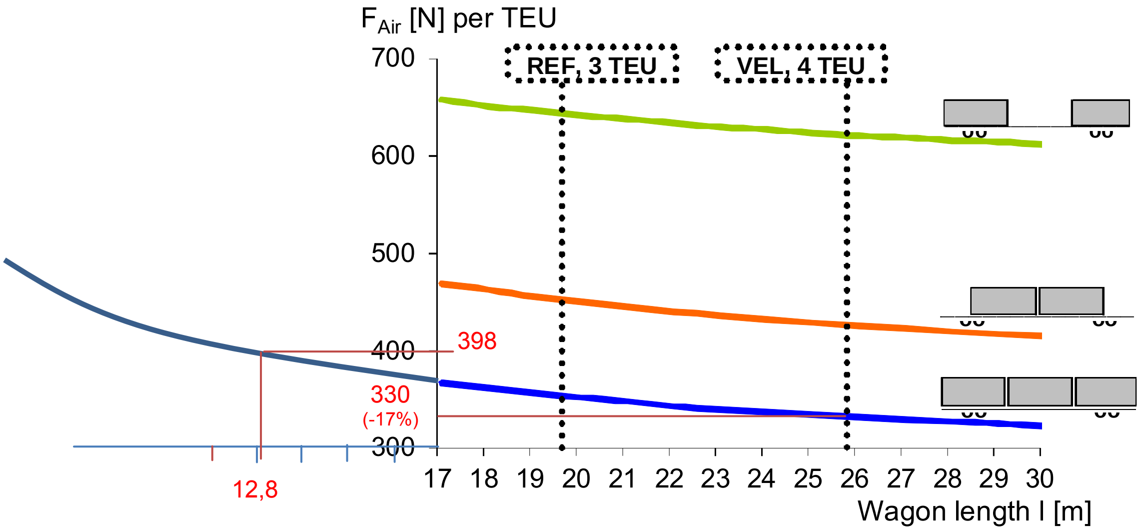
According to the calculated data, VEL-Wagon train will be lighter and have fewer axles than the reference train. The average axle load will be higher in a VEL-Wagon train and this will imply less rolling friction and therefore less energy consumption. In concrete, a diminishment of 16,3% is expected. See figure below:



Correlation of Train Mass and Rolling Resistance. (higher axle load is a consequence of having fewer axles and therefore the lower energy consumption, parametrized for VEL Wagpon) Source: VEL-Wagon Deliverable 2.1

The aerodynamic resistance, among many other things, depends on the gaps existing along the train. In this case the aerodynamic properties of the upper part of the train will be considered equal since the arrangement of the containers is very similar for both cases. However the part underneath the train is very different since the reference case has more bogies than the VEL-Wagon train and that increases the amount of gaps and thus the aerodynamic resistance.

The drag force resulting from the aerodynamic properties of the wagons has been as well chartered in Deliverable 2.1, exhibit 54. It displays the relation between container arrangement, wagon length and aerodynamic resistance.



The wagons of the reference train are 15 x Sggmrss (art. 80ft) and 5 x Sgns (60 ft). Each articulated 80 ft wagon can be assumed as 2 x 12 m long wagons, the Sgns wagon is an 19,8 m long wagon. Therefore the average length of a reference wagon is 13,11 m, calculated as:

$$\text{Ref. wagon length (aerodynamic)} = \frac{(19{,}8 \times 5 + 12 \times 15 \times 2)}{5 + 15 \times 2} = 13{,}11\ m$$

VEL-Wagon length is 26 m, thus, introducing these values in the depicted chart the resulting energy decrease is 17,07%.

The potential energy consumption is directly proportional to the train gross weight.

The reduction on potential energy consumption due to a reduced train mass can be obtained directly by a simple rule of three.

	Train mass	Potential energy consumption
Reference train	1385 t	7,02 kWh / km
VEL-Wagon train	1253 t	6,35 kWh / km

It is obtained a 9,53% reduction on the energy consumed by a VEL-Wagon train due to potential energy reasons.

The rest of the energy categories will be neglected for not having enough representation on the total energy sum; in any case they should favor the VEL-Wagon case due to reduced mass and amount of axles.

Hence, making the sum according to the obtained values:

	Train energy consumption in kWh per km

	Rolling (33%)	Aero (32%)	Potential (27%)	Rest (8%)	**Total (100%)**
Reference train	8,58	8,32	7,02	2,08	**26,00**
VEL-Wagon train	7,19	6,90	6,35	2,08	**22,52**
Change	-16,20%	-17,07%	-9,53%	0% neglected	**-13,38%**

VEL-Wagon would represent a 13,38% save on energy cost against the reference case.

3.1.3 Track access cost

The track access charge depends, among many other things, of the train weight and train length. Depending of the track access system considered the importance of the weight is different.

Suitably, there is a tool called EICIS (European Infrastructure Charging Information System) of RailNetEurop based on the RNE Corridors context which is able to deliver approximate price information of track utilization for many European routes.

The EICIS software yields for the case of the rail service between Rotterdam and Busto (NEA-et.al report) a cost of 4254,4 € one way (2008 prices). Today in 2012 the same calculation with the same software online tool and same train parameters yields 4387,22 €. In order to do the comparison between the VEL-Wagon train and the train described on NEA-et.al report it is necessary to know the track access costs of VEL-Wagon train in 2008. This will be calculated by a rule of three using the data of 2012.

The VEL-Wagon train is about 10% lighter than the reference case, using the EICIS tool the track access charge is 4276,47 €, which is a -3% in respect to reference. This relation is used to calculate the 2008 value. See table below:

Track access charge Rotterdam-Busto (EICIS software RailNetEurope)	Reference	VEL-Wagon
Year 2008	4254,40 €	4.147,00 €
Year 2012	4387,22 €	4276,47 €

Naturally, VEL-wagon increases the averaged axle load and this has an effect on the infrastructure. This effect is being appraised in WP4 of VEL-Wagon.

For the moment and with the existing track access system it is possible to enunciate that:

VEL-Wagon would represent a 2,52% save on track access cost against the reference case.

3.1.4 Overall costs

The overall costs are summed up according to table X in order to produce the following table:

Turnaround costs	Locomotive	Wagon	Access	Energy	Personnel	Overall

Reference	6.647,32 €	2.122,62 €	8.508,81 €	6.047,26 €	2.209,34 €	25.535,35 €
VEL-Wagon	6.647,32 €	1.828,82 €	8.294,01 €	5.238,08 €	2.209,34 €	24.217,57 €
Change	0,00%	-13,84%	-2,52%	-13,38%	0,00%	**-5,16%**

According to the available information it is possible to enunciate that:

VEL-Wagon would represent a 5,16% save on total rail cost against the reference case.

Rail costs summary:

	Cost per turnaround (includes 30% overhead)	Cost per one way	Transported TEUs	Cost per TEU (one way)	Distance (km)	Cost per TEU/km
Reference	33.195,96 €	16.597,98 €	75	221,31 €	1.101,71	0,2009 €
VEL-Wagon	31.482,84 €	15.741,42 €	76	207,12 €	1.101,71	0,1880 €

Annual savings in rail transport:

Annual savings = (Cost turnaround reference - Cost turnaround VEL-Wagon) * 260 = 445.410,88 €

In this business case,

The rail operator could **save up to a half million Euros a year** if using VEL-Wagon instead of using the typical rolling stock.

The savings per wagon are: 445.410,88 €/ 57 = **7.814,23 € / wagon and year.**

3.2 Business case 2 Conventional traffic, part-load traffic.

3.2.1 Background

In the past the freight railways used to have an important amount of traffic dedicated to the part-load consignments, “Stückgutverkehr” in German.

Part-load traffic activity in Berlin and Cologne in the 1930s. Source http://www.eisenbahnstiftung.de Author: RVM (Ittenbach).

Crossdocking road-rail station in Holzwickede in 1930. Source http://www.eisenbahnstiftung.de Author: RVM (Ittenbach).

Part-load traffic in Würzburg Hbf. (1978) ***Source*** **http://www.eisenbahnstiftung.de**
Foto: A. Wagner

With the gain on efficiency of the road transportation during the second half of the 20th century this kind of traffic was progressively shifted to the road, which was better suited for the modern logistics requirements. Hence, nowadays the part-load traffic does not form part of the typical market of European railways anymore.

Crossdocking road-road station in Asia. Source: http://www.mwpvl.com/html/knowledge.html

In the last years there has been a clear intention to revitalize the freight railways at all levels; an accent has been put into the combined transport (road-rail intermodal transport) which pursues the exchange of defined intermodal loading units between the modes. There are also actors focused on the so called multimodal transport, which strives for the concept of the part-load traffic. In this way, the Railport ® product of DB Schenker and some products of Rail Cargo Austria are aligned with this concept. Typically, the part-load traffic is one of the lightest and more valuable traffics to be found in freight transportation, therefore the VEL-Wagon application may be considered very positive as regards as its very focus on light transportations.

3.2.2 Business case definition

The present business case will analyze the costs of a rail connection between two multimodal centers (logistics centers), one placed in Cologne and the other one in Lyon. Again, the calculations performed in NEA report will be of important use when making the comparison against a VEL-Wagon solution and a pure road solution.

It has been supposed that the rail service is dedicated to the transportation of grouped goods. In this case the europallets are the employed transport unit to consolidate and carry the cargo in the cross-docking station and/or the logistics center.

The europallet averaged load has been calculated as a consequence of the values obtained for loaded semitrailers in Europe (See page 38 of VEL-wagon deliverable 2.1).

Averaged weight of loaded pallet = Averaged net weight of loaded semitrailer / pallets per semitrailer

0,61 t = 20 / 33

The author is aware that this is a pessimistic estimation since the pallets are lighter on average than this, they may weight around 400-500 kg (confirmed after conversations with truckers and IRU statistics). However it is preferable to work with this conservative value, 610 kg per pallet, to take in account that there are cases in which heavier non-palletizable, cargo e.g. paper rolls, big bags, etc. have to be transported too.

Route in NEA-et.al report:

(DE) **Cologne**

Mainz

Manheim

Kehl (border)

(FR) Strasbourg

Mulhouse

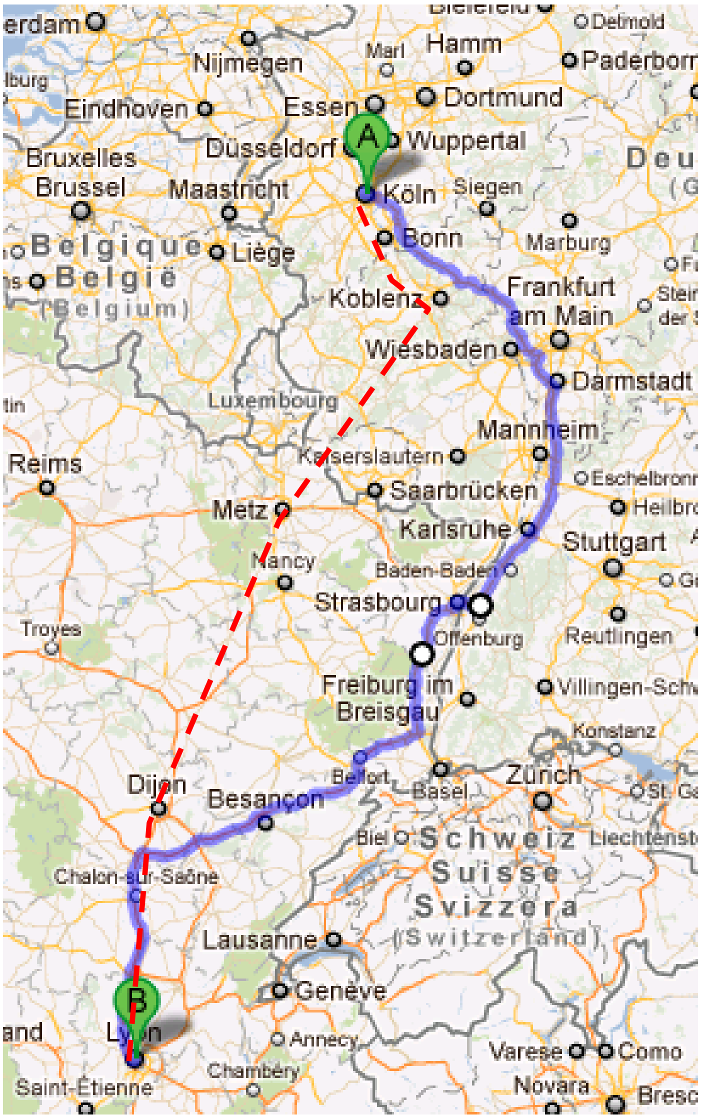
Besançon

Lyon

Distance (one way):

869,00 km (381,4 km in DE; 487,6 in FR)

Alternative route via Koblenz, Perl, Metz, Dijon; distance 741,44 km. (Rne Corridor n°6)

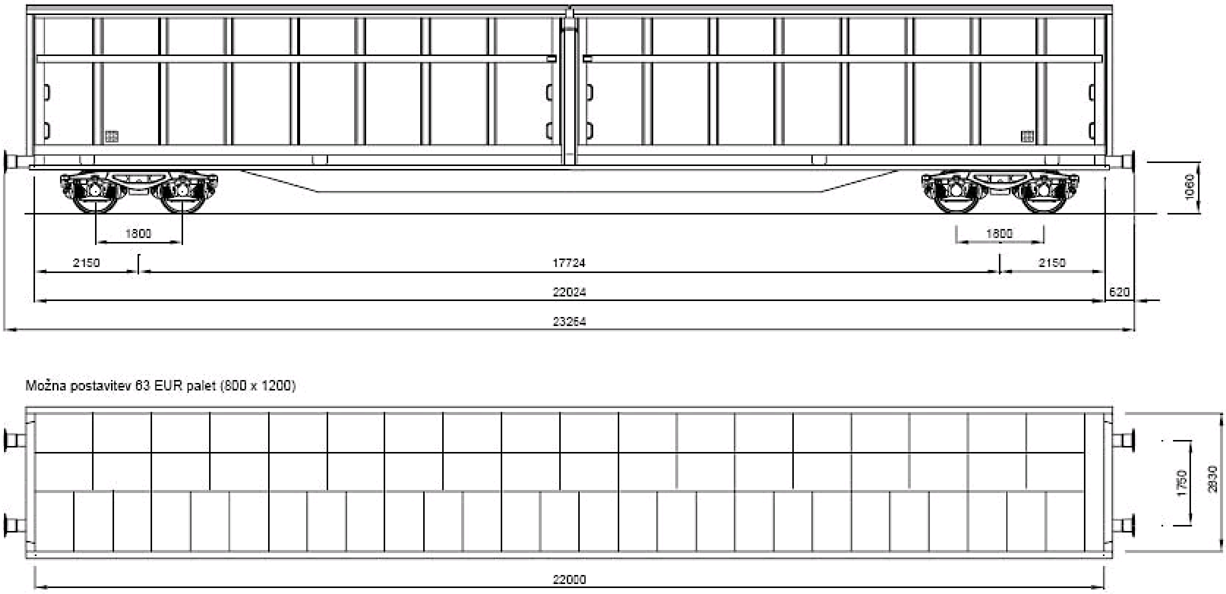


Route 2: Cologne-Lyon. Source: Googlemaps 2012 (approximation).

Train characteristics

	No. wagons	Pallets / wagon	No. pallets in train	Total length	Total tare	load	Gross weight	No. axles	Axle load	Total volume	Pallets / tare	m^3/ tare
Habbins train	20	63	1260	484 m	615 t	764 t	1379 t	84	16,4 t	3348 m^3	2,0	5,4
H-VEL train	18	70	1260	486 m	553 t	764 t	1317 t	76	17,3 t	3528 m^3	2,3	6,4
Change %			0%	0%	-10%	0%	-4%	-10%	+6%	+2%	11%	17%
European articulated lorry (2+3 axles semitrailer)			33	16,5 m	14 t	20 t	34 t	5	7 t	<100 m^3	2,4	7

Wagon drawing

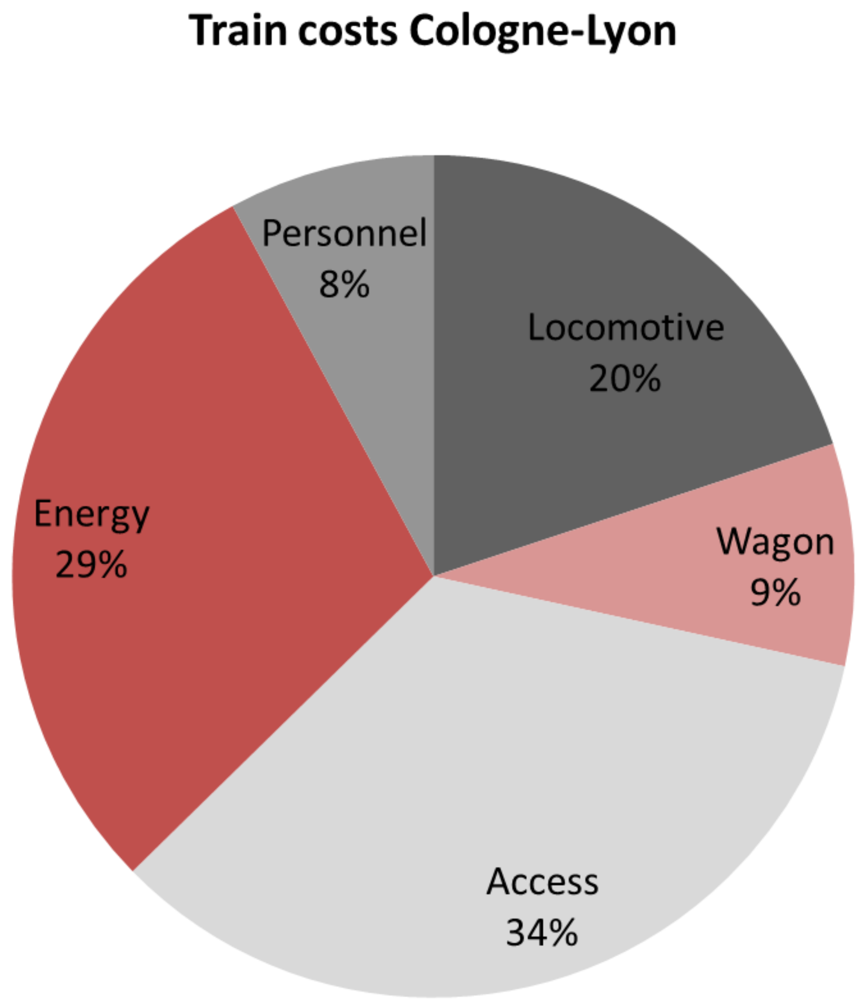


Habbins wagon. Source Slovenian Railways

Under these suppositions the following costs are obtained:

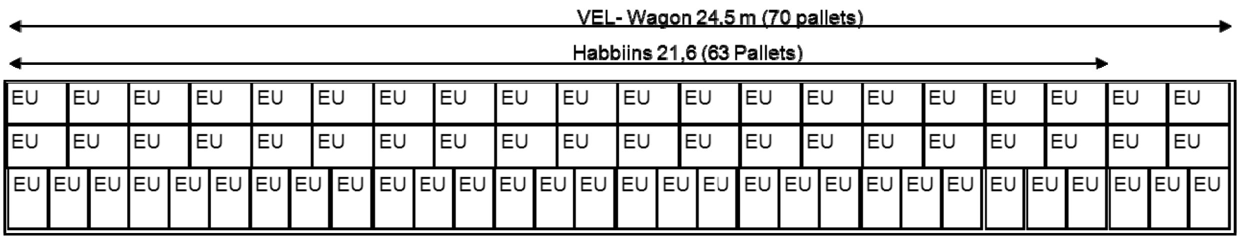
Country	Locomotive	Wagon	Access	Energy	Personnel	Overall
Overall	3.538,46	1.684,62	6.085,78	5.232,77	1.406,19	17.947,82
Overall incl. 30% overhead						23.332,16 €

Cost categories and values in a freight train service between Cologne and Lyon, Source: NEA-et.al Report and own calculations. Red figures indicate costs items that will be modified by the use of VEL-Wagon, overhead is calculated as 30% of overall costs. Figures in Euros.



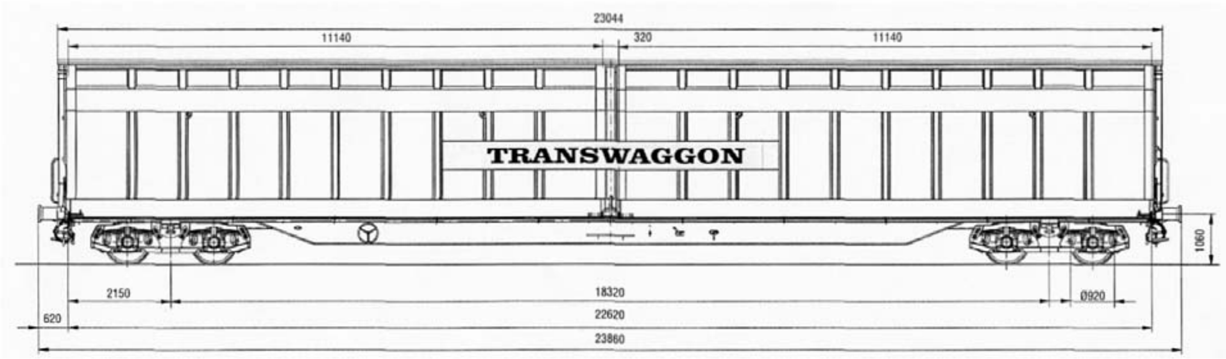
First of all it is necessary to approximate the costs of a VEL-Wagon equipped with a floor and a cover with sliding walls.

An intelligent construction would be to design VEL-Wagon in such a way that it would be able to accommodate 70 pallets.



In this case VEL-Wagon could carry 7 pallets more per wagon than a Habbins.

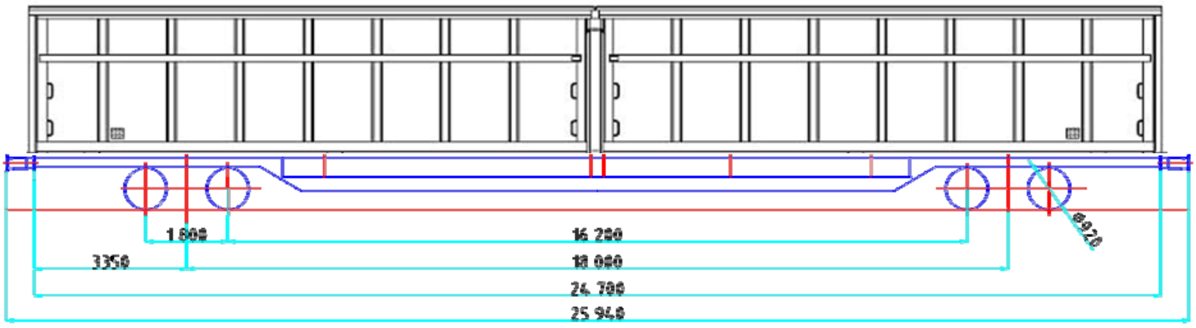
According to the technical expertise, a comparable wagon to a covered VEL-Wagon would be the Habbiins-14 with a pivot distance of 18,3 m and loading length 22,6 m.



Habbiins-14, Source Transwaggon.

The VEL-Wagon characteristics would be:

	Length over buffers	Loading length	Pivot distance	Tare	Volume	Payload	EUR-pallets	Gauge
H-type VEL-Wagon	25,94 m	24,70 m	18,00 m	26,5 t	196 m^3	63,5 t	70	G1
Habbins	23,26 m	22,02 m	17,72 m	26,5 t	167,4 m^3	63,5 t	63	G1
Habbiins-14	23,86 m	22,60 m	18,32 m	26 t	173 m^3	64 t	65	G1



H-VEL-Wagon

Recalculation of the cost items affected by the utilization of VEL-Wagon

This section will analyze and re-calculate the costs chapters that may be affected by the use of VEL-Wagon.

3.2.3 Wagon costs

The wagon costs are obtained from the NEA-et.al publication; VEL-Wagon costs have been estimated.

Wagon	Units	Depreciation per wagon and year	Interest per wagon	Insurance per wagon and year	Maintenance per wagon and year	Total per wagon and year	Total costs per year	Cost per turn (260 turns/ year)

			and year					
Habbins	40	4.000	2.750	1.200	3.000	10.950	438.000	1.684,62
H-VEL	36	4.459	3.066	1.338	3.344	12.206	439.431	1.690,12

The necessary amount of VEL-Wagons for the service is 36, this has been calculated as follows:

According to NEA-et.al report it is necessary to have 2 complete trains in order to complete the 260 turnaround circulations a year (5 trains a week) between Cologne and Lyon with a travel time of 17h and 30 min. The train length is 484 m, which divided by the VEL wagon length 25,94 m gives 18 units in a VEL-Wagon train.

H-VEL costs have been very roughly estimated as follows.

Habbins costs / Habbins length = H-Wagon costs per m

H-VEL-Wagon costs = H-Wagon costs per m * VEL-Wagon length

The author is aware about the roughness of this approximation, which may be pessimistic provided that both wagons have the same amount of axles and mobile parts, however it is considered sufficient for this stage of calculation. Further discussion about the costs and variability thereof will be presented in the sensitivity chapter.

Hence, in principle there would be not a significant variation on the costs for wagon.

3.2.4 Energy costs

A calculation is presented here utilizing the values published in the NEA-et.al report.

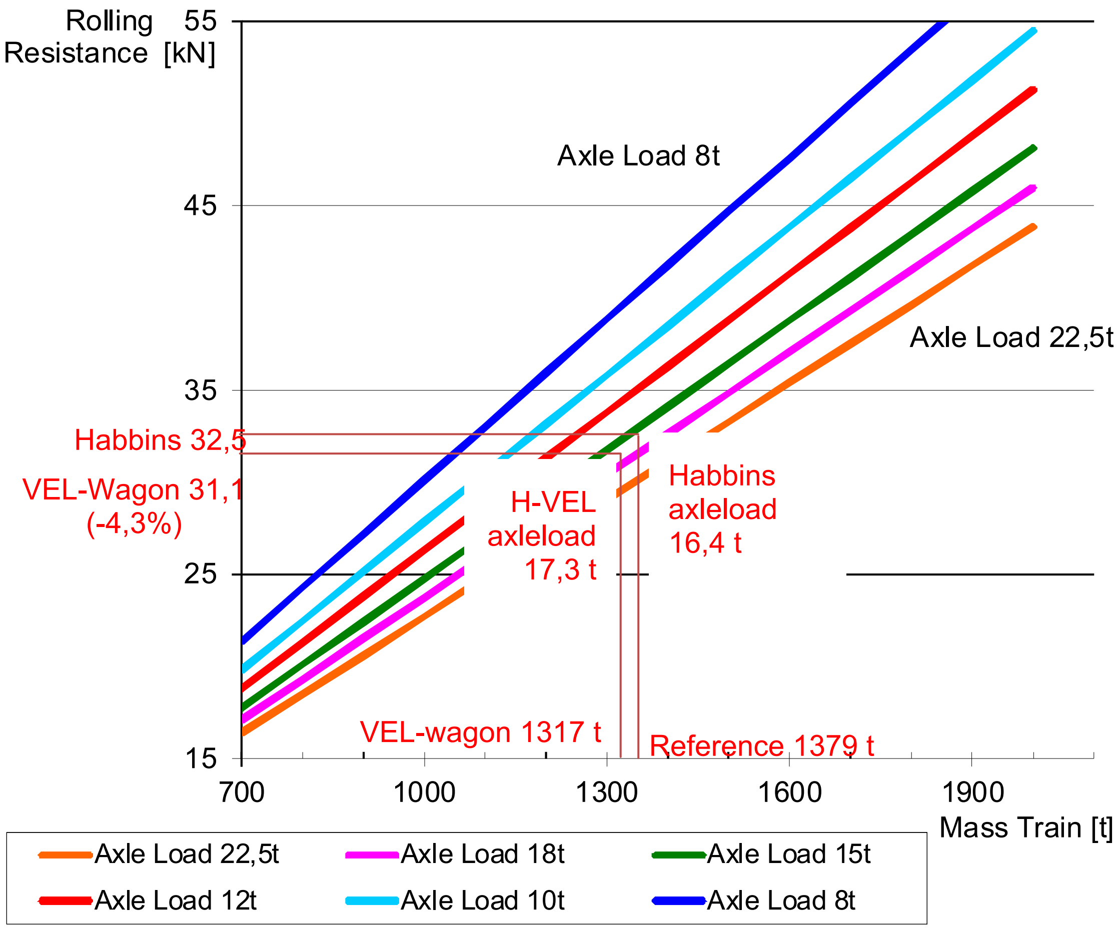
NEA-et.al reports a consumption of 26 kWh per km and train. According to calculations carried out in the TUBerlin Fachgebiet Schienenfahrwege und Bahnbetrieb, the energy consumption can be divided in four categories which have the following percentages.

- Rolling resistance: Due to the wheels rolling on the rails. (33% of total energy consumption)
- Aerodynamic resistance: Due to the air friction against the train body. (32% of total energy consumption)
- Potential energy: Due to a change on the potential energy on ramps and slopes. (27% of total energy consumption)
- Other 8%
    - Acceleration resistance: Due to the acceleration to increase speed. (6% of total energy consumption)
    - Curve resistance: transverse, rotating and longitudinal movements due to runs on curves. (2% of total energy consumption)

	Train energy consumption in kWh per km				
	Rolling -33%	Aero -32%	Potential 27%	Rest -8%	**Total -100%**
habbins	8,58	8,32	7,02	2,08	**26**

The rolling resistance is directly proportional to the train weight and the amount of axles (or the axle load). In exhibit 51 of Deliverable 2.1 is portrayed a chart that establishes the relation between these parameters.

According to the calculated data, VEL-Wagon train will be lighter and have fewer axles than the reference train. The average axle load will be higher in a VEL-Wagon train and this will imply less rolling friction and therefore less energy consumption. In concrete, a diminishment of 4,3 % is expected. See figure below:

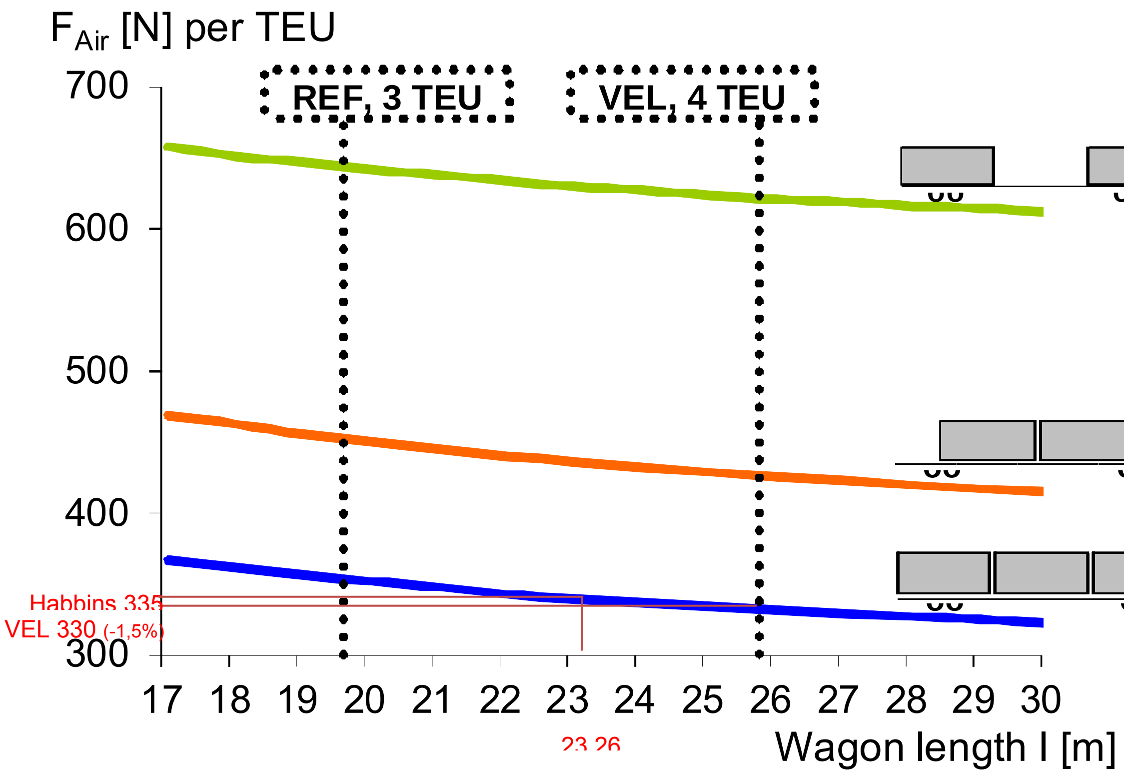


Correlation of Train Mass and Rolling Resistance. (higher axle load is a consequence of having fewer axles and therefore the lower energy consumption, parametrized for VEL Wagpon) Source: VEL-Wagon Deliverable 2.1

The aerodynamic resistance, among many other things, depends on the gaps existing along the train. In this case the aerodynamic properties of the upper part of the train will be considered equal, although the VEL-Wagon train has two wagons less and thus it has two gaps less, they will be neglected as these gaps are very small, only 1,2 m. The part underneath the train is somewhat different since the habbins train case has 4 more bogies than the VEL-Wagon train, this increases the amount of gaps and thus the aerodynamic resistance.

The drag force resulting from the aerodynamic properties of the wagons has been as well chartered in Deliverable 2.1, exhibit 54. It displays the relation between container arrangement, wagon length and aerodynamic resistance.

The wagons of the reference train are 23,26 m long. VEL-Wagon length is 26 m, thus, introducing these values in the depicted chart the resulting energy decrease is 1,5 %.



The potential energy consumption is directly proportional to the train gross weight.

The reduction on potential energy consumption due to a reduced train mass can be obtained directly by a simple rule of three.

	Train mass	Potential energy consumption
Reference train	1379 t	7,02 kWh / km
VEL-Wagon train	1317 t	6,70 kWh / km

It is obtained a 9,53% reduction on the energy consumed by a VEL-Wagon train due to potential energy reasons.

The rest of the energy categories will be neglected for not having enough representation on the total energy sum, in any case they should favor the VEL-Wagon case due to reduced mass and amount of axles.

Hence, making the sum according to the obtained values:

	Train energy consumption in kWh per km				
	Rolling -33%	Aero -32%	Potential 27%	Rest -8%	**Total** **-100%**
habbins	8,58	8,32	7,02	2,08	**26**
H VEL	8,21	8,20	6,70	2,08	**25,2**
Change	-4,30%	-1,50%	-4,50%	0% neglected	**-3,11%**

VEL-Wagon would represent a 3,11 % save on energy cost against the reference case.

3.2.5 Track access cost

The cost variation in track access charge due to a decreased mass of the train (62 tones) will be neglected.

3.2.6 Overall costs

The overall costs are summed up according to table X in order to produce the following table:

Turnaround costs	Locomotive	Wagon	Access	Energy	Personnel	Overall
Reference	3.538,46 €	1.684,62 €	6.085,78 €	5.232,77 €	1.406,19 €	17.947,82 €
VEL-Wagon	3.538,46 €	1.690,12 €	6.085,78 €	5.069,82 €	1.406,19 €	17.790,37 €
Change	0,00%	0,33%	0,00%	-3,11%	0,00%	-0,88%

According to the available information it is possible to enunciate that:

VEL-Wagon would represent a 0,88 % save on total rail cost against the reference case.

Rail costs summary:

	Cost per turnaround (includes 30% overhead)	Cost per one way	Transported pallets	Cost per pallet (one way)	Distance (km)	Cost per pallet/ 100km
Reference	23.332,16 €	11.666,08 €	1260	9,26 €	869,00	1,07 €
VEL-Wagon	23.127,48 €	11.563,74 €	1260	9,18 €	869,00	1,06 €

Annual savings in rail transport:

Annual savings = (Cost turnaround reference - Cost turnaround VEL-Wagon) * 260 = 53.216,94 €

Hence in this business case,

The rail operator would not see a cost difference between using a Habbins or an H-VEL-Wagon.

The important conclusion is that this alternative use of VEL-Wagon would be perfectly competitive or even slightly better than the most advanced wagons on the market such as the Habbins.

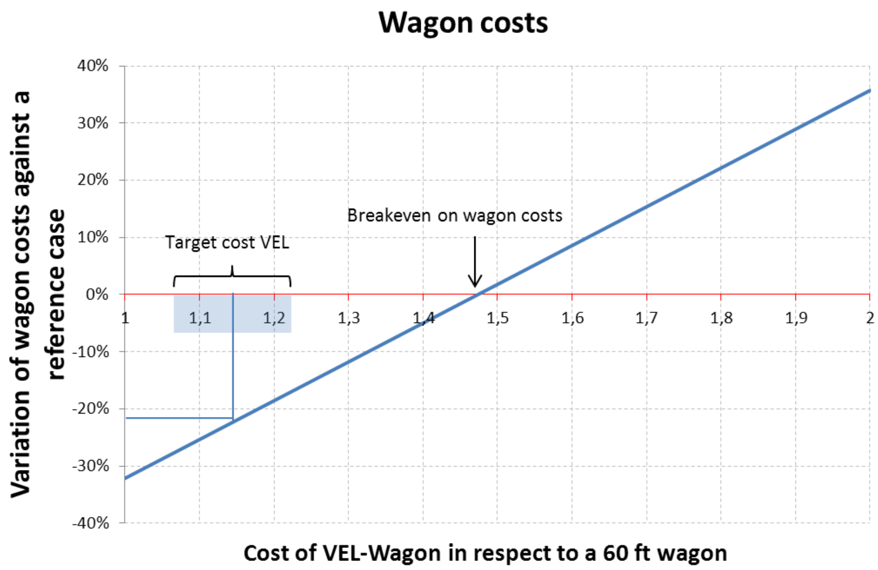
4 Sensitivity analysis and extrapolation (TUB/KTH)

In this section some assumptions, parameters and concepts will be varied in order to know the effect on the business case results.

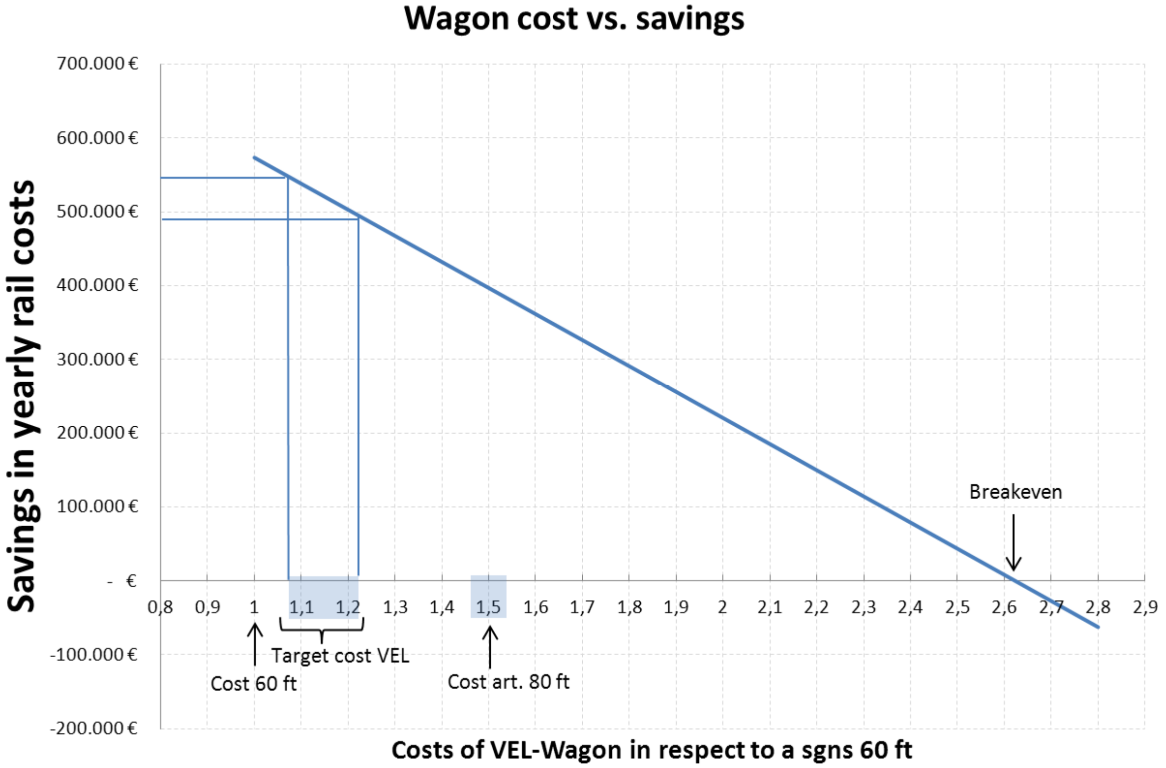
4.1 VEL-Wagon costs

In the first business case, the cost of VEL-Wagon is assumed to take the averaged value between the cost of a 60 ft container wagon and an 80 ft container wagon. This assumption is pessimistic since most probably the cost of a VEL-Wagon will be closer to the cost of a 60 ft wagon provided that it has the same amount of axles.

The relation between expected VEL-Wagon costs and percentage of wagon costs variation is plotted as follows.



However the wagon costs only represent 8% of the total rail costs. The variation of the VEL-Wagon costs and its influence in the total savings on rail costs is chartered as follows.



Wagon costs versus savings in business case 1

The most relevant conclusion is that the parameter "cost of VEL-Wagon" does not have a significant influence on the total expected benefits of the business case. Hence, the significant gain of VEL-Wagon is in energy and capacity efficiency rather than the wagon construction costs.

The elasticity of the rail costs savings in respect to the cost of the wagon is -0,62, which is not a very sensitive dependency.

The same occurs with the business case n°2.

The recommendation is not to spare expenses on wagon construction or design.

4.2 Distance of transportation and mode choice

The distance of transportation is a parameter that influences very much the costs of the rail service. It is one of the key arguments for the modal choice between pure rail (e.g. single wagon load), intermodal (combined transport), multimodal (eg. part-load traffic road-rail) and pure-road.

The intermodal costs refer to the total door-to-door costs using a container or an interchangeable intermodal loading unit. These costs are interesting from the point of view of the intermodal operator who competes against the all-road solution.

These are the principal cost items (simplification):

- Cost for transshipment: 25 € per crane movement, 2 crane movements per service.
- Cost for pre- and post-haulage: Cost per trip, 1 €/ km with a minimum fee of 50 € each.
- Container leasing: 50 € per service.

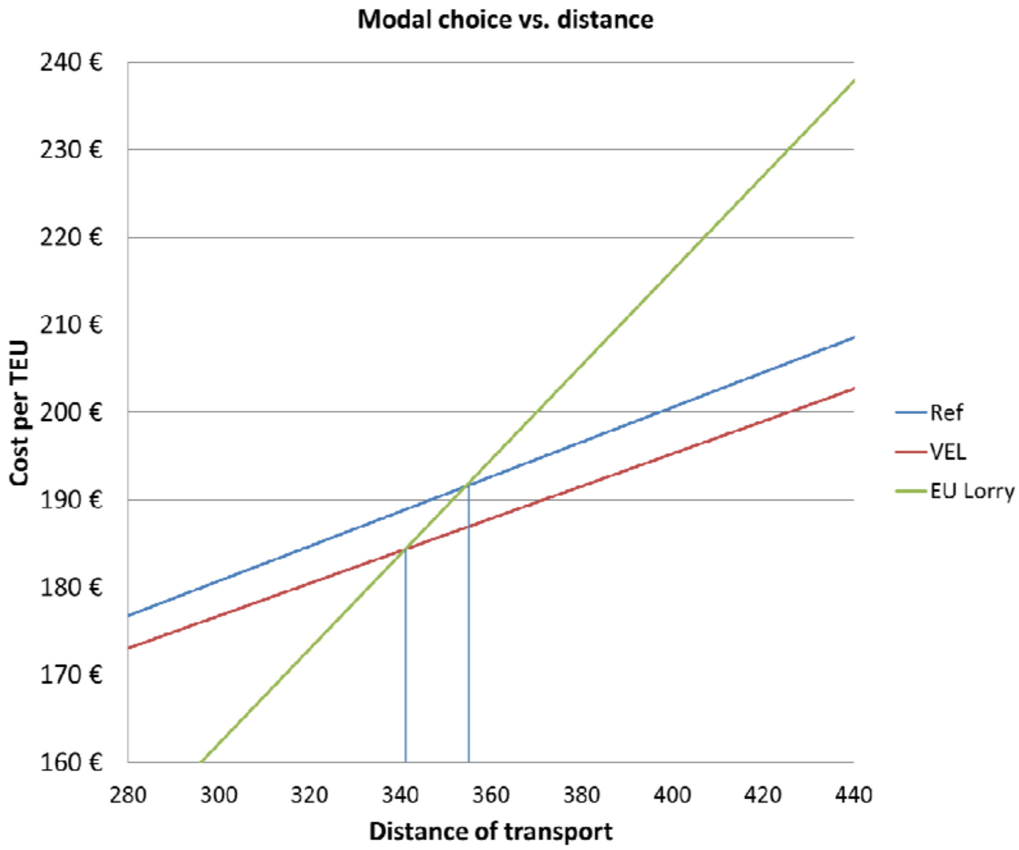
(Prices from RENFE http://www.contrenrenfe.com/condiciones_redmulticliente.html)

- Rail costs (already calculated in business case 1)
- Overheads (would not be taken in account neither for the intermodal solution nor for the all-road solution)

Therefore the total door to door costs for the different modalities are:

	(1) Rail cost per TEU (one way)	(2) Terminal costs (per container)	(3) Pre- and post-haulage (per container)	(4) Container leasing (per container)	(5) TEU per container	(6)=((2+3+4)/5) Non-rail costs (per TEU)	(1+6) One way service (per TEU)
Reference	218,39 €	50 €	100 €	50 €	1,65	121,21 €	339,61 €
VEL-Wagon	203,97 €	50 €	100 €	50 €	1,65	121,21 €	325,18 €
Lorry (EU)	The European lorry (articulated vehicle 2+3 axles-semitrailer) has a cost of 1,243€ / km and a capacity of 2,3 TEU. Source Observatorio del transporte de mercancías por carretera 2011, Spain. (Cost per TEU=1101,71 x 1,243 / 2,3)						595,40 €

The intermodal solution is in every case cheaper than the all-road solution, this is mainly because the distance of transportation is very long and thus the rail mode deploys its economic advantages fully. For shorter distances the rail mode would not be viable, the breakeven for this case would be around the 350 km, VEL-Wagon would contribute to diminish this breakeven distance. See figure:



The multimodal costs are quite difficult to calculate on a door-to-door basis. This is because the multi-modal production systems may include as well some other logistics operations such as warehousing, sorting, distribution and packaging among many others. As regards as the difficulty of performing such bottom-up calculation that would include the warehouse and logistics costs calculation, the author is going to perform a bottom-up calculation of the total costs on a hypothetic service.

Let's suppose that between two big cities, say Cologne and Lyon, there is an important flow of goods.

A company in Lyon has to send a consignment to Cologne, for that, a standard articulated lorry (semitrailer) is employed.

The lorry has a capacity of 33 pallets, a volume of 90 m3 and a payload capacity of 25 t, this is more than enough for the service.

The average cost of an all-road service may be around 1,243€ / km (Source Spanish Ministerio de Fomento).

There are some toll costs to add to this figure, after observing the values of http://www.toll-collect.de and due to the variability on cases it is going to be assumed that these costs will be around 15% of the lorry costs. Hence the total cost of the all-road service will be 1,42 €/ km.

The distance is 730 km (Googlemaps), hence total costs will be: 1036,6 € per service.

Which gives ca. 31 € per pallet.

The revenue speed of the lorry for distances >600 km decreases because of the regulations concerning to rest times for the lorry driver. In this case the average revenue speed is 35 km / h (Source Intermodal Transport in Europe EIA).

The transport time is. 730*35 = 20h 48 min. (Which is a Day A /Day C Schedule)

In order to increase this speed, two lorry drivers should be employed, which increases the all-road costs in about 40 % (own appraisal based in data of Ministerio de Fomento Spain).

According to the calculations performed in Business Case 2 the **rail costs** per pallet and 100 km are 1,07 €.

Which gives ca. 7,81€ per pallet. Hence:

The rail transport costs are 4 times less than the road costs.

Now, in order to be competitive, and that is the problem, the multimodal transport has to offer good transport quality, this is: good transport time, punctuality, safety, security and flexibility.

Let's suppose that a rail company offers a service of 5 trains a week between Cologne and Lyon. This makes 260 circulations a year, with 1260 pallets per train, which gives a total of 655.200 pallets to be moved back and forth.

The total rail costs are calculated as: Distance * 2 * circulations a year * pallets on a train * cost per pallet and km= 730*2*260*1260* 0,0107 = ca. 5 Million euros a year in rail transport costs.

The equivalent road costs would be: Pallets to be moved / pallet capacity of a lorry * distance * cost lorry per km= 655.200 / 33 *730 * 1,42 = 20,5 million euros a year in road transport costs.

Now the question is:

Is the difference 20,5-5= 15 million euros a year enough incentive for:

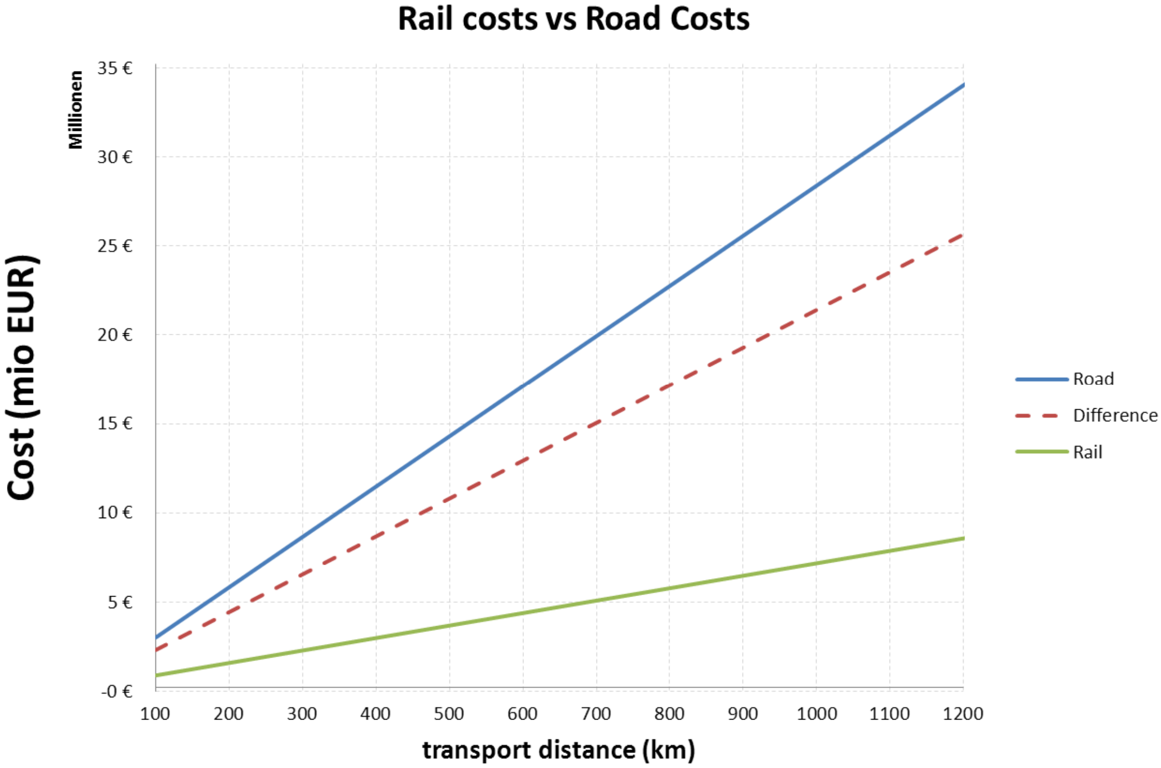
- Building and operating two multimodal stations? and
- Arranging and operating a distribution and pick-up system for the pallets with short distance lorries? and
- Doing the necessary marketing and client gathering for guaranteeing a good loading factor of the trains? and
- Being fast, punctual secure, safe, flexible and reliable? and
- Make a reasonable percentage of benefits from all these operations?

The answer to these questions is very difficult, it would require another business case appraisal, which is out of the scope of this project.

In this context other questions would arise when it comes to other logistics services that could be transferred to the multimodal stations, namely:

- Can the warehousing and warehousing management be outsourced efficiently at multimodal stations?
- What about the customer service?
- What about the distribution decisions in respect to demand or supply?
- What about partnerships developments possibilities and know-how transfer with local hauliers?
- Is the product development, added value, post-packaging, labeling, further cargo groupage something that can be outsorced and performed efficiently in multimodal stations too?
- What would be the costs prospects for all these outsourced operations if centralized in a multimodal station?

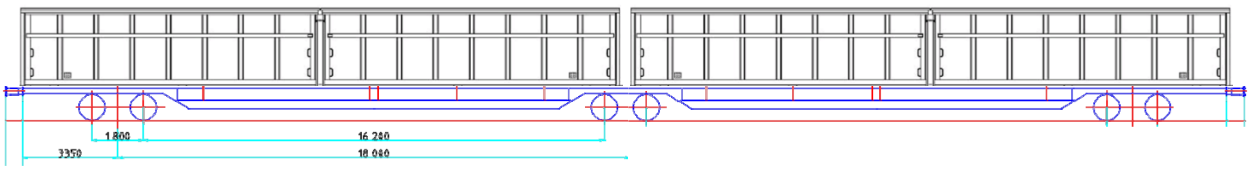
Finally the distance of transportation plays an important role here, then, the longer the distance of transport the higher the potential savings due to the rail use. These savings may be around 1 million euro per 50 km longer distance of transport in the studied business case (see figure).



Another point is the threshold of 600-700 km transport distance, which has to do with the quality of transport. This would be the distance at which a lorry driver should legally rest, making the deliverable schedule one night longer, the solution with two lorry drivers increases the road costs in a 40%. The rail mode should be able to compete in quality at distances longer than 700 km.

4.3 Lighter articulated VEL-Wagon for pallet transportation.

The following wagon concept is proposed for a further study.



- Total loading length 2 x 22 = 44 m
- Length over buffers: Loading length + 2 buffers (0,6m)+ interspace articulation (1,20 m)= 46,4 m
- Pallet capacity: 2 x 63 = 126
- Total weight = Weight of two VEL-Wagons – weight of 1 bogie – weight of 4 buffers and 6 m of frame + weight of cover = 22 + 22 - 4,8 - 2 + 9,5 **= 44,7 t.** (weight of the cover calculated as weight per meter, obtained from H-VEL-Wagon, multiplied by 44, weight of frame and bogies calculated as an averaged weight per meter)
- Total payload= 22,5 * 6 – 44,7 = 90,3 t
- Maximum payload offered per pallet: 753 t
- Volume 338,8 m^3

The next table compares a standard road vehicle with the articulated VEL-Wagon for pallets, and other vehicles such as the Giga liner and a wagon habbins:

vehicle	tare	payload	volume	pallets	**payload/ pallets**	volume/ pallets	payload/ tare	pallets /tare	tare/ volume	payload/ volume
Standard Lorry	14	26	100	33	**788**	3,0	1,86	2,36	140	260
giga 60 t (SE)	22	38	150	51	**745**	2,9	1,73	2,32	147	253
bigmaxx	16,5	27,5	110	37	**743**	3,0	1,67	2,24	150	250
giga 44 t (EU)	18	26	150	51	**510**	2,9	1,44	2,83	120	173
Habbins	26,5	63,5	167	63	**1008**	2,7	2,40	2,38	158	379
H-VEL articulated	44,7	90,3	339	120	**753**	2,8	2,02	2,68	132	267

Data Source: Study on the Effects of the Introduction of LHVs on Combined Road-Rail Transport and Single Wagonload Rail Freight Traffic (K+P, 2011) and Deliverable 2.1 VEL-Wagon.

An important figure to observe is the maximal payload per pallet, which in the case of the standard lorry is 788 t per pallet. This amount is more than enough to handle the normal traffic situations since it is assumed that the average weight of the pallet in road transportation is 400 kg (Source K+P). In concrete the following values are declared:

- 400 kg the pallet space for general cargo
- 270 kg the pallet space for textiles
- 730 kg the pallet space for paper, e.g. paper roll

This may be one of the reasons for which the road industry is lobbying for longer lorries with same payload capacity, as the volume and loading length seems to be more important than the payload.

In this way an articulated VEL-Wagon is addressing such light and volumetric requirements, whereas a habbins wagon is offering more than the double of necessary payload per pallet, this may be not competitive in a modern logistics concept.

A comparison against a habbins train would yield the following parameters:

	No. wagons	Pallets / wagon	No. Pallets in train	Train length	Train tare	Train payload	Train g. weight	No. axles	Axle load	train volume m3
Habbins train	20	63	1260	484 m	615 t	764 t	1379 t	84	16,4 t	3348,0
Art H-VEL train	10	120	1260	483 m	532 t	764 t	1296 t	64	20,2 t	3388,0

An approximation of the costs of an articulated H-Wagon has been done as follows:

Cost of articulated H-VEL wagon = 1,6 x cost of a habbins.

The cost of maintenance has been calculated as:

Maintenance of articulated VEL-Wagon= (2 x maintenance of Habbins – maintenance of a bogie) * 1,23 *(due to increase of axleload)*

Thus, the wagon costs result in (figures in Euros):

Wagon	Units	Depreciation per wagon and year	Interest per wagon and year	Insurance per wagon and year	Maintenance per wagon and year	Total per wagon and year	Total costs per year	Cost per turn (260 turns/ year)
Habbins	40	4.000	2.750	1.200	3.000	10.950	438.000	1.684,62
VEL	20	6.400	4.400	1.920	6.248	18.968	379.368	1.459,11

The wagon costs could be 13,4% cheaper.

A calculation of the business case for an articulated H-VEL-Wagon yields the following results:

Rolling resistance will decrease in about a 6% due to fewer axles and lighter mass.

Aerodynamic resistance will decrease in about 2% due to fewer bogies

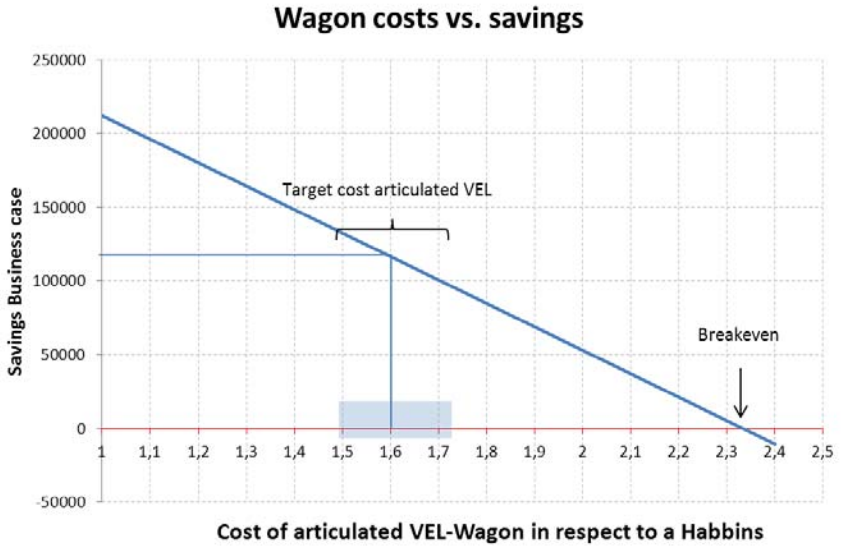
Potential energy will be reduced in a 6% due to a lighter train.

The total costs would look as follows:

	Locomotive	Wagon	Access	Energy	Personnel	Overall
Habbins	3.538,46 €	1.684,62 €	6.085,78 €	5.232,77 €	1.406,19 €	17.947,82 €
VEL	3.538,46 €	1.459,11 €	6.085,78 €	5.010,26 €	1.406,19 €	17.499,80 €
difference	0 %	-13,39%	0%	-4,25%	0%	-2,5%

This means a potential saving of about 100.000 euros per year in respect to the habbins solution.

In this case the influence of wagon costs looks as follows.



The conclusion is that this new design could save an important amount of energy and be more sustainable and competitive against a road transportation.

Finally the solution of **pure-rail transport** such as the single wagon load demands even more logistics planning in order to achieve a satisfactory transport quality and it even requires important rail infrastructure developments such as rail sidings to the companies.

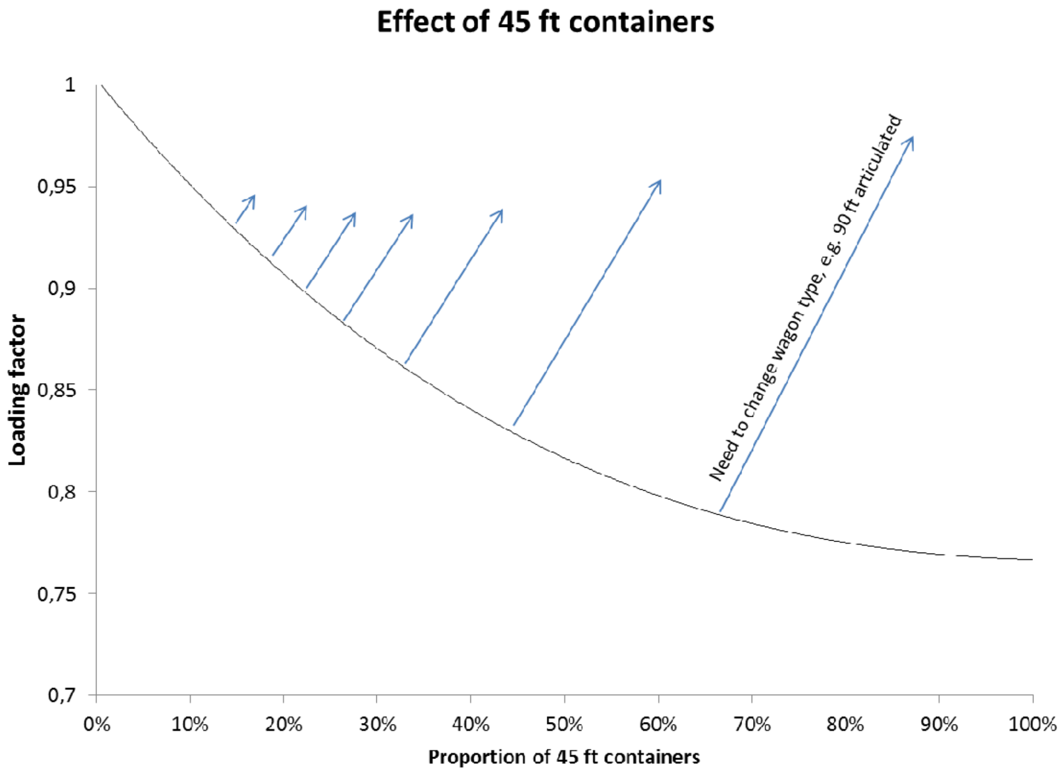
4.4 The intermodal transport market

In the first business case (intermodal) the supposition has been that the surface of the trains is completely occupied by containers, which means that there is not a slot free and the trains have a 100% loading factor. This assumption may be correct in the case of the sea hinterland container traffic as the container length proportion matches almost perfectly with the given wagon arrangement (see Deliverable 2.1 of VEL-Wagon). Obviously, in the daily operation, the surface of the trains may be not always optimally employed due to the variability of the demand. In spite of this, in deliverable 2.1 was demonstrated that a surface of 80 ft long was the optimal for any combination of 20 ft and 40 ft containers.

4.4.1 Intermodal maritime traffic

It is accepted that 20 ft and 40 ft (standard and Hi-Cube) containers are almost exclusive in maritime traffic, however in the last times the 45 ft unit is more and more employed. Hence, it can happen that at some point 45 ft units have to be transported too. This will immediately reduce the loading factor of the trains since the wagon arrangement is not optimal for such container length.

In the case of the 80 ft articulated wagon the 45 ft container is fatal since it cannot be transported at all, therefore the more 45 ft units to be transported, the more 60 ft wagons (or articulated 90 ft wagons) have to be employed in substitution of 80 ft articulated wagons. Conversely, a 45 ft container can be transported on a VEL-Wagon without any particular problem, however, up to a certain proportion of 45 ft units the VEL-Wagon would not be efficient either and a longer wagon, say a 85 ft or a 90 ft should be necessary.

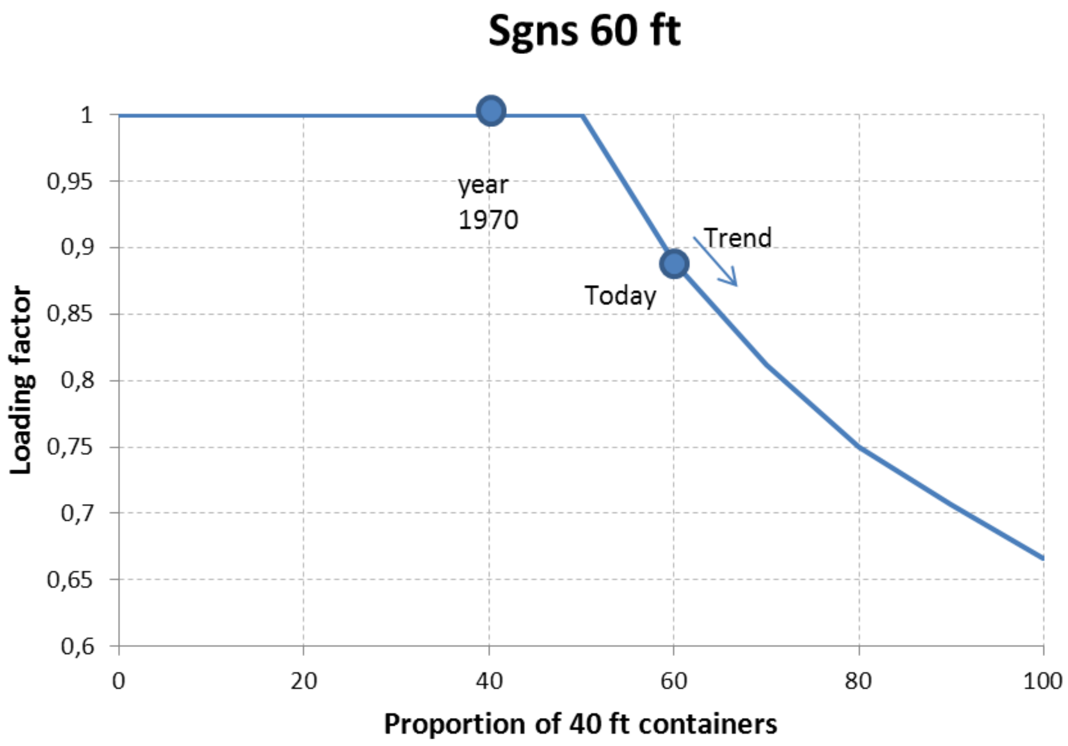


Interpretation of the effect of 45 ft containers in a reference train, the higher the proportion of 45 ft units the more 60 ft are needed (in detriment of 80 ft articulated). At a certain point a specific designed wagon has to be employed, for example an articulated 90 ft wagon or a 90 ft VEL-Wagon.

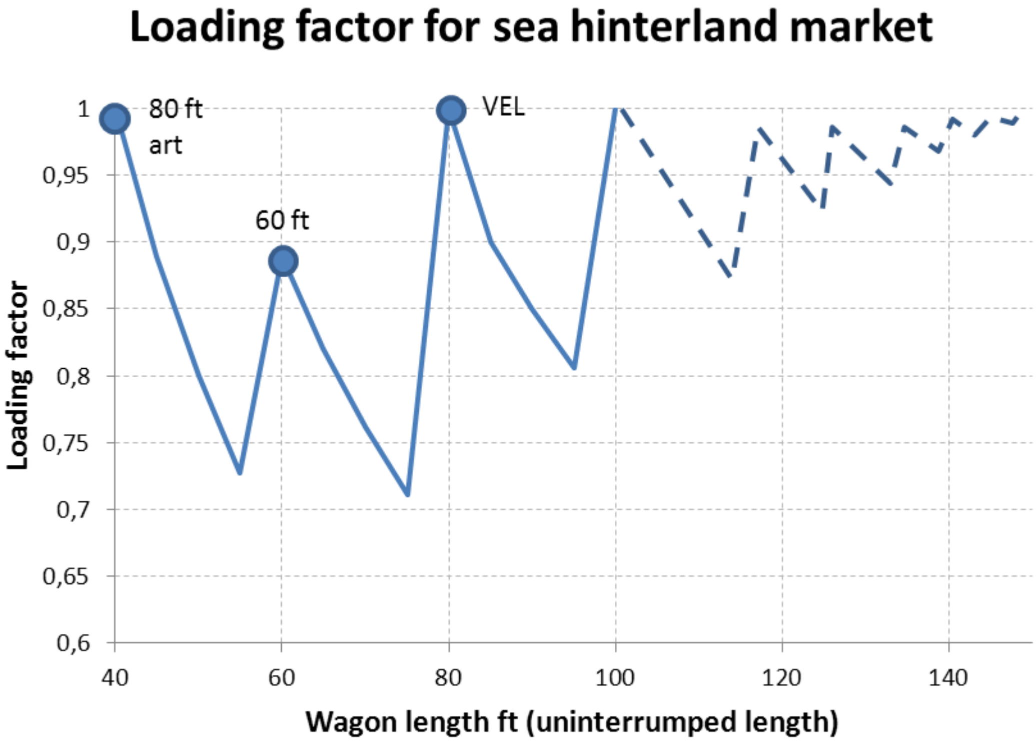
The VEL-Wagon solution would be more resistant to 45 ft units proportion, in this way it would not be necessary to change the wagon arrangement if having a small proportion of 45 ft units, which implies a better satisfaction of the “shuttle operation” principles.

The important advantage of VEL-Wagon is that it has a longer uninterrupted loading surface which is better for increasing the loading factor of the trains. This has been already demonstrated in previous activities of the project.

In the case of the maritime traffic, with only 40 and 20 ft containers, the ideal wagon will be the 80 ft or the 2 x 40 ft (80 ft articulated) because it matches any length proportion. The 60 ft wagon will be efficient as long as the proportion of 40 ft and 20 ft containers remains 50/50. If the 40 ft containers proportion start to grow, as it happens nowadays, then the 60 ft wagon leads to empty spaces and thus to inefficiency.



Loading factor of 60 ft wagons in respect to proportion of 40 ft and 20 ft containers.

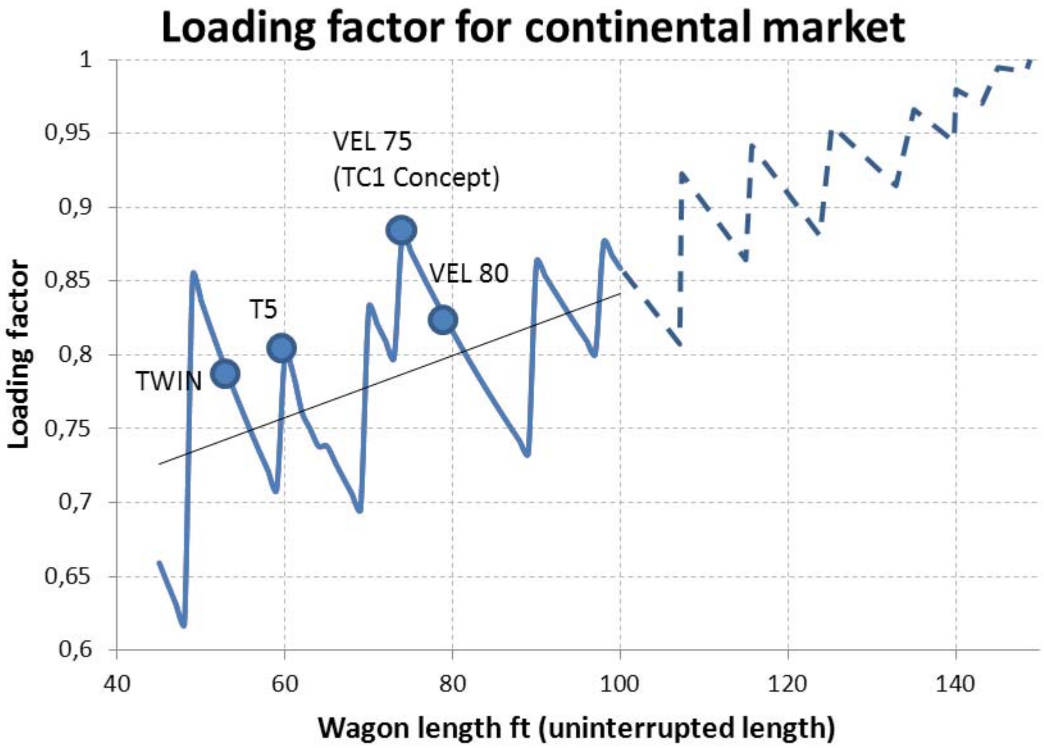


Loading factor of a wagon in respect to its length. Fixed proportion of 40 ft / 20 ft containers (60% /40%)

4.4.2 Continental transport.

The intermodal continental transport demands higher effort on wagon composition in order to match with the higher variability of loading unit cases. An important characteristic of this traffic is the presence of semitrailers. The unaccompanied semitrailer traffic has undergone a boom during the last decade and it is expected that it continues growing during the next years.

Here, longer uninterrupted loading surfaces lead to better loading factors. The simulation has been done with the following unit proportions: 40 % tanks and swap bodies < 7,82 m, 20 % silos and 30 ft bulk containers, 40 % Semitrailers and 45 ft boxes.



The TWIN wagon is a quite popular wagon employed in continental transport, it is able to transport 2 semitrailers and a wide combination of other loading units. The T5 could be understood as the 60 ft wagon for semitrailers. The simulation shows that T5 has better loading factor than the TWIN wagon as it can fit a good number of loading cases, however a shorter wagon of 50 ft would be even better, this is because the majority of units are 7,45 m long and two of them would fit perfectly in one wagon.

The observed trend is that the longer a wagon is, the smaller the variability of loading factor in respect to a length change and the better loading factor overall. In this way the VEL-wagon 75 ft long would offer the better arrangement and a 80 ft VEL-wagon would be an acceptable solution.

The wagons for semitrailers are more expensive than the container-only wagons, about 50% more according to Tatravagonka. The maintenance costs are slightly higher too.

The business case will be reformulated. These are the new train parameters:

Train characteristics:

	Train length	Train g. weight	Train tare	Train payload	No. wagons	Wagons Sgns 60 ft	TWIN wagons	No. axles	TEU Capacity	Axle load
REFERENCE	520 m	1385 t	605 t	780 t	17	5	12	96	80	14,43 t
VEL Wagon 80 ft for 1 semitrailer	512 m	1340 t	560 t	780 t	19	-	-	80	76	16,75 t

The incurred costs of a complete turnaround intermodal train (two-way) are depicted on the following table (NEA-et.al -Report):

	Locomotive	Wagon	Access	Energy	Personnel	Overall
Reference	6.647,32 €	2.356,68 €	8.508,81 €	6.047,26 €	2.209,34 €	25.769,41 €

Of which:

Wagon costs

Wagon	Units	Depreciation per wagon and year	Interest per wagon and year	Insurance per wagon and year	Maintenance per wagon and year	Total per wagon and year	Total costs per year	Cost per turn (260 turns/ year)
Sgns 60ft	15	2.400	1.650	720	1.800	6.570	98.550	379,04
TWINt	36	5.520	3.795	1.656	3.312	14.283	514.188	1.977,65
60ft + TWIN (train)	51	7.920	5.445	2.376	5.112	20.853	612.738	2.356,68
VEL	57	3.600	2.475	1.080	2.160	9.315	530.955	2.042,13

As said, the acquisition costs of a TWIN wagon have been estimated as 1,5 times the cost of an 80 ft articulated wagon and its maintenance costs in 1,2 times.

The cost of a VEL-Wagon able to carry semitrailers will increase too, the supposition is that the cost of a VEL-wagon able to carry semitrailers will be 1,5 times (1,2 on maintenance) the costs of a 60 ft wagon.

Under these suppositions, VEL-Wagon would represent a 13,3% save on wagon cost against the reference case.

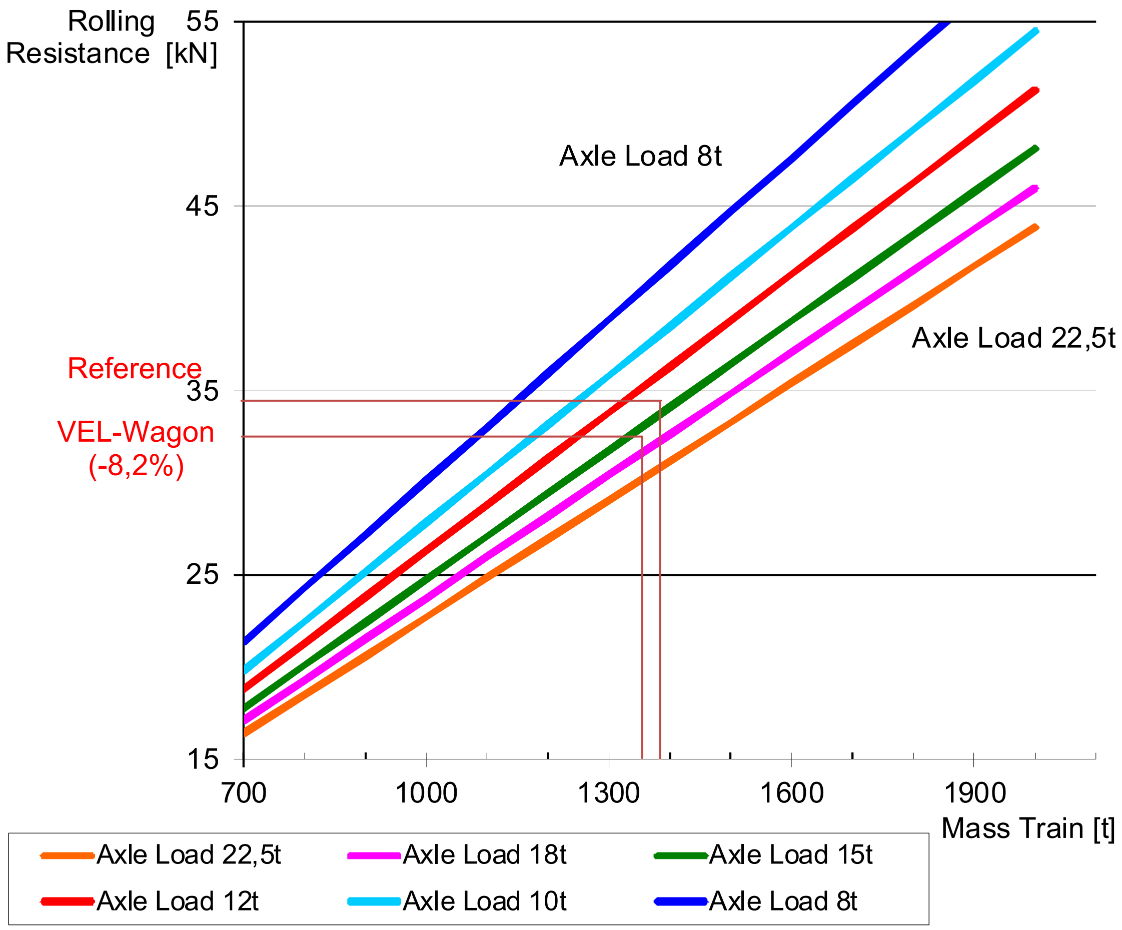
Energy costs

								Train energy consumption in kWh per km				
	Train length	Train g. weight	Train tare	Train payload	No. wagons	No. axles	Axle load	Total (100%)	Rolling (33%)	Aero (32%)	Potential (27%)	Rest (8%)
NEA report	520 m	1385 t	605 t	780 t	17	96	14,43 t	26,00	8,58	8,32	7,02	2,08
VEL-Wagon	512 m	1340 t	560 t	780 t	19	80	16,75 t	24,25	7,88	7,49	6,81	2,08

A first appraisal of the energy consumption of a VEL-Wagon train was undertaken in a previous chapter of VEL-Wagon project (See D2.2, pages 83 to 101).

The rolling resistance is directly proportional to the train weight and the amount of axles (or the axle load). In exhibit 51 of Deliverable 2.1 is portrayed a chart that establishes the relation between these parameters.

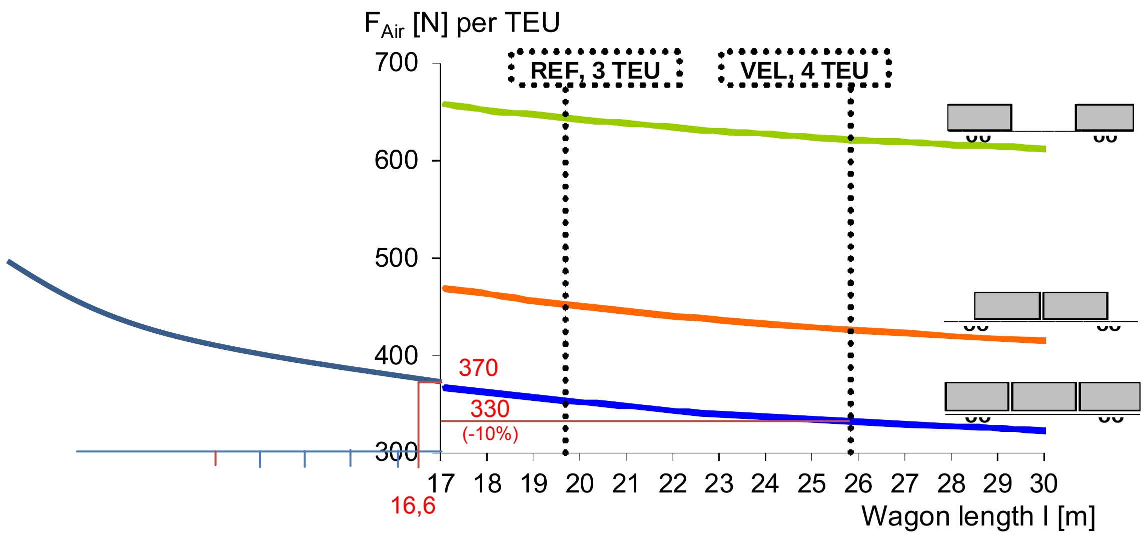
According to the calculated data, VEL-Wagon train will be lighter and have fewer axles than the reference train. The average axle load will be higher in a VEL-Wagon train and this will imply less rolling friction and therefore less energy consumption. In concrete, a diminishment of 8,2% is expected. See figure below:



Correlation of Train Mass and Rolling Resistance. Source: VEL-Wagon Deliverable 2.1

The aerodynamic resistance, among many other things, depends on the gaps existing along the train and their length. The arrangement of the containers and the semitrailers along the train yields gaps, these gaps are different for any loading case, which varies along the time. We are going to suppose that the compared trains have the same aerodynamic resistance on the upper part, this is a pessimistic assumption for VEL-Wagon provided that a longer wagon entails better loading factor and thus better compression of the containers and fewer gaps.

The drag force resulting from the aerodynamic properties of the wagons has been as well chartered in Deliverable 2.1, exhibit 54. It displays the relation between container arrangement, wagon length and aerodynamic resistance.



The wagons of the reference train are 12 x TWIN (art. 106ft) and 5 x Sgns (60 ft). Each articulated 106 ft wagon can be assumed as 2 x 16 m long wagons, the Sgns wagon is an 19,8 m long wagon. Therefore the average length of a reference wagon is 16,6 m, calculated as:

$$\text{Ref. wagon length (aerodynamic)} = \frac{(19{,}8 \times 5 + 16 \times 12 \times 2)}{5 + 12 \times 2} = 16{,}6\ m$$

VEL-Wagon length is 26 m, thus, introducing these values in the depicted chart the resulting energy decrease is 10%.

The potential energy consumption is directly proportional to the train gross weight.

The reduction on potential energy consumption due to a reduced train mass can be obtained directly by a simple rule of three.

	Train mass	Potential energy consumption
Reference train	1385 t	7,02 kWh / km
VEL-Wagon train	1340 t	6,79 kWh / km

It is obtained a 3% reduction on the energy consumed by a VEL-Wagon train due to potential energy reasons.

The rest of the energy categories will be neglected for not having enough representation on the total energy sum, in any case they should favor the VEL-Wagon case due to reduced mass and amount of axles.

Hence, making the sum according to the obtained values:

	Train energy consumption in kWh per km				
	Rolling (33%)	Aero (32%)	Potential (27%)	Rest (8%)	**Total (100%)**
Reference train	8,58	8,32	7,02	2,08	**26,00**
VEL-Wagon train	7,88	7,49	6,81	2,08	**24,25**
Change	-8,20%	-10,00%	-3,00%	neglected	**-6,72%**

VEL-Wagon would represent a 6,72% save on energy cost against the reference case.

Track access cost

Change is neglected.

Overall costs

The overall costs are summed up according to table X in order to produce the following table:

Turnaround costs	Locomotive	Wagon	Access	Energy	Personnel	Overall
Reference	6.647,32 €	2.122,62 €	8.508,81 €	6.047,26 €	2.209,34 €	25.535,35 €
VEL-Wagon	6.647,32 €	2.042,13 €	8.508,81 €	5.641,13 €	2.209,34 €	25.301,28 €
Change	0,00%	-13,35%	0,00%	-6,72%	0,00%	**-2,80%**

According to the available information it is possible to enunciate that:

VEL-Wagon for semitrailers would represent a 2,80% save on total rail cost against the reference case.

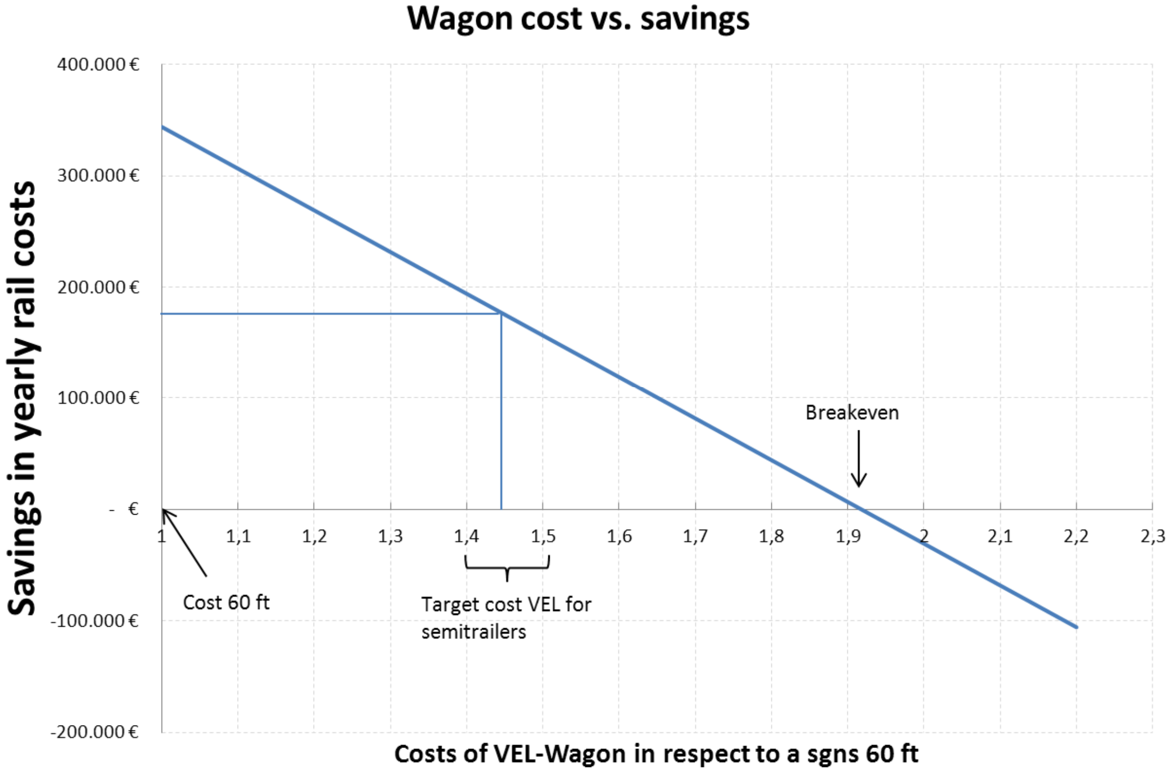
Annual savings in rail transport:

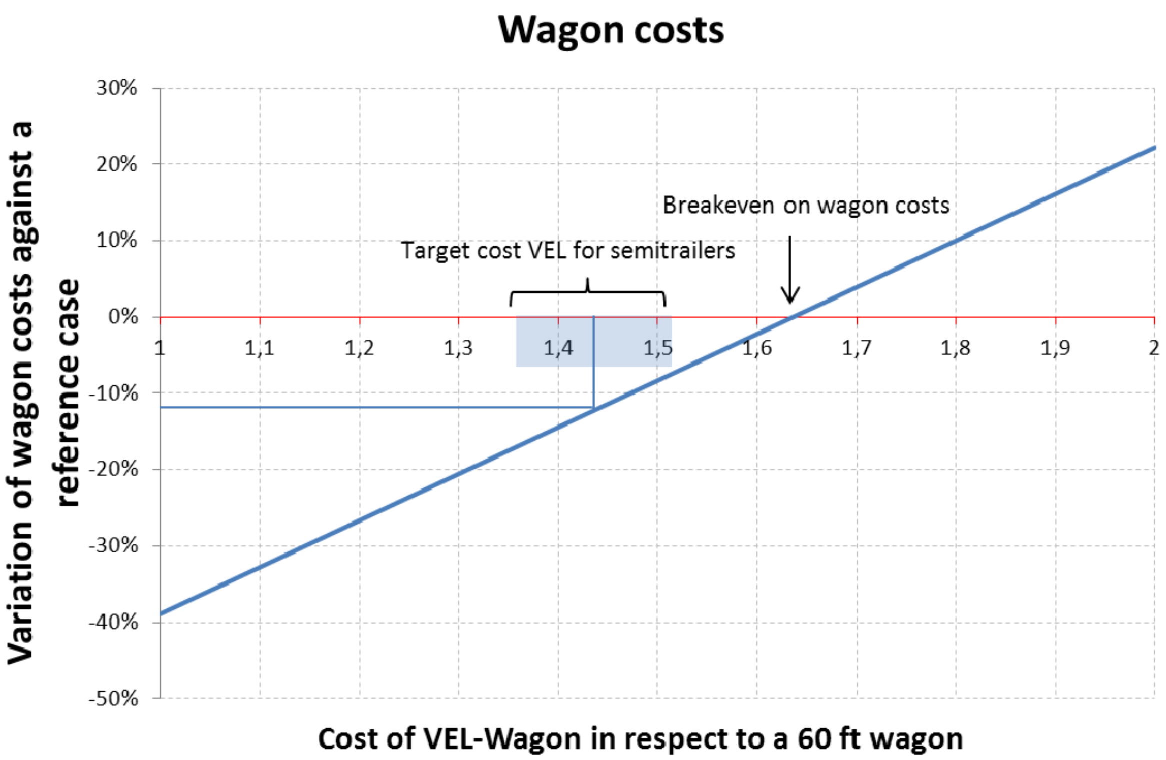
Annual savings = (Cost turnaround reference - Cost turnaround VEL-Wagon) * 260 = 187.377,84 €

Hence, in this business case about continental transport:

The rail operator could **save up to 200.000 Euros a year** if using VEL-Wagon for semitrailers instead of using the typical rolling stock.

The variability of the VEL-wagon cost and its influence on the benefits would look as follows.





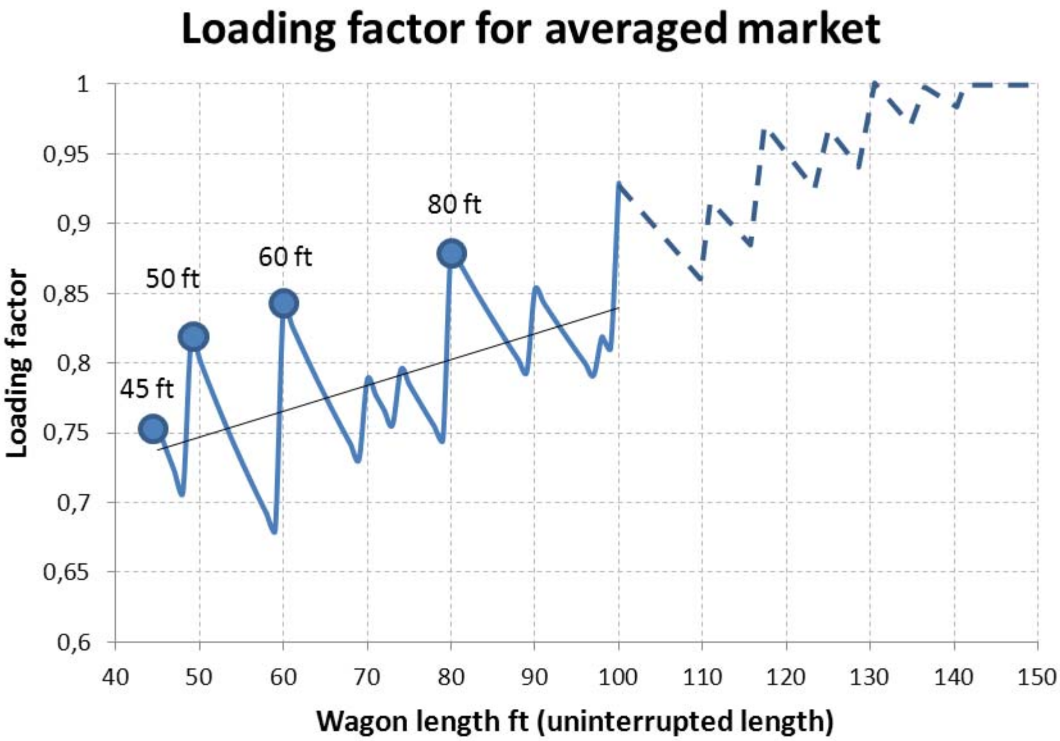
The conclusion is that a VEL-Wagon for semitrailers should have a cost lower than 1,5 times the cost of a standard 60 ft wagon in order to generate sufficient benefits for this business case.

4.4.3 Averaged market (Maritime and Continental together)

The VEL-Wagon project intends to address the case that both maritime and continental traffics share the same intermodal trains. The basic objective by this is to diminish the risk of having wagons idle when the demand of a specific market shrinks.

Usually in European intermodal transportation the continental and maritime markets are differentiated and are served with different kind of trains. Nowadays the trend is that articulated 80 ft wagons are employed in maritime shuttles while articulated pocket wagons, e.g. TWIN, are employed in continental trains. 60 ft wagons are employed in both types of trains indistinctly.

In this case it happens again that the longer a wagon is (uninterrupted length) the better loading factor it has.



In this case, a VEL-Wagon with one pocket for a semitrailer would be a wagon that could be employed indistinctly both in continental and maritime traffic offering in both cases very good loading factors.

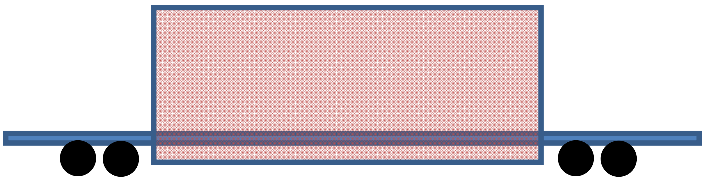
Obviously a VEL-Wagon for semitrailers would be more expensive than a wagon for containers-only, it is estimated that the pocket version could be 40% more expensive than the container-only version (Estimation based in observation of pocket wagons compared to equivalent container-only wagons.. This would entail a cost up to 100.000 euros a year of difference in wagon costs.

A VEL-Wagon for semitrailers would be also heavier than a wagon for containers-only. According to observations a wagon for semitrailers can weigh up to 10-30 % more than its version for containers only. This could lead to important losses on payload capacity.

The recommendation is to focus on the container-only segment.

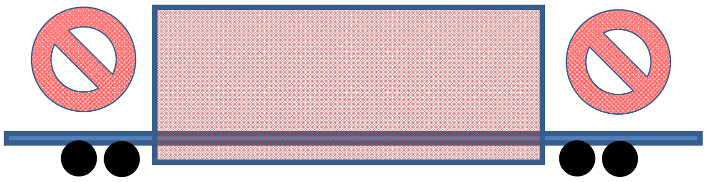
4.4.4 Market for tall containers (e.g. Megaboxes)

VEL-Wagon can have a design that allows transporting very tall boxes on a lower level between the bogies.



This ability may be interesting for traffics that require the transportation of tall boxes e.g. automobile parts, tires, machines in racks etc. or traffics that require the transportation of standard boxes in very narrow gauges, for instance in Great Britain.

A VEL-Wagon transporting a tall unit between the bogies can only be partially employed since the remaining free edges are not sufficiently long to accommodate any standard loading unit.

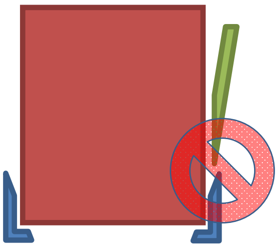


A wagon employed in Europe for such transports is the Sffggmrrss (MEGAFRET), this is the reference wagon.

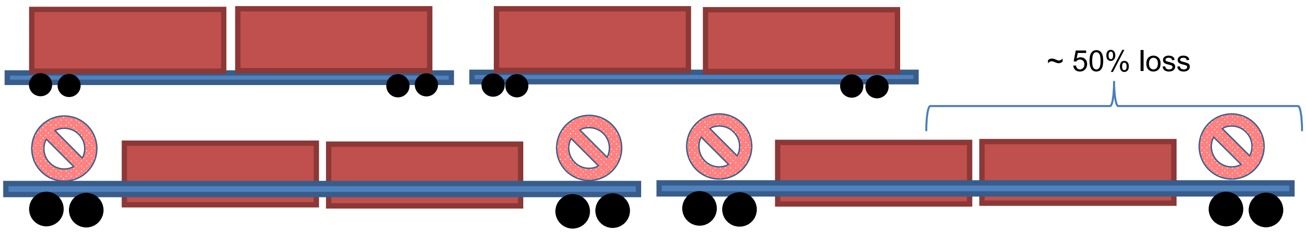
This wagon has the following technical properties:

Technical details	
Length over buffers	36'440 mm
Loading length	2 x 16'105 mm
Floor height above top of rail, unloaded	825 mm
Cargo weight (at 120 km/h)	89 t
Tare weight	39 t
Maximum axle load	16 t
Wheel diameter	730 mm
Maximum Speed	120 km/h
Minimum curve-radius	150 m*
Ferry boat capability	1° 30'

VEL-Wagon has a loading length of ca. 15 m between the bogies, which has place for two swap-bodies. The swap bodies can be only top-lifted since it is physically impossible to introduce the grapple arms for bottom-lift inside the pocket of VEL-Wagon.



For a given length of train the Megafret is able to accommodate about 50% more units and TEUs than a VEL-Wagon, this is because the loading factor is much more better in the Megafret, which is a wagon specifically designed for such transportations.



Apparently VEL-wagon would not bring about any especial advantage but rather a general decrease on efficiency.

The calculation using the same methodology yields a negative result for VEL-Wagon, in concrete the values are:

Country	Locomotive	Wagon	Track access	Energy	Personnel	Overall	TEUs	€/ TEU
Megafret	6.647,32 €	1.804,22 €	8.508,81 €	6.047,26 €	2.209,34 €	25.216,95 €	73,97	340,89 €
VEL 2nd Level	6.647,32 €	1.828,82 €	8.508,81 €	5.731,23 €	2.209,34 €	24.925,52 €	46,75	533,14 €

The conclusion is that the pocket of VEL-Wagon is not an interesting option, in comparison with existing rolling stock, for the transportation of tall units. Furthermore the necessary structural design to allow this transportation leads to higher tare and higher cost of VEL-Wagon which has a negative effect on its application for regular transports.

The recommendation is to discard the option of a central pocket for tall containers in order to focus on a simplified and lighter VEL-Wagon design.

4.5 Wagon tare, payload and axle load.

One of the most sensible questions to criticize VEL-Wagon is the apparent inability to carry heavy loads.

In principle the target weight of a VEL-Wagon for containers-only would be 21 t, this yields a payload of 69 t over 4 TEUs space. Which makes 17,25 t payload capacity per TEU.

Provided that:

The average weight of a loaded TEU in Europe is 12,8 t,

the VEL-Wagon has more than enough payload capacity for the majority of loading cases.

SEVENTH FRAMEWORK PROGRAMME

VEL-Wagon

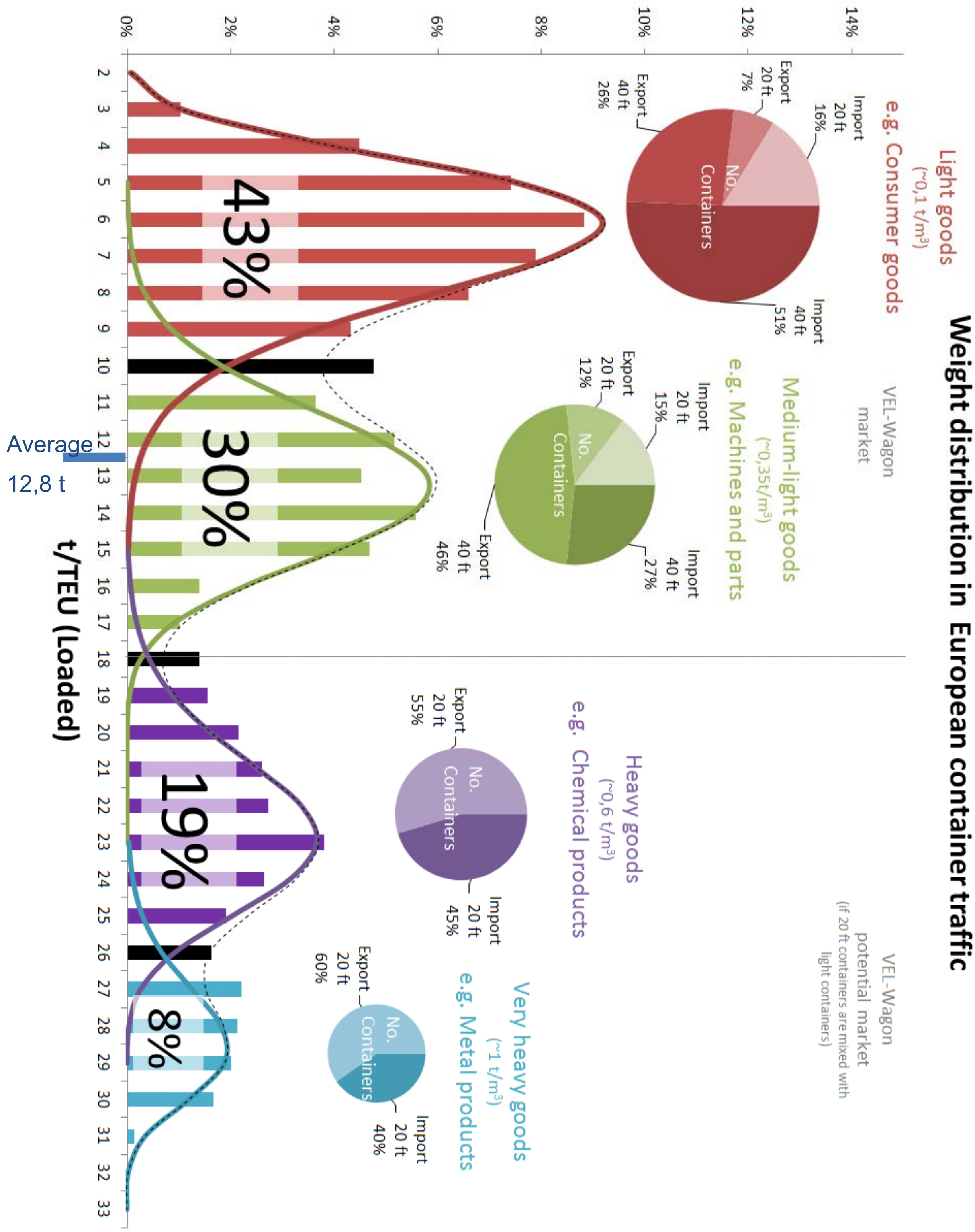
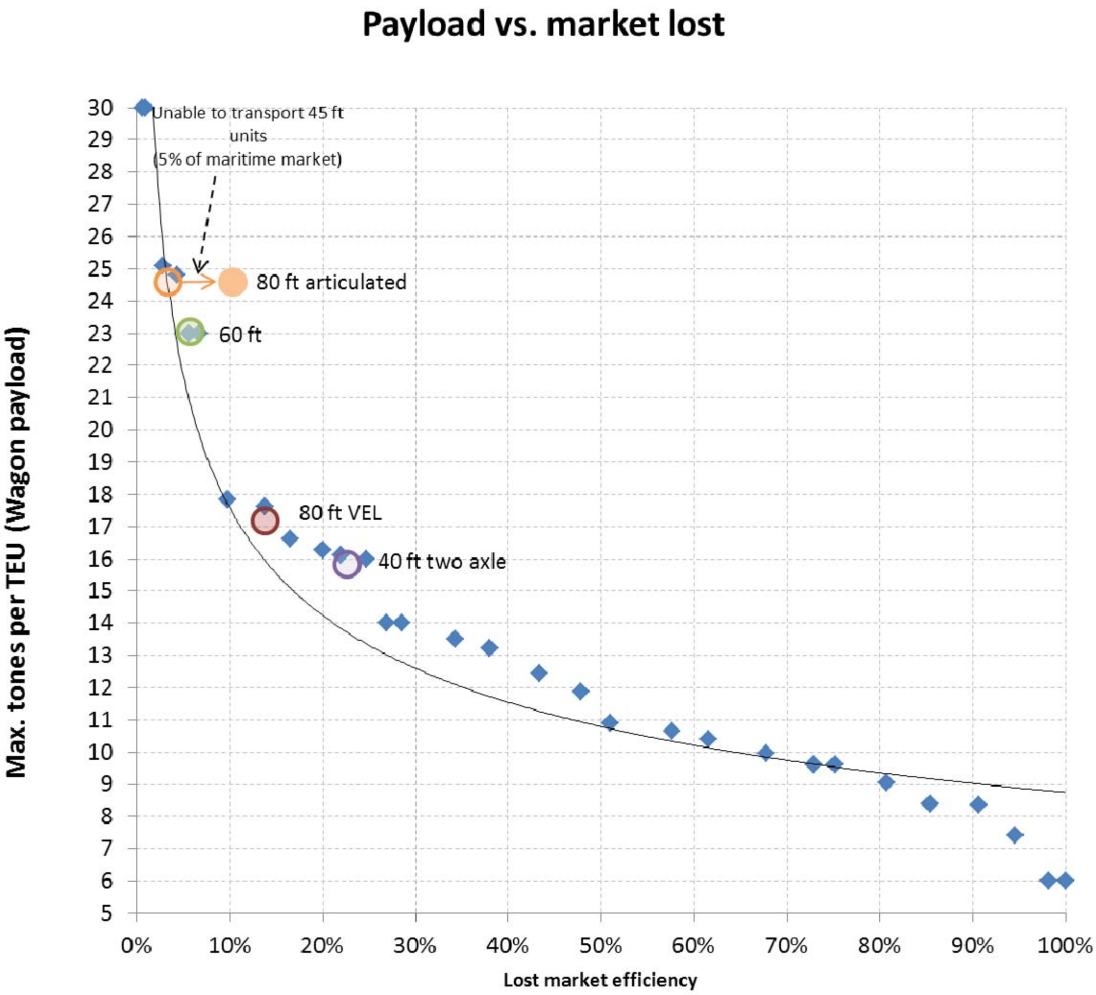


Exhibit. X Weight distribution in European container traffic (in No. containers and gross weights, only loaded containers). Source data: 2011 Eurogate and Euromax terminals, Antwerp Port statistics and Eurostat.

In addition, if considering empty containers (16 % of total containers) the average TEU weight decreases to 11 tones, which makes VEL-Wagon even more suitable.

The next graph represents the efficiency lost in a market by a wagon type in respect to its offered averaged payload per TEU. It has been obtained with data from the Deliverable 2.1.



Market efficiency loss of a wagon in respect to its averaged payload per TEU

It is possible to see that the 80 ft articulated wagon is able to address almost any kind of traffic (95% of the cases), especially the very heavy one, however when it comes to 45 ft units this wagon is useless. 45 ft units represent about 5% of maritime traffic, a market that is lost for an articulated 80 ft.

Hence the articulated 80 ft is able to address the market efficiently in terms of loading surface utilization, however it is rather inefficient in terms of deadweight utilization since it is a very heavy wagon for the majority of transportation cases.

A 60 ft wagon is also able to address an important number of traffics, however it results inefficient when there is a majority of 40 ft containers.

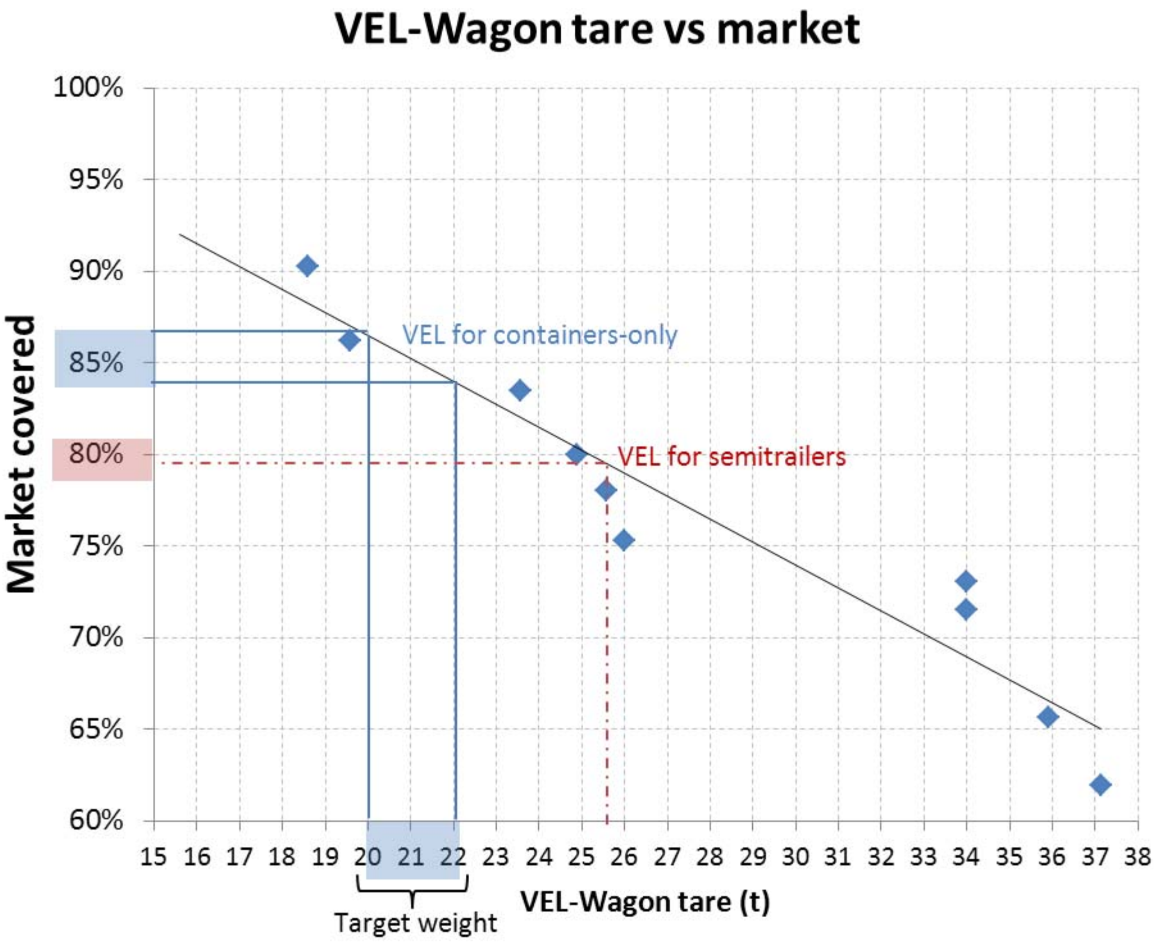
An 80 ft VEl-Wagon cannot address very heavy containers efficiently, this market is estimated in a 15%. However it is very efficient (in trems of length and weight) for the remaining 85%.

A 40 ft two axle wagon has an important market efficiency loss of 25%.

It is important to notice that the market efficiency loss begins to be very important from 18 tones downwards, this means that a decrease of 1 tone in payload capacity per TEU entails an important market efficiency loss of about 10%.

The next graph displays the relation between the tare of VEL-Wagon and its market ability. It is assumed a maximum axle load of 22,5 t which gives a total wagon gross weight of 90 t.

In this case each tone extra of wagon tare entails about 1,3 % of market efficiency loss. Considering the target weight of 21 t for a VEL-Wagon it is expected an efficient market covering of 85 % of the cases.



In conclusion VEL wagon is able to address 85% of the market very efficiently both in terms of deadweight and surface, the remaining 15% can be still addressed but it entails a loss of loading factor. A VEL-Wagon for semitrailers (with a pocket) will be heavier than a VEL-Wagon for container only and this will decrease the payload entailing an efficiency loss of 5%.

The efficiency loss in the heavy cases can be corrected with empty container transport.

An 80 ft articulated will address very efficiently almost all kind of traffics but it will be over-dimensioned in terms of deadweight when doing it, especially when transporting light containers, which are majority. This entails important energy consumption and waste of resources.

5 Conclusions

From a business perspective VEL-Wagon is a very interesting and profitable wagon for intermodal transports, especially when it comes to the maritime market. In this context it would be able to generate a yearly saving potential of 500.000 € in a shuttle relation between Rotterdam and Milan. The business case of continental transport shows a positive yield as well. The application for volumetric loads, pallets and the like is as well very interesting since the VEL-Wagon with a detachable superstructure can perform at the same or even slightly better level than the typical wagons for this kind of cargo such as the habbins.

In the sensitivity chapter it has been observed that the wagon cost of production has much less influence in the total business than the properties of it such as the tare and length capacity. For this reason it is recommended to focus very much on achieving a good design and reliability even if the price becomes slightly higher.

The tare of the wagon has a high influence on the market that the wagon can address, every extra tone of tare may entail about 1,3% of market loss.

Finally, the uninterrupted loading length of the wagon has an enormous impact on the loading factor of it being longer loading lengths better for the loading factor. From a pragmatic view VEL-Wagon should have 80 ft of loading length, however it is expected a growth of the lengths of the containers e.g 45 ft units and this may make necessary to extend the length of VEL-Wagon to 90 ft or even more.

SECOND PART (Cost analysis of KTH)

Authors: Bo-Lennart Nelldal, Hans Boysen

1 Introduction

This report is a complement to a report from TU Berlin dealing with business formulations and target costing for VEL-wagon. The cost models in this report have been developed at KTH and the report has been written by Bo-Lennart Nelldal and Hans Boysen.

The aim of this report is to figure out how competitive VEL-wagon is compared with existing inter modal wagons as well as alternative wagons for wagon load transports.

In this KTH cost model has been used which is a more general cost model in which different production systems can be calculated. In this case the model has been completed with a wagon cots-model in which different wagon types can be tested, both existing and hypothetical. Detailed data in the calculations from part 1 i.e. data for energy consumption has been used also in part 2 and the results have been calibrated to the results in part 1. Both VEL-wagon for inter modal and wagon load has been calculated and compared with other wagons.

2 Cost model

KTH has developed a cost model to make our own calculations for different wagon types. The aim was to construct a flexible model which can be used for calculations for different wagon types in different countries. The purpose is to specify the most significant costs, therefore the model is not very detailed.

The model consists of a train operating model and a wagon specification model. The structure of the train operating model is shown in Table 1 and that of the wagon specification model is shown in Table 2.

The train operating model consists of transport specification and train specification data from which data for the cost calculation is processed i.e. yearly production per locomotive and wagon, number of train kilometres, wagon kilometres and gross tonne kilometres per trip. Several parameters are possible to change, including the distance of operation, time table time and supplement for shunting, number of locomotives, number of wagons, load factor and empty run factor.

The aim is to calculate all costs for the locomotive itself that means also the pure cost for the train if it were operating without wagons. That means that not only the locomotive capital cost, its maintenance cost and the cost for the engineer but also the energy cost and the track access costs for the locomotive are allocated to the locomotive. To the wagons apart from their capital and maintenance cost the marginal cost for energy and track access according to the gross tonne kilometres of the wagons including payload are allocated. There is also an amount for insurance per wagon according to the investment cost.

Finally there is also an overhead for administration, planning and risk. This is calculated as a ~~%~~ percentage of the total operating and capital costs.

It is possible to change all costs according to actual costs in different countries i.e. track charges costs depending on cost structure in train kilometres and gross tonne kilometres. The basic model has been developed for Swedish conditions at the year 2011. However, the model has been calibrated to the NEA-et.al calculations for the Rotterdam-Lugano intermodal train. Today the models calculate in SEK (Swedish crowns) and € but the currency is possible to change.

In the wagon specification model the most important features of a freight wagon can be implemented. There is also a rough model to calculate the investment costs and the maintenance costs according to the components of the wagon. Therefore it is possible to construct a hypothetical wagon with bogies or single axles, different frames and equipment. There are also possibilities to make calculations of payload depending on axle load, number of TEU depending of loading length and other measures which are important to the economy.

For this project 6 intermodal wagons and 4 wagon load wagons have been specified, but it is rather easy to input new wagons.

Table 1 Cost model for train operation

Specification	Variable	Cost
Transport data		
Running distance	km	
Scheduled transit time	h:min	
Supplement for shunting	% of timetabltime	
Trips per year	number	
Train data		
Number of locos	number	
Number of wagons	number	
Tractive power/loco	KW	
Weight/loco	tonnes	
Length/loco	m	
Length/wagon	m	
Tare weight/wagon	tonnes	
Max load/wagon	tonnes	
Load factor	%	
Empty run factor	%	
Cost for locomotive		
Engineer	timetabletime	Cost/hour
Maintenance locomotive	locokm	Cost/km
Energy for locomotive	KWh/locokm	Cost/KWh
Track fees for locomotive	trainkm	Cost/trainkm
Capital cost	Investment cost	Depritiation/year
		Average Interest/year
	Yearly operation	Cost/locokm
Cost for wagons		
Maintenance for wagons	wagonkm	Cost/wagonkm
Energy for wagons	KWh/grosstonkm	Cost/KWh
Track fees for wagons	grosstonkm	Cost/grosstonkm
Insurance	Investment cost	% of investment cost
Capital cost	Investment cost	Depritiation/year
		Average Interest/year
	Yearly operation	Cost/wagonkm
Overhead		
Adm and planning	% of total cost for	Operation and capital
Risk/profit	% of total cost for	Operation and capital
Total cost		
Cost for locomotive	Summarized	All costs for locos
Cost for wagons	Summarized	All costs for wagons
Overhead	Summarized	All overhead costs

Table 2 Wagon specification model

Specification	Variable	Cost	Wagon 1 Wagon 2 Wagon 3
Input data to train model			
Type	Class		
Axles/wagon	number		
Axle load	tonnes		
Max gross weight/wagon	tonnes		
Tare weight/wagon	tonnes		
Max load weight/wagon	tonnes		
Load volyme	m^3		
Number of TEU:s per wagon	number		
Loading length	ft		
Total loading length	m		
Total length	m		
Energy consumption	KWh/gross tonne km		
Maintenance cost		Cost/km	
Investment cost		cost/wagon	
Input data to wagon model			
Manufacturing costs			
Underframe	m	cost/m	
Bogies	number	cost/bogie	
Single axles	number	cost/axles	
Carbody	sum	cost	
Other equipment	sum	cost	
Sum investment cost		cost/wagon	
Maintenance cost			
Underrame and others	% of investment cost	cost/km	
Running gear	% of investment cost	cost/km	
Sum maintenace cost		cost/km	

3 Cost for intermodal transport with VEL and alternative wagons

The cost for using the VEL wagon in a train has been compared with other wagons available on the market:

- 60 ft 4 axles wagon Sgns/ss
- 80 ft 6 axles wagon Sgrs/ss
- 80 ft 4-axles VEL wagon (Sggns/ss)
- 40 ft two-axles wagons Lgns/ss
- 45 ft two-axles wagons Lgns/ss

The wagons are specified in table 3. There are several options to calculate the transportation cost. It can be calculated as the cost per TEU in trains with equivalent capacity, the cost depending on variable capacity in TEU and the cost per TEU with variable train length. Evaluation can also be made of the cost structure of the total cost of the train so it is for example possible to examine the costs of the wagons as a share of the overall cost of the train.

The first figures shown here are for a 900 km intermodal train in Sweden. The cost has been calculated per TEU in a train with an equivalent capacity of 80 TEU and 80% load factor for VEL wagons and if possible the same or almost the same numbers with other wagons.

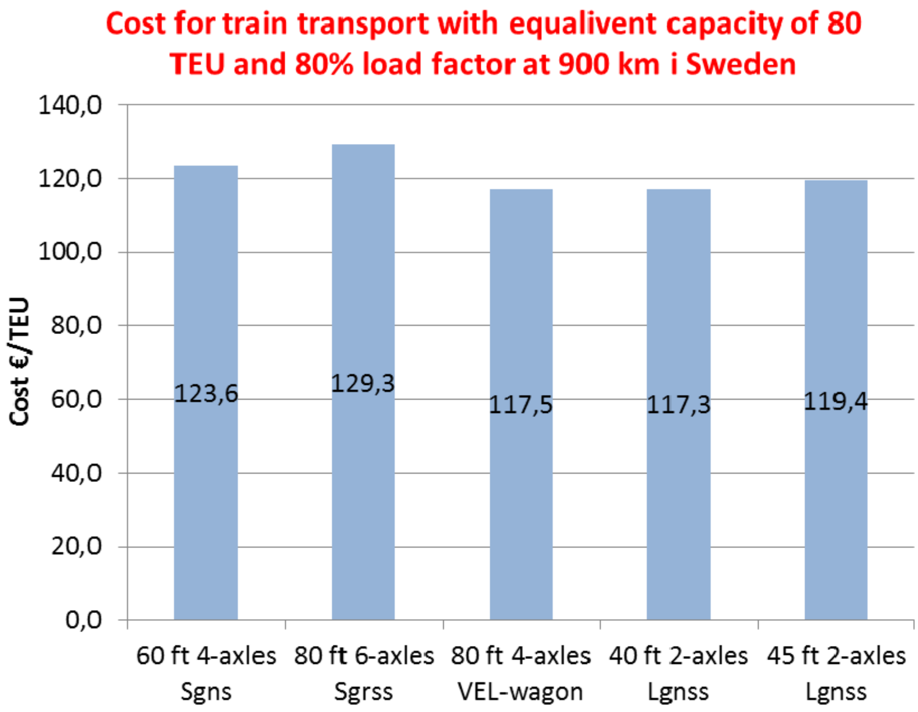


Figure 1: Cost in€/TEU for a train with capacity of 80 TEUs, 80% load factor and 900 km running distance

As can be seen in Figure 1, VEL wagon is more efficient than the 60 ft 4-axles wagon Sgns as well as the 80 ft articulated 6-axles wagon Sgrs. The transport cost/TEU is 5% lower than for Sgns and 9% lower than for Sgrs. The 80 ft Sgrs has the advantage of more flexible loading of 20 ft and 40 ft containers than the 60 ft Sgns but this advantage has also VEL wagon.

The two-axles 40 ft wagon ~~has~~ gives the same transport cost per TEU as the VEL wagon but have has the disadvantage of limited payload, that means that many containers cannot be load on this wagon. The same is the situation of the 45 ft two-axle wagon but on the other hand this is the only one which can handle 45 ft containers efficiently.

Table 3: Specification of wagons for inter modal analysis.

Type			Sgns DB 735	Sggrss DB 757	VEL-IM	Lgnss HZ DDSV	Lgns SNCB DDS
Type			Sgns	Sggrss	VEL-IM	Lgnss	Lgns
Axles/wagon			4	6	4	2	2
Axle load	tonnes		22,5	22,5	22,5	22,5	22,5
Max gross weight/wagon	tonnes		90,0	135,0	90,0	45,0	45,0
Tare weight/wagon	tonnes		20,0	28,0	24,0	11,5	12,5
Max load weight/wagon	tonnes		70,0	107,0	66,0	33,5	32,5
Load volyme	m3						
Number of TEU:s per wagon	number		3	4	4	2	2
Loading length	fot		60	80	80	40	45
Total loading length	m		18,4	24,5	24,5	12,5	13,8
Total length		1,25	19,7	26,7	25,8	13,8	15,1
Energy consumption	KWh/grosstonkm		0,0152	0,0152	0,0140	0,0155	0,0155
Maintenance cost	SEK/km		0,16	0,25	0,17	0,08	0,08
Investment cost	1000 SEK		850	1 350	1 000	450	480

In Figures 2 and 3 the transport cost per TEU depending on train capacity is shown. The costs per TEU decrease ~~by~~ with increasing train length; for VEL wagon from 155 €/TEU at 40 TEUs to 105 €/TEU at 80 TEUs. This train has 1650 gross-tonnes and is 660 m long so this is a maximum value in many countries today. VEL wagon is always less expensive than the ordinary 60 ft and articulated 80 ft wagons but has the same transport cost as the 2-axle 40 ft wagons. A train with 2-axle~~s~~ wagons with a capacity of 80 TEUs will have approximately the same gross mass but will be longer at 706 m and cannot load heavy containers above approx. 33.5 tonnes if the axle load is restricted to 22.5 tonnes. Although the ISO standard for 40 ft containers limits gross mass to 30.5 tonnes, this is a minimum limit, and there are 40 ft and 45 ft containers at up to 39 tonnes gross mass.

Even heavier and longer trains are possible with one modern loco as Traxx if the infrastructure and traffic pattern will permit this. The transport cost will be even lower. The maximum will be a train with a capacity of 128 TEUs with a wagon mass of 2600 gross-tonnes and a length of 1051 m and the cost will be reduced to 84 €/TEU.

With the cost model it is also possible to evaluate differences between countries depending. A simplified comparison has been made between Sweden and Germany. The cost that has been taken into account is different track access charges, energy prices and engineer costs.

The calculations have been done for a 600 km running distance with a train consisting of 20 VEL wagons and with a load-factor of 80%. The results are shown in Figures 4 to 6.

In Figure 4 it is shown that the cost for track access is much higher in Germany than in Sweden – 20% share of the total costs in Germany compared with 7% share of the total costs in Sweden. On the contrary the cost for the engineer is 14% in Sweden and 7% in Germany. Also the cost for energy is higher in Germany than in Sweden. The other differences in cost-shares in Germany compared with Sweden and the fact that the higher share for track access and energy in Germany will affect the shares. The absolute cost for locomotives and wagons are the same in the calculation.

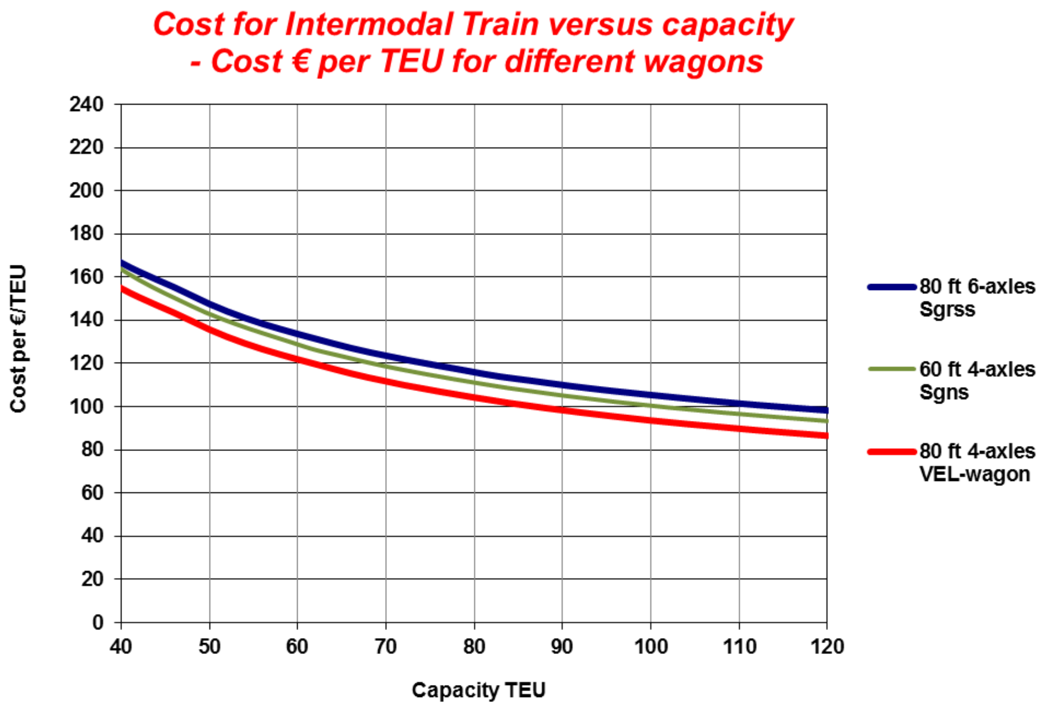


Figure 2. Transport cost per TEU depending on capacity for trains with different wagons and 80% load factor.

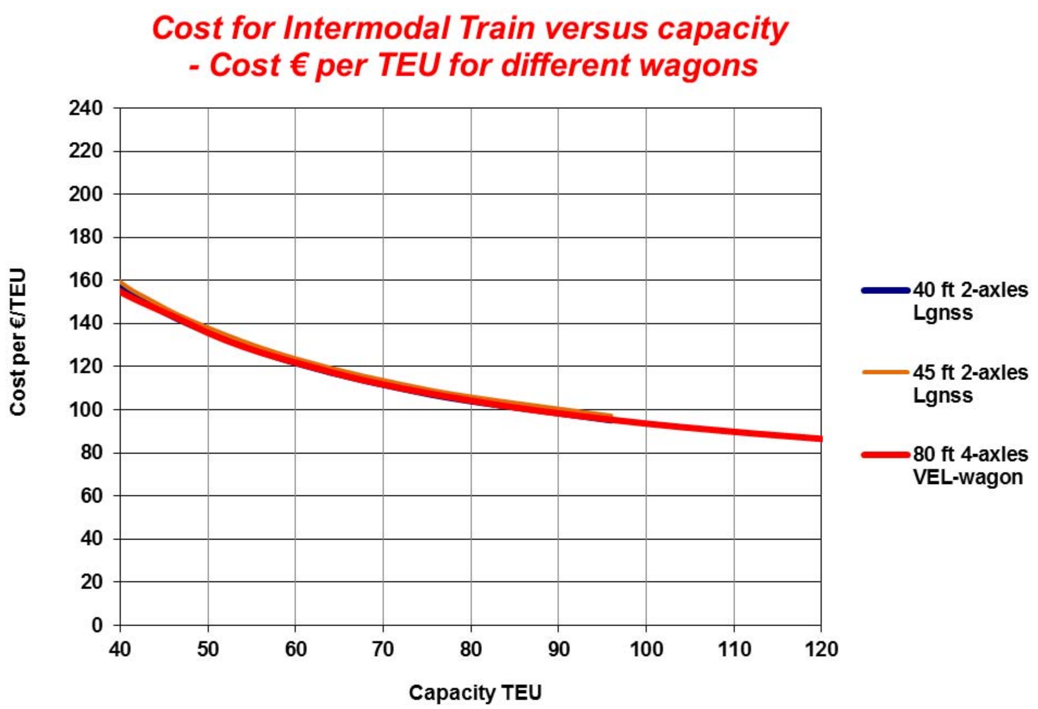


Figure 3. Transport cost per TEU depending on capacity for trains with different wagons and 80% load factor.

The costs allocated to locomotives and wagons are shown in Figure 5. Here the cost-share for the locomotive is higher because the track access charges are calculated according to the train-kilometres and this has been allocated to the locomotive. Therefore the cost-share for the wagons is lower. This means that a more efficient wagon such as the VEL wagon is more important in Sweden than in Germany. In Sweden the track access charges are more affected by the gross tonne-kilometres than the train-kilometres. So even if the energy-cost, which has been allocated according to the gross tonne-kilometres for the locomotives and the wagons, respectively, is higher in Germany than in Sweden, this is less important than the relatively higher track access charges.

Finally, the total transport cost per TEU is shown in Figure 6. The total cost is 19% lower in Sweden than in Germany. The cost differences between different wagons are slightly larger in Sweden than in Germany. But the savings of using the VEL wagon instead of a 80 ft articulated 6-axles Sgrs-wagon is 9.5% in Sweden and 8.5% in Germany so the differences is not so great. It is still evident that the VEL wagon is an effective wagon concept despite differences in cost structure between nations.

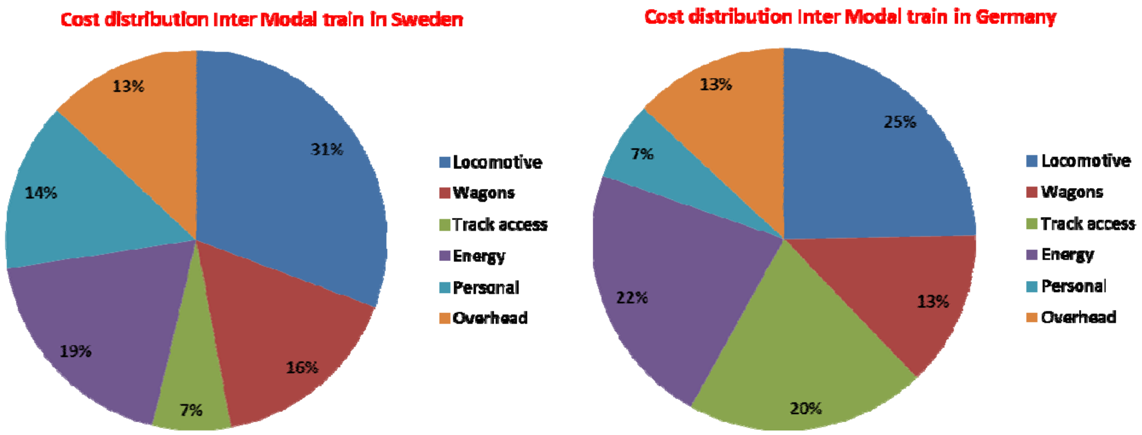


Figure 4. Cost structure for an intermodal train in Sweden and Germany. Distance 600 km, train with 20 VEL wagons with a capacity of 80 TEUs and a load factor of 80%.

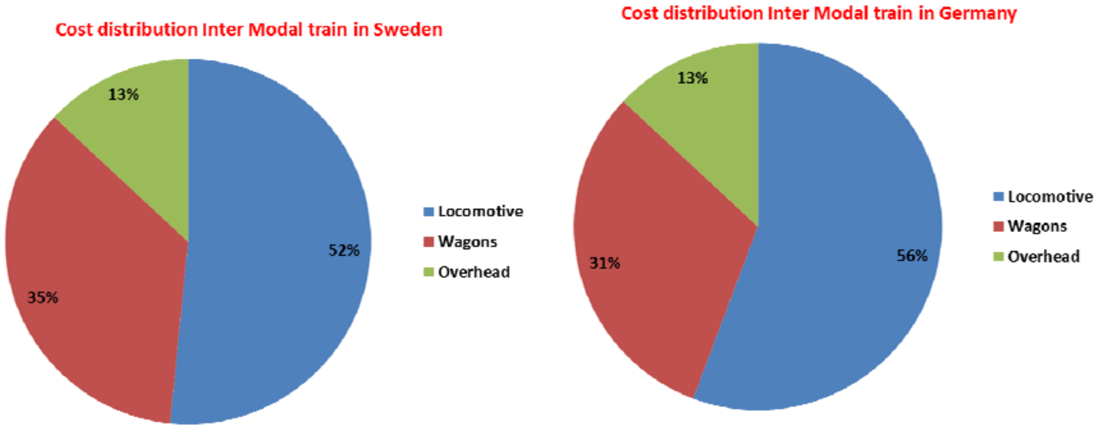


Figure 5. Cost distribution between locomotive, wagons and overhead for an intermodal train in Sweden and Germany. Distance 600 km, train with 20 VEL wagons with a capacity of 80 TEUs and a load factor of 80%.

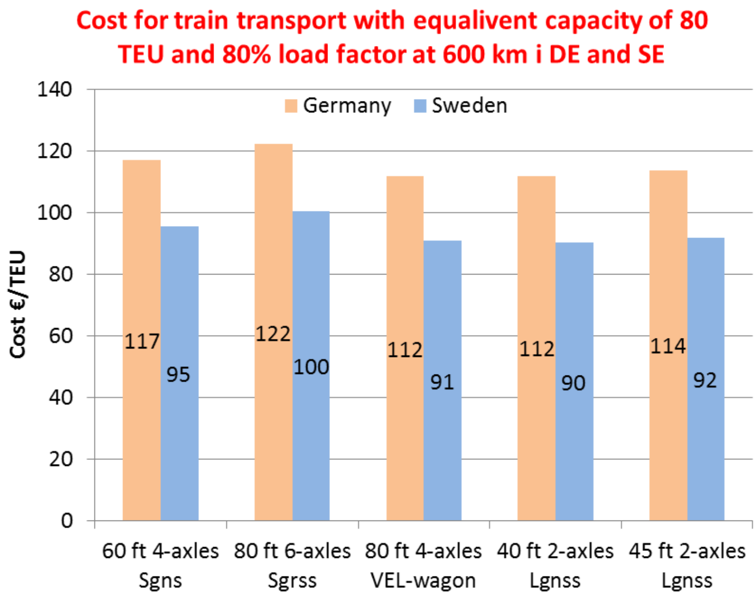


Figure 6. Transport cost per TEU for an intermodal train in Sweden and in Germany. Running distance 600 km, train with 20 VEL wagons with a capacity of 80 TEUs and a load factor of 80%.

4 Cost VEL wagon in wagon load transports

4.1.1 Alternative wagons for transports of automobile parts

If the VEL wagon with an added superstructure like a big box will be competitive compared with ordinary wagon load it must be in the transportation of goods with low density. A preliminary layout of the VEL wagon equipped as a box car is shown in Figure 7 and a similar standard wagon Habbins in Figure 8.

In this chapter we will as an example analyse transportation of automobile parts which is normally done in containers or specially designed wagons. The automobile industry ships automobile parts and subassemblies between manufacturing and assembly plants, and generally has track access at its larger plants. Thus, large flows of automobile parts are transported by rail between plants. Much of this flow uses purpose-built enclosed wagons, characterized by a comparatively low mass-to-volume ratio (i.e. density), e.g. 0.25 to 0.30 t/m^3. The volumes are large compared to most other wagons.

The automobile part wagons in Europe are generally 2-axle wagons or articulated wagons, with an inside length per section approximately 10 m to 14 m. Perhaps a longer single wagon like the VEL wagon would provide improved loading flexibility and efficiency for automobile parts. Table 3 shows a comparison between different wagons for transports of automobile parts. Also a US Jumbo box car is analysed as a bench-mark. Pictures of the wagons are shown in Figures 9 to 14.

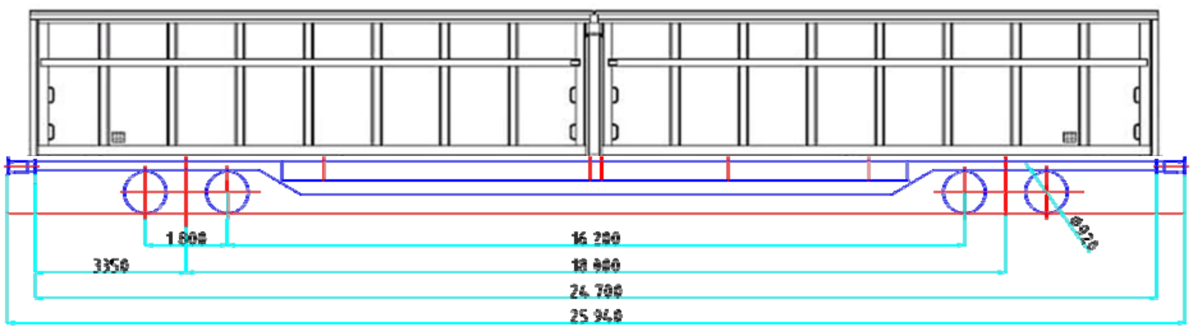


Figure 7: VEL wagon equipped for wagon load traffic similar to Habbins. Source: Armando Carrillo Zanuy.

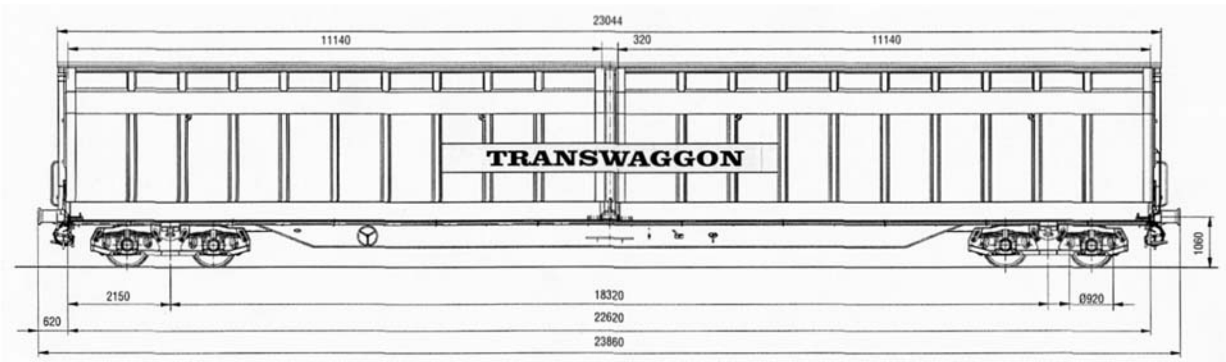


Figure 8: Standard Habbins wagon. Source: Transwaggon

Table 4. Comparison of various wagons for transport of automobile parts.

	NSC jumbo box car		Haimmrs	Himrrs-tt 326	Hiirrs-tt 324	VEL
Load limit	184000 lbs	83.461 t	ABC: 2×25 t	D: 57 t	D: 58 t	D: 61 t? E: 71 t?
Tare mass	102000 lbs	46.266 t	33.700 t 33.820 t	32.6 t	31.6 t	29 t?
Gross rail load	286000 lbs	129.727 t	ABC: ≈84 t	D: 90 t	D: 90 t	D: 90 t E: 100 t
Length over couplers	92’8”	28.2448 m	25.8 m	31.800 m	28.440 m	
Truck centers	64’	19.5072 m				
Inside length	86’6”	26.3652 m	2×10.87 m	2×14.636 m	2×12.774 m	≈25m
Extreme width	9’11”	3.0226 m				
Width over side sills	8’7”	2.6162 m				
Inside width between rub rails	8’4”	2.54 m		2.58 m	2.60 m	≈2.5 m
Door	16’0”	4.8768 m				
Extreme height	19’1-9/16”	5.8308875 m		4.652 m	4.656 m	4.83 m to 4.65 m
Door height	14’11”	4.5466 m				
Inside height	15’4”	4.6736 m		3.05 m	3.00 m	≈3.5 m to ≈3.1 m
Volume	11384 ft^3	323 m^3	≈2×90 m^3?	2×115 m^3	2×105 m^3	≈219 m^3 to ≈194 m^3
Wheel diameter, new	36”	0.9144 m	≈0.68 m?	0.92 m	0.92 m	0.92 m
Loading gauge	F+	F+				P/C 450 to P/C 410
Load limit/volume		≈0.26 t/m^3	≈0.28 t/m^3	≈0.25 t/m^3	≈0.28 t/m^3	D: 0.28 t/m^3 to 0.31 t/m^3 E: 0.32 t/m^3 to 0.37 t/m^3

Notes: 1 lb = 0.45359237 kg (exactly), 1 in = 25.4 mm (exactly)

Sources: National Steel Car, wagon lettering, DB Schenker.

Figure 9: Haimmrs 83-80-2971086-3 Linz 2008-08-19 André Schachtschabel

Figure 10: Haimmrs 83-80-2971189-5 Passau 2010-07-10 Willibald Johann Jobst

Figure 11: Ralion Hiirrs-tt 324 42-80-2940002-8 Antwerpen-Schijnport 2009-02-08 Bart Luyten

Figure 12: Railion Himrrs-tt 326 42-80-292674-3 Leipzig-Engelsdorf 2011-07-13 André Schachtschabel

Figure 13:Railion Hbins-tt 292 42-80-2262041-6 2009-09-16 André Schachtschabel

Figure 14: US Jumbo Box Car, Norfolk and Southern 489700 Buffalo, NY 2010-09-06 Dave Eagan.

Table 5: Specification of wagons for wagon load analysis.

Type			Hiirrs-tt DB 324	Habbins 274-1	VEL-WL	Haimmrs WW	US jumbo box
Type			Hiirrs-tt	Habbins	VEL-WL	Haimmrs	US jumbo
Axles/wagon			4	4	4	6	4
Axle load	tonnes		22,5	22,5	22,5	20,0	32,4
Max gross weight/wagon	tonnes		90,0	90,0	90,0	120,0	129,7
Tare weight/wagon	tonnes		31,6	26,0	30,0	33,7	46,3
Max load weight/wagon	tonnes		58,0	64,0	60,0	50,0	83,4
Load volyme	m3		210,0	166,0	196,0	180,0	323,0
Number of TEU:s per wagon	number						
Loading length	fot						
Total loading length	m		25,6	22,0	24,5	20,2	28,2
Total length		1,25	28,4	23,3	25,8	25,8	26,4
Energy consumption	KWh/grosstonkm		0,0152	0,0152	0,0153	0,0152	0,0160
Mainetnance cost	SEK/km		0,20	0,21	0,21	0,28	0,23
Investment cost	1000 SEK		1 400	1 350	1 400	1 700	1 550

5 Economic analysis of VEL-wagon for wagonload

Finally these wagons have been cho~~o~~sen for economic analysis:

- 4-axle DB Hiirss-tt
- 4-axle DB Habbins
- 4-axle VEL high cube
- 6-axle DB Hiirss-tt
- 4-axle US jumbo box car

The specifications of wagons are shown in table 5. The calculations have been made for a 600 km long distance in Sweden with 100% load factor in cubic meters ~~m~~^{3} and 50% empty running (i.e. no back haul). The train consists of 20 VEL wagons and an equivalent number of the other types of wagons to transport the same amount of approx. 4 000 m^3. The transport cost per cubic meter ~~m~~^{3} has been compared with total capacity in m^3. The result is shown in Figure 15.

As can be seen in Figure 15 the VEL wagon is not so competitive compared with the specially built wagons for large volume. Compared with Habbins it is more effective but compared with the specially designed Hirrss-tt ~~it~~ the transport cost per m^3 is 4% higher. Compared with an ordinary Habbins is 5% less expensive per m^3. The most expensive seems to be the specially designed 6-axle~~s~~ Haimmrs, but perhaps this wagon is built for particular dimensions. The US box car offers the lowest transport cost but the differences in cost per m^3 are not so big.

Another way to analyze trains and wagons is to compare trains with the same number of wagons. One example is shown by Figure 16. Here still the Hirrss-tt is most competitive but VEL is rather good. The US box car is however extreme efficient with only 73% of the cost per m^3 compared with Hirrss-tt.

In Figures 17 and 18 the cost per m^3 according to total capacity of the train between 2000 and 7000 m^3 is shown. There is a range from approx. 5€/m^3 at 2000 m^3 to approx. 2.5€/m^3 at 7000 m^3 that means that the transport cost per m^3 is only half with a very long train, in this case with 35 VEL wagons and an almost 1000m long trains with a gross wagon mass of 2200 tonnes. With the US jumbo box car this cost of 2.5€/m^3 will be reached already with 15 wagons and a 420m train with 1400 gross tonnes and 5000 m^3 in total capacity.

The differences in transport cost per m^3 between Habbins, Hirrs-tt and the VEL wagon are small as can be seen in Figure 18. The differences between Haimmrs, the VEL wagon and the US jumbo box car are greater. Haimmrs is more expensive than the VEL wagon but is probably built for special dimensions of automobile parts which cannot be handled in ordinary wagons. The US jumbo car is the least expensive but with these dimensions it cannot be used in Europe. However it may be a bench mark for what is possible with other prerequisites.

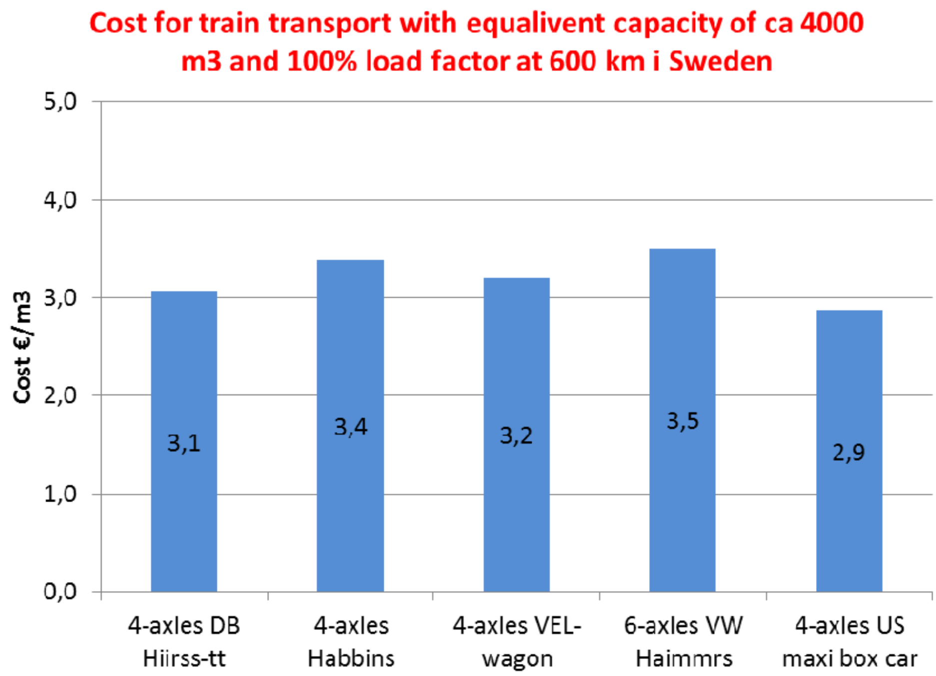


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Figure 15: Transport cost per m^3 with various wagonload box cars equivalent to 20 VEL wagons

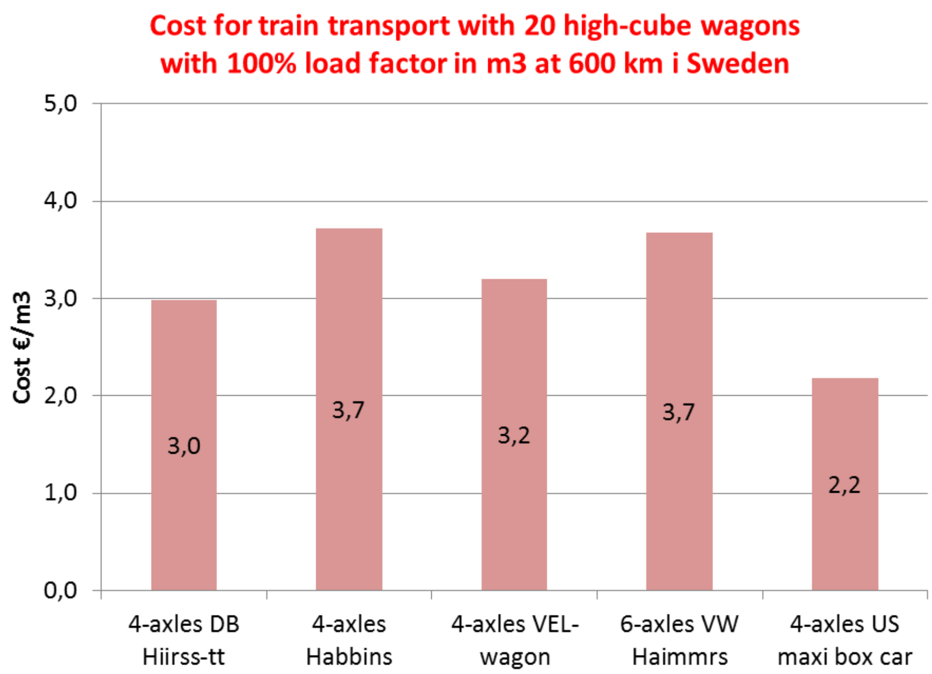

Figure 16: Transport cost per m^3 with different covered wagons for trains with 20 wagons and different capacity per train.

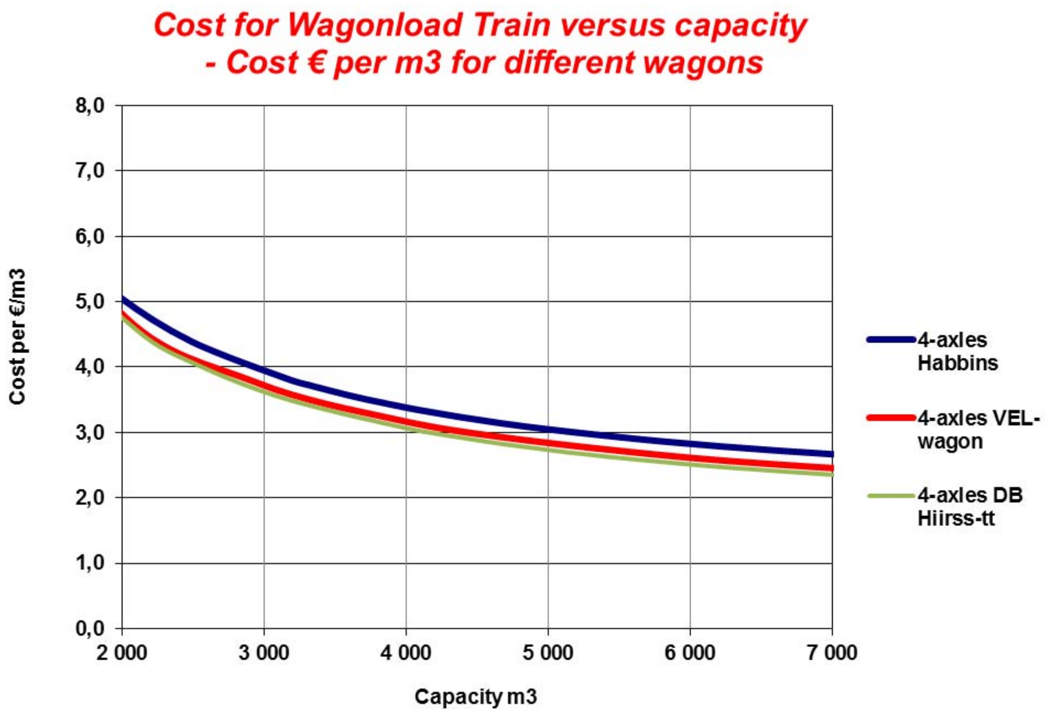

Figure 17: Transport cost per m^3 with different car load box cars according to total capacity of the train.

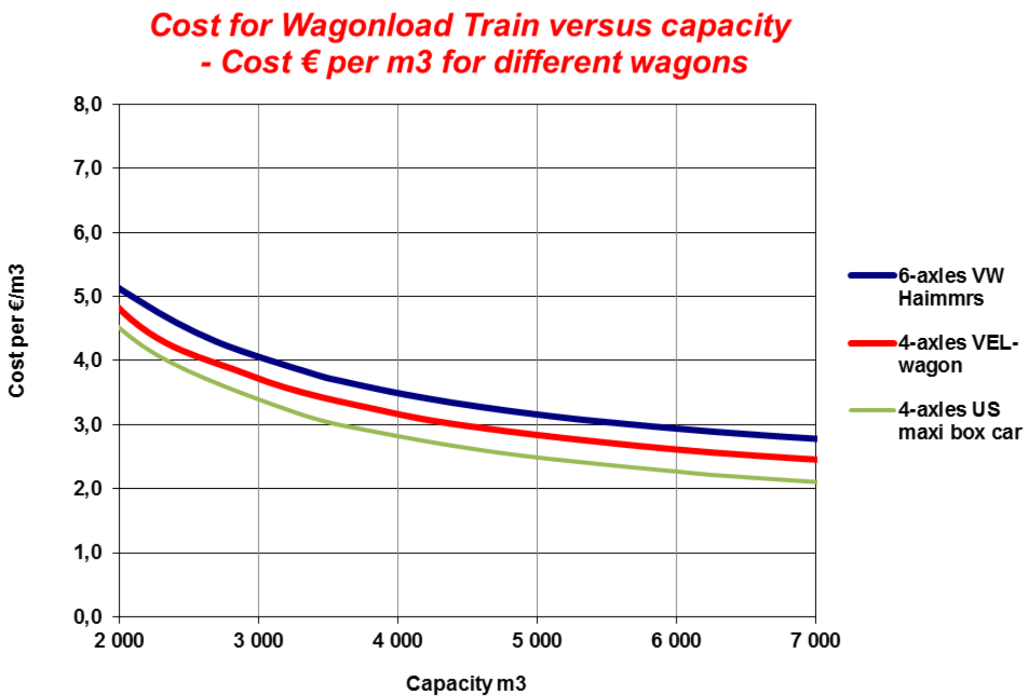

Figure 18: Transport cost per m^3 with different enclosed wagons according to total capacity of the train

6 Conclusions

The VEL wagon equipped for wagonload may be more efficient than ordinary wagons for low-density commodities, and give approximately the same transport cost as specially designed wagons. There is probably little need for a detachable box to put on the VEL-wagon because if the car industry needs a wagon they need it continuously. So perhaps if large quantities of VEL wagons are built, they may also be efficient to build them for permanent use as a box car, otherwise existing cars may be efficient enough.