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CONTENTS

List of symbols and abbreviations

ADAS	Advanced driver-assistance systems
CCNR	Central Commission for the Navigation of the Rhine
CEMT	Classification of European Inland Waterways
DWT	Deadweight tonnage
IMO	International Maritime Organization
IWT	Inland Waterway navigation
KPI	Key Performance Indicators
nD	no data
NOVIMAR	**NOV**el **I**wt and **MAR**itime transport concepts
OD	Origin destination
PI	Performance Indicator
RoRo	Roll on / Roll off
SCM	Supply Chain Management
SCOR	Supply-chain operations reference
SSS	Shortsea Shipping
ToR	Terms of References
VT	Vessel Train
WP	Work Package

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1 EXECUTIVE SUMMARY

This summary provides results of the deliverable and allows the EC or Project Management to assess the progress of the work. This chapter could be available to Project Management Team (PMT), QA Manager and Steering Committee (SC), if requested to fulfil European Commission (EC) obligations, such as the writing of the periodic reports.

Problem definition

The vessel train (VT) should become a new waterborne transport system, which should fit into the current and well-developed system. To cite the objectives of the Project, the '*Project NOVIMAR strategic aim is to adjust the waterborne transportation such that it can make optimal use of the existing short-sea and inland waterways and vessels, while benefitting from a new system of waterborne transport operations that will expand the entire waterborne transport chain up and into the urban environment.*'

In deliverable 1.1 only some broad, initial requirements were defined as starting points for the development of a model of a vessel train concept. Since the concept is entirely new, a lot of factors have to be considered. Thus, an extensive literature research has been performed to further specify the requirements for the vessel train concept that can fulfil the above-mentioned aim. The results were worked out in WP 2 task 2.1 and are summarised in this deliverable.

Technical approach and work plan

Tasked 2.1 is the first task in Work Package 2 'Transport systems', it started in month four and runs until month six. The deliverable is due end of month five.

The basic work consists of desk research. The work was distributed according to the sub-tasks to different partners. The gathered material was then analysed with the focus on relevant information for the vessel train concept.

Together with the input of deliverable 1.1 all gathered and analysed information are the basis of this deliverable, which serves as starting point for the development of the vessel train model.

Results

In this deliverable, the current situation of the working principle in inland waterway transport, shortsea shipping and sea-river transport are analysed and outlined. Competitive modes of transport, namely rail and road transport, have been examined to obtain insight into the working principle and to take advantage of their experiences in freight transport, especially in concepts similar to the vessel train. As a preparation for the development of the transport system model, current flows for two case studies have been compiled and performance indicators have been determine. Thus, this deliverable will serve as basis for the upcoming development of the transport system model.

2 INTRODUCTION

Task and Sub-tasks

Task objectives:

- To build a comprehensive sketch of the current multi-modal transport system
- To define how a vessel train should fit into the water transport segment
- To determine broad vessel train requirements

Clarification of objectives:

The task will use desk research, interviews and expert meetings to determine the different roles of all stakeholders involved. In total 8-10 interviews and meetings with experts from the NOVIMAR partnerships and from members of the Stakeholders Group will be held.

Envisaged activities are:

- Sub-task T2.1.1: Outline the working principles of the shortsea, sea-river transport and IWT: market share, infrastructures, vessels, stakeholders and their roles, services and relations. Identify current problems and gaps in waterborne transport, its competitiveness and the type of solution that a VT concept could provide.
- Sub-task T2.1.2: Determine the broad economic, environmental, energy and social requirements and Performance Indicators (PI's) and their values that benchmark the VT concept transport characteristics. The PI's will be checked with task T1.1 and, when required, new and/or modified PI's will to be worked out.
- Sub-task T2.1.3: Analyse the functioning of the railway operations. Rail has certain similarities to the VT idea, and will therefore be studied closely to learn from these: infrastructures, services, actors, and roles etc.
- Sub-task T2.1.4: Analyse the functioning of road transport operations. Road is the main 'competitor' to the vessel train concept and infrastructure, service actors and roles etc. need to be fully understood.
- Sub-task T2.1.5: Compile current cargo flows, a prerequisite to determining the effect of the vessel train
- Sub-task T2.1.6: Prepare Terms of References (ToR) for the VT
- Sub-task T3.1.7: Prepare the task deliverable

Analysis

The NOVIMAR project researches the vessel train, a waterborne platooning concept featuring a manned lead ship and a number of follower ships that follow at close distance by automatic control. Based on the initial requirements given in deliverable 1.1, the current situation was analysed and outlined with focus on the relevant input for the vessel train concept.

Approach

Tasked 2.1 is the first task in Work Package 2 'Transport systems', it started in month four and runs until month six. The deliverable is due end of month five.

The basic work consists of desk research. The work was distributed according to the sub-tasks to different partners. The gathered material was then analysed with the focus on relevant information for the vessel train concept.

Together with the input of deliverable 1.1 all gathered and analysed information are the basis of this deliverable, which serves as starting point for the development of the vessel train model.

Document outline

In chapter 3, the terms of reference, determined in deliverable 1.1 'Initial requirements' are summarised. Chapter 4 deals with the reflection of the current situation in inland waterway transport, shortsea shipping and sea-river transport. Further, concepts in competitive modes of transport, namely rail and road transport are displayed. The current cargo flow, which is the basis for the two case studies which should be performed later on are determined in chapter 5. Chapter 6 deals with the definition of relevant performance indicators for the transport system model. Finally, results are summarized and conclusions are drawn in chapter 7.

3 TERMS OF REFERENCE

Deliverable 1.1, titled 'Initial requirements', sets some basic requirements and frame work conditions for the physical composition of the VT, the relevant operational and organizational aspects as well as the control concept which are to be more specified within this document. Thus, in the following section a short summary of the aspects relevant for WP 2 is given.

Physical composition of the VT

First of all the physical composition of the VT is discussed. It is pointed out, that the ship types and the number of ships which sail together in the VT shall be various as a first assumption. The navigation areas of vessels in the VT may also be diverse as long as the VT can pass its current navigation zone. These zones may be large and small rivers and canals for inland vessel trains, while seagoing vessel trains will navigate at sea and on inland waterways between the sea and the seaports. For ports like Antwerp Hamburg and Bremen, this implies they will have to sail on inland or confined waterways over a significant distance.

One of the goals of the VT concept is the penetration of urban areas, thus, small ships (class I or II) shall be regarded. Besides, the most common class V vessels in the European fleet should also be included. Also shortsea vessels may join the VT, where the waterway allows.

The study shall always consider a vessel train with at least two follower vessels, thus, in total three vessels to have a more flexible concept and to investigate a sufficiently complex system. It shall be assumed that size, speed, and manoeuvring capabilities of all vessels in the train are substantially different, whereas it needs to be investigated if any sizes of vessels would fit in one train (e.g. small and large or fast and slow vessels) nicely. WP 2 therefore provides information on three inland, three seagoing and three shortsea vessels regarding their cargo capacities and vessel classes by the end of 2017. These types are to be studied in detail in other work packages. The decision whether a new build or a retrofit approach is more suitable is also left open until at least the midterm assessment, both approaches should be considered for now.

Lead and Follower Vessels

The specific roles of the lead vessel and the follower vessels are assumed to be various. The lead ship might either be a dedicated lead ship with no cargo hold, but maybe also a cargo ship with additional leading abilities. The follower ships might either be dedicated followers, with a limited crew or even without a crew altogether, or be followers equipped with leader abilities. The role of the latter option might be leader or follower. Whether this concept is economically reasonable is left open for further investigation. This investigation shall be done before the midterm assessment.

Assembling and disassembling of the VT

Next, a closer look upon operational and organisational aspects is taken. It is pointed out that the predefined points are, first, the control of the VT by a digital control system during sailing and second, that the VT or individual vessels will never be fully autonomous without human supervision. A large number of special operations are defined, that shall be considered in detail. These include, amongst others, the arrival at terminals, navigation in restricted waterways or in traffic, several emergency manoeuvres and the VT's formation. By February 2018, WP2 shall describe how the level of crewing influences the time, cost and logistics of these special operations and which solutions to encountered problems seem feasible. This will form the basis for a project-wide evaluation of possible solutions to encountered VT-challenges

Also the range of followers outside the train is to be investigated: how far shall the distances be, that these vessels are able to navigate independently? Especially, considering the project's aim to reach small waterways in urban areas, the small vessels, once leaving the VT, will need to be able to navigate independently for at least a few kilometres or more.

Cargo types in the VT

Several cargo types may be transported. For the beginning, only "boxed cargo", i.e. containers and RoRo cargo, shall be regarded, as they face the lowest intermodal barrier. It needs to be taken into account that dangerous goods might be part of the cargo. Later, after midterm assessment, other types of cargo, such as bulk, might be considered if a powerful business case cannot be developed based on containers and RoRo alone.

There are several business concepts that might be suitable for the VT. One, amongst others, is the classical coupled formation. Whether the VT operates on a fixed or flexible schedule is one of the questions that is also an important topic for further investigations.

The role of human operators

The role of human operators is a crucial point for the VT concept and will be addressed within this document. As initial requirements, only a few basic points are set. First, while in the train, the follower vessels shall follow the lead vessel automatically. Second, when leaving the train, vessels shall be controlled by human operators, either directly or remotely. Nonetheless, the role of the human operator is much larger for the VT than for autonomous ships. The VT concept assumes that humans control, supervise or operate the VT.

The follower vessels within the train shall follow the human controlled leader vessel automatically. Once the follower vessels leave the VT they shall either be manned or be controlled remotely. Whether the control station for the leader vessel and the (remotely controlled) follower vessels is placed on shore, on the lead ship, on the follower ship or distributed over at least two of the formerly mentioned shall be investigated as part of the research in the project. WP 5 shall provide WP2 with important inputs on this topic.

In the following, the VT aspects to be taken into account in WP 2 are summarised.

Table 1: Summary of aspects to be taken into account in WP 2

Navigation area	Shortsea Inland Sea-River
Cargo Type	RoRo - no hazardous cargo / hazardous cargo Container - no hazardous cargo / hazardous cargo
Number of vessels in train	Lead vessels + 2 follower vessels
Vessel design speeds	Identical Similar

	Different
Relative size of vessels in train	Identical Similar Different
Absolute size of vessels in train	IWT – Class I to >V / Sea-River / Shortsea
No., roles & competences of crew	In shore control centre On lead ship On followers while in/outside train On followers during special manoeuvres (see next item)
Special manoeuvres to be addressed	Docking/undocking at terminals Passing locks Joining/leaving a train Avoiding encountered/crossing traffic Passing bridges Navigating narrow/bendy/shallow waterways Anchoring as part of calamity countermeasure Countering calamities while underway Embarking/disembarking vessels
Max. follower distance when not in train	> 10 km
Lead ship concept	Cargo ship with control station Dedicated ship with full control station
VT business concepts	Tramp: strongly varying opportunity driven composition Line: often same/similar combination of lead & followers 'Coupled' unit: fixed combination of lead & followers

4 CURRENT SITUATION

The evaluation of the current situation is inevitable for the integration of the VT concept into the existing transport market. A VT will be successful, if it can fill gaps in the existing transport concept of inland navigation, shortsea shipping or sea river transport in particular, or in the transport sector in general. The latter would imply a shift in modal shares. Further, a VT will be successful, if its performance is better than the existing transport possibilities, what might as well imply a shift in modal shares.

The aim of this chapter is to outline the current transport situation, focused on the benefit for the vessel train concept.

Decision criteria

The decision on the mode of transport is determine by many different factors and differs for the kind of cargo [1]. The general strength of inland waterway transport lies in the unrestricted transport timing, due to absence of driving bans for Sundays and public holidays. On the other hand, the transport frequency is restricted by the high capacity. This is enhanced by the demand of fast delivery, where shipping space is often over dimensioned. Further, the transport by ship is highly depending on weather conditions. High water, low water, as well as ice building can disturb the operation. The transport security and transport quality is high, with low numbers of accidents. Unrivalled is the transport capacity, compared to rail and road transport. The transport capacity also positively influences ecological aspects, such as pollutant and noise emissions, when comparing emission per tkm. Inland waterway transport is cheap, regarding external costs, as well as energy costs. However, inland waterway transport is mostly depending on further transport modes, since the waterway network usually not suitable for door to door delivery. This also implies additional transport costs. The transport time is determine by a low velocity, as well as lock times and is much longer than rail and road transport times. This also implies additional transport costs.

Based on a selection of criteria, an evaluation form has been developed to, firstly, determine the five most important decision criteria for the transport of different types of cargo, and, secondly, to evaluate the performance of road, rail and inland waterway transport according to this decision criteria.

For a start, the port of Duisburg (duisport) was asked to determine the five most important decision criteria by transport goods, assuming, that all transport modes are available. The most important decision criteria, independent of the kind of cargo, are transport costs and the price-performance ratio. Transport volume and transport frequency are of medium importance for dry bulk and liquid bulk cargo. A minor importance is attributed to transport time and flexibility for dry bulk and transport time and legal matters for liquid bulk. For the transport of containers, flexibility and timeliness are of medium importance, whereas, transport time and personal preferences have a low priority. For heavy cargo transport time is the second important decision criteria, followed by safety, transport volume and personal preferences. The decision criteria for each type of cargo are summarised in Figure 1.

Later, after a more concrete concept for the VT concept has been developed, this evaluation form can also be used to rank the VT in comparison to the existing transport mode.

Decision criteria*	Dry bulk	Liquid bulk	Container	Heavy cargo
Transport time	C	C	C	B
Flexibility	C		B	
Transport costs; price-performance ratio	A	A	A	A
Capital lockup costs				
Safety, damage susceptibility				C
Physical suitability of the transported goods				
Transport volume	B	B		C
Environmental sustainability				
Timeliness			B	
Regularity (schedules)				
Frequency	B	B		
Weather sensitivity				
Legal matters (e.g. regulations for dangerous goods)		C		
Information level / knowledge of decision-maker about the mode of transport				
Habits / personal preferences of the decision-maker			C	C

* Necessary precondition: Availability (e.g. waterway access or railway connection ...)
Source: Interview

Importance: A high; B medium; C lower; No tag lower than C

Figure 1: Five most important decision criteria by transport goods

After decision criteria are determined in general, the actual performance by transport goods and transport modes is evaluated by duisport. A total of 100 points are distributed between the three transport modes, road, rail and inland waterway transport, to weight the fulfilment of these criteria. The colour marked decision criteria are in accordance with the determined criteria in Figure 1. The results of the comparison of performance by transport modes are shown in Figure 2 to Figure 5, for dry bulk, liquid bulk, container, and heavy goods, respectively.

Dry bulk

Inland waterway transport obtains a high score for the most important transport costs and the price-performance ratio, performing better than rail and road. Further, IWT can perform best regarding the transport volume. Regarding the flexibility and transport time, IWT cannot compete with rail and road.

Decision criteria	Dry bulk		
	Road	Rail	IWT
Transport time	50	35	15
Flexibility	80	10	10
Transport costs; price-performance ratio	10	40	50
Capital lockup costs			
Safety, damage susceptibility			
Physical suitability of the transported goods			
Transport volume	10	40	50
Environmental sustainability			
Timeliness			
Regularity (schedules)			
Frequency	40	30	30
Weather sensitivity			
Legal matters (e.g. regulations for dangerous goods)			
Information level / knowledge of decision-maker about the mode of transport			
Habits / personal preferences of the decision-maker			

Source: Interview

Importance: A high; B medium; C lower; No tag lower than C

Figure 2: Decision criteria for dry bulk by transport mode: Ranking according to degree of fulfilment by transport modes

Liquide bulk

For the most important criteria, the transport costs and price-performance ratio, IWT can obtain the highest score in comparison to rail and road. Further it is able to fulfil a good performance for transport volume (medium importance) and legal matters (minor importance). However, the fulfilment in respect to transport time (medium importance) is weak.

Decision criteria	Liquid bulk		
	Road	Rail	IWT
Transport time	50	35	15
Flexibility			
Transport costs; price-performance ratio	20	30	50
Capital lockup costs			
Safety, damage susceptibility			
Physical suitability of the transported goods			
Transport volume	10	40	50
Environmental sustainability			
Timeliness			
Regularity (schedules)			
Frequency	40	30	30
Weather sensitivity			
Legal matters (e.g. regulations for dangerous goods)	10	30	60
Information level / knowledge of decision-maker about the mode of transport			
Habits / personal preferences of the decision-maker			

Source: Interview

Importance: A high; B medium; C lower; No tag lower than C

Figure 3: Decision criteria for liquid bulk by transport mode: Ranking according to degree of fulfilment by transport modes

Container

Regarding the transport of containers, the performance of IWT and rail are almost equal, but are far behind the transport by road. Transport costs and price-performance ration, are similar for all three transport modes, giving no clear advantage for any of them. However, road transport is strong in respect to flexibility.

Decision criteria	Container		
	Road	**Rail**	**IWT**
Transport time	50	30	20
Flexibility	80	10	10
Transport costs; price-performance ratio	30	35	35
Capital lockup costs			
Safety, damage susceptibility			
Physical suitability of the transported goods			
Transport volume			
Environmental sustainability			
Timeliness	35	30	35
Regularity (schedules)			
Frequency			
Weather sensitivity			
Legal matters (e.g. regulations for dangerous goods)			
Information level / knowledge of decision-maker about the mode of transport			
Habits / personal preferences* of the decision-maker	80	10	10

* No real advantage for transp. mode
Source: Interview

Importance: A high; B medium; C lower; No tag lower than C

Figure 4: Decision criteria for container by transport mode: Ranking according to degree of fulfilment by transport modes

Heavy bulk

For the transport of heavy cargo, IWT can score slightly higher for the most important decision criteria transport costs and price-performance ratio. The transport time (medium importance) is evaluated equally with rail transport, but much better than road transport. Even for the criteria of minor importance, the IWT can score better than rail and road. However, the personal preference of the decision-maker is clearly in favour for road transport.

Decision criteria	Heavy cargo		
	Road	Rail	IWT
Transport time	20	40	40
Flexibility			
Transport costs; price-performance ratio	25	35	40
Capital lockup costs			
Safety, damage susceptibility	20	30	50
Physical suitability of the transported goods			
Transport volume	20	35	45
Environmental sustainability			
Timeliness			
Regularity (schedules)			
Frequency			
Weather sensitivity			
Legal matters (e.g. regulations for dangerous goods)			
Information level / knowledge of decision-maker about the mode of transport			
Habits / personal preferences of the decision-maker	80	10	10

Source: Interview

Importance: A high; B medium; C lower; No tag lower than C

Figure 5: Decision criteria for heavy cargo by transport mode: Ranking according to degree of fulfilment by transport modes

It can be concludes, that in general, the inland waterway transport can be competitive with rail and road. However, these results are only showing a single opinion. The importance of decision criteria and the evaluation of the performance might differ strongly for other companies and regions. Further, it has to be taken into account, that not all of the three transport modes are always available. This is reflected in the actual model split.

Modal split

Figure 6 shows the evolution of the modal split of land transport of goods in the European Union since 1999, with no significant change between modes of transport being discernible. There is no sign of any transfer of transports from truck to rail or ship in the recent years. The modal share for inland navigation is quite inhomogeneous within the EU. Figure 7 shows the modal split and the development from 2009 to 2014 in the different Member States. The Netherland are leader with a total modal share of ~45 %, followed by Romania (~30 %), Bulgaria (~27 %), Belgium (~15 %) and Germany (~10 %).

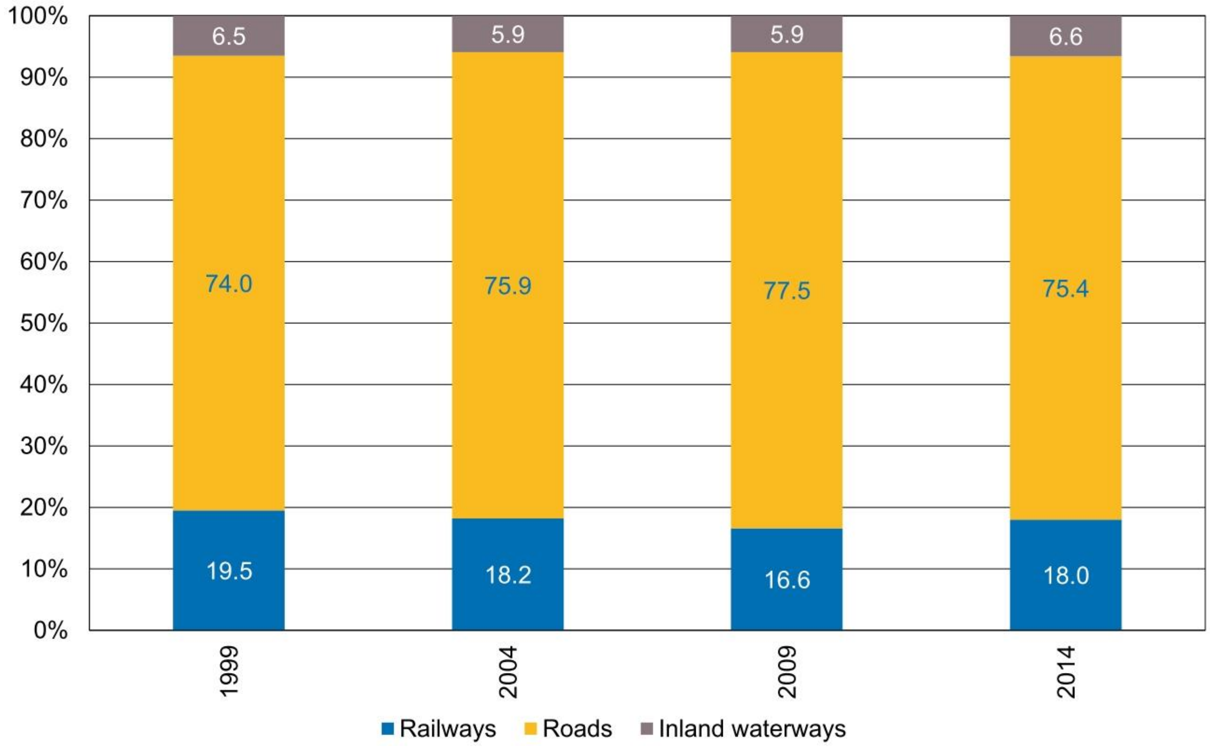


Figure 6: Freight land transport modal split (%), Source: Eurostat and Statistical pocketbook 2016 (see [2])

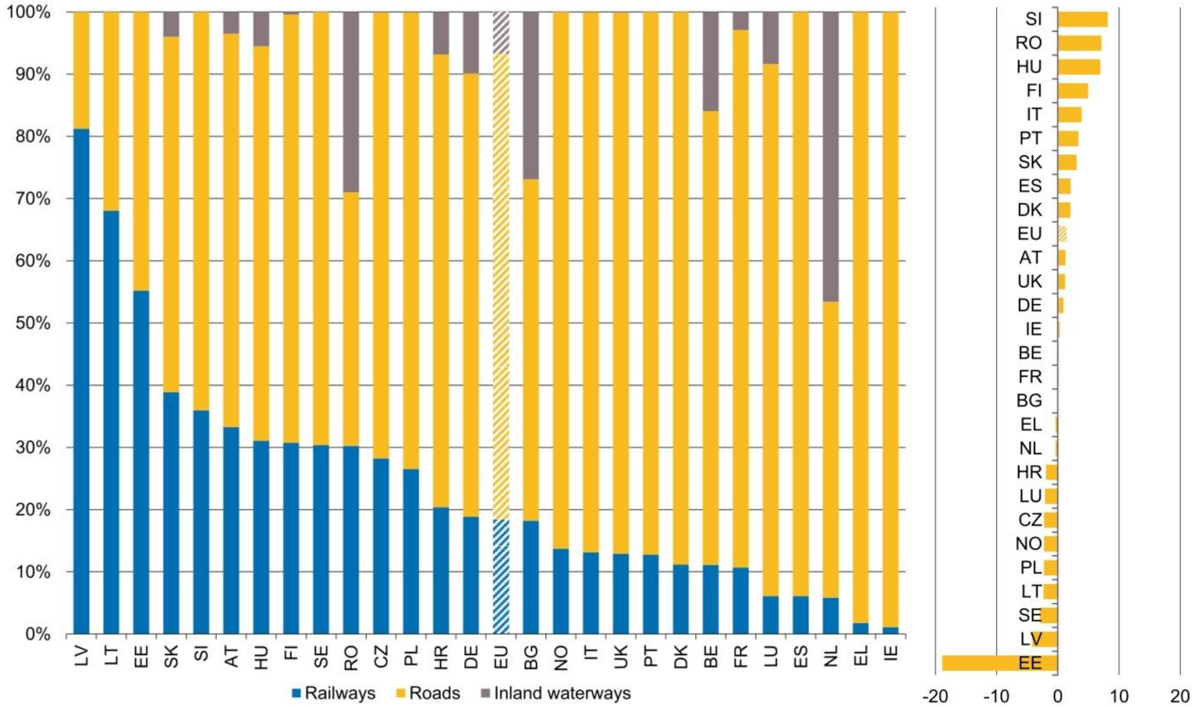


Figure 7: Freight land transport modal split by Member State (2014) and change since 2009 (in percentage points), Source: Eurostat and Statistical pocketbook 2016 (see [2])

Inland navigation

4.1.1 European inland waterways

The most fundamental reason for the inhomogeneity in modal split is the inland waterway infrastructure. Of course, first of all suitable waterways must be available to enable inland navigation. Figure 8 shows the inland waterway network in Europe categorised according to the Classification of European Inland Waterways (CEMT). The above mentioned countries, the Netherland, Romania, Bulgaria, Belgium, and Germany have a very good waterway network.

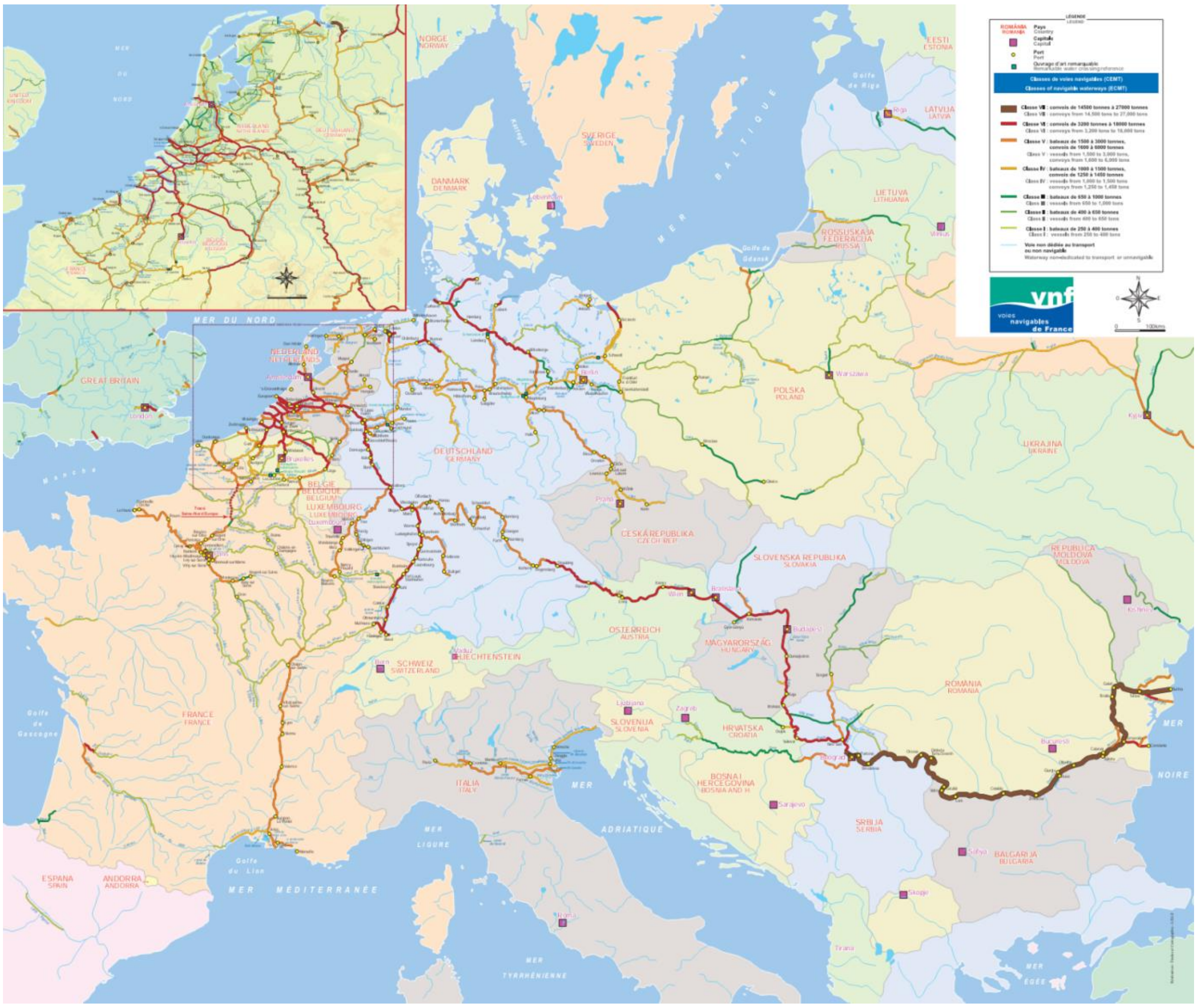


Figure 8: European inland waterways network [3]. Enlarged key is shown in Figure 11

Germany, the Netherlands and Belgium are very well connected by the Rhine. A more detailed view of the waterway structure for the Rhine region is displayed in Figure 9, including the ‘Antwerp region’, which should be investigated as the first case study. The Rhine itself is a class VI waterway, the main tributary rivers are still class V waterways. Connecting waterways in South Germany to France are class I waterways. The connection from Antwerp to the Rhine via the Scheldt-Rhine canal is also a class V waterway.

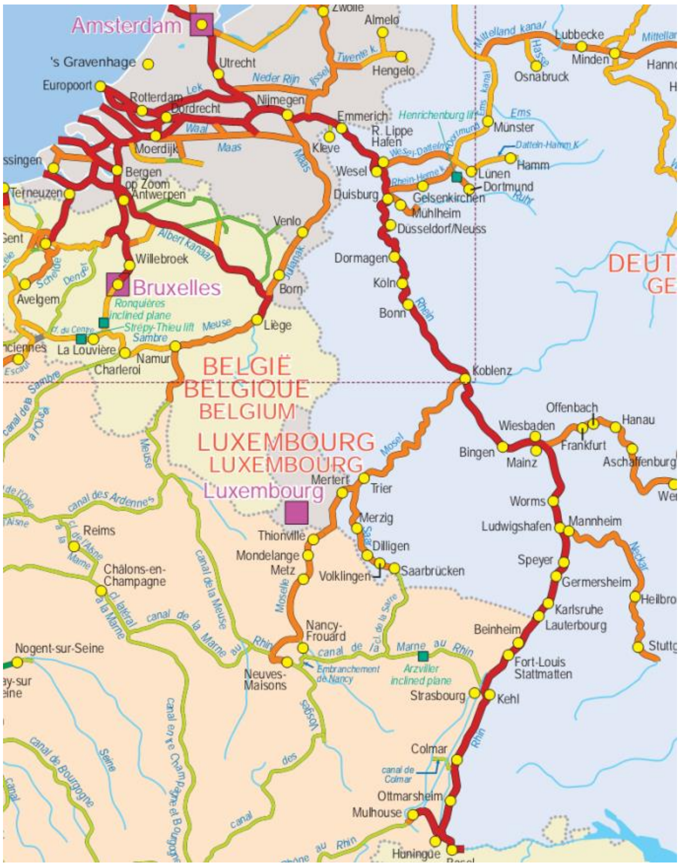


Figure 9: Classification of waterways in the Rhine region. Enlarged key is shown in Figure 11

Inland navigation in Romania and Bulgaria benefits from the Danube, which is a class VII waterway in this region. A detailed view of the Danube corridor is given in Figure 10.

Figure 10: Classification of waterways in the Danube region. Enlarged key is shown in Figure 11

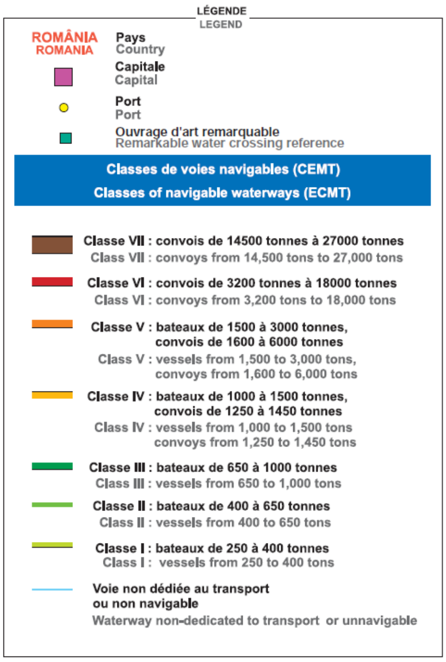


Figure 11: Key to Figure 1, Figure 9 and Figure 10

The high modal share, in comparison with all EU members, and the availability of suitable waterways for the Netherlands, Romania, Bulgaria, Belgium and Germany is reflected in the transport performance, depicted in Figure 12. On the lower Rhine delta in the Netherlands, the Albert Canal, and parts of the Meuse, Canal du Centre in Belgium, and the Scheldt around 60 billion tkm were transported in 2016. On the lower, middle and upper Rhine still 40 billion tkm were transported. The Danube shows a transport performance of 23 billon tkm.

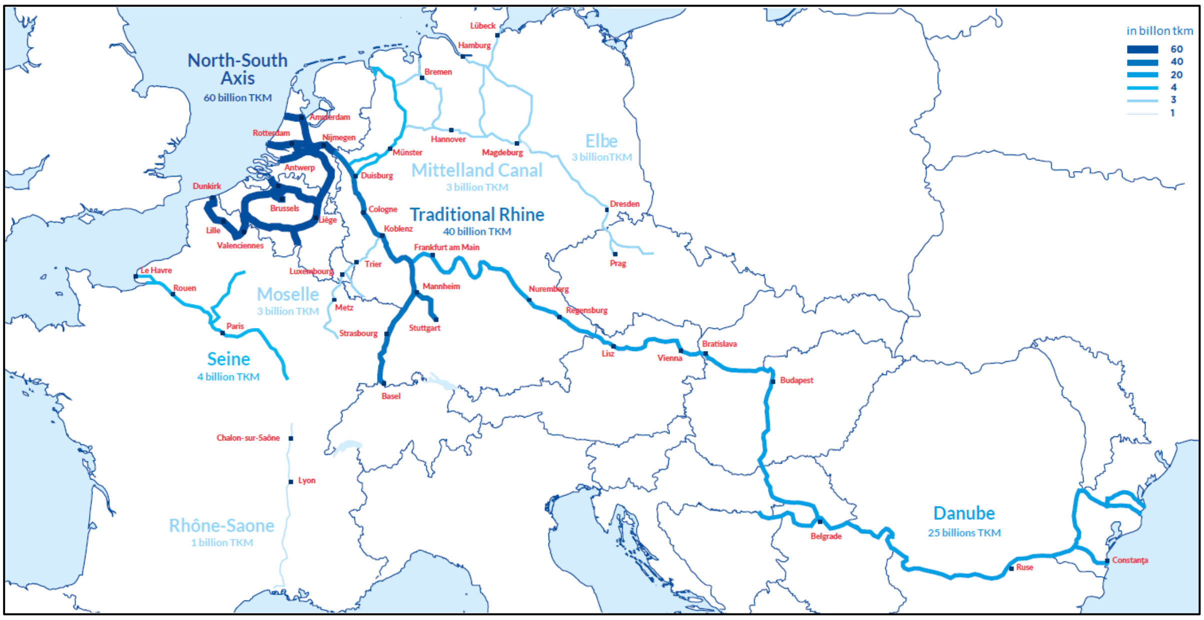


Figure 12: Transport performance in main European river basins in 2016 [4]

One of the aims in the NOVIMAR project is penetration into urban region. Therefore, European waterways and ports were analysed to reveal potential new relations.

4.1.2 Cargo

Besides the total amount of transported goods, the split of goods can be analysed. In the terms of references it has been stated, to consider container and RoRo cargo at first. The share of transport of containers on total inland waterways transport in the total EU-28 based on the comparison in tkm is quite low but constantly rising. Figure 13 shows the development from 2009 to 2015 for the share of container transport in inland waterway transport. A steady increase form around 7.8 % in 2009 to 10.2 % in 2015 can be observed. However, Figure 8 only shows the total trend, not considering the local inhomogeneity.

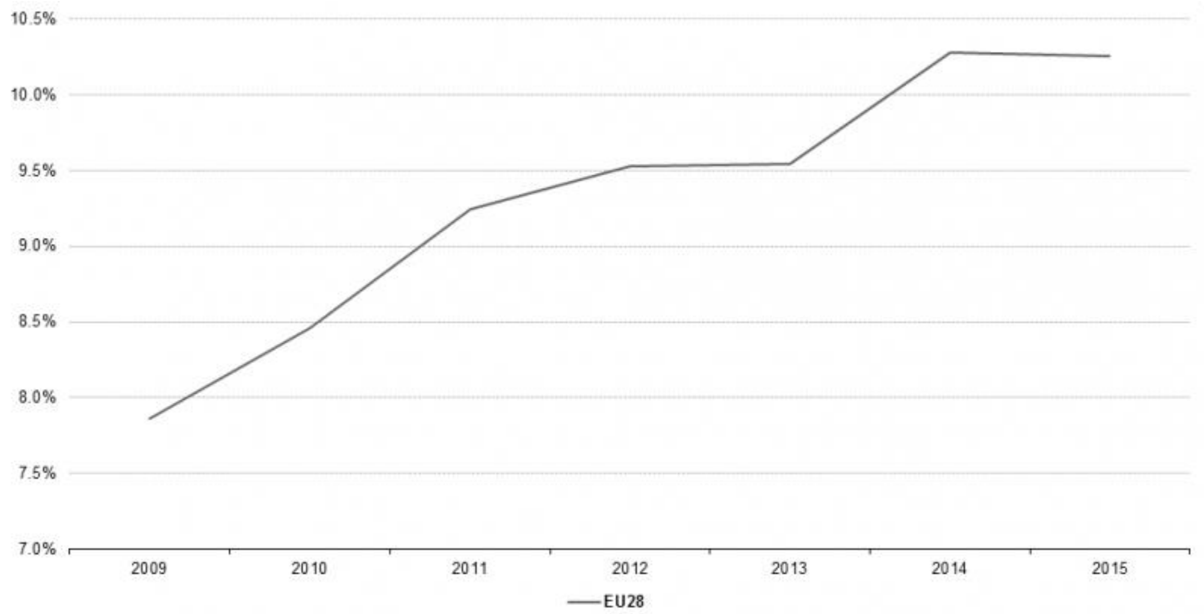


Figure 13: Share of transport of containers (loaded and empty) on total inland waterways transport in EU-28 - based on tkm

In Table 2 the top ten international county flows for transport of containers in 2015 in listed. 20.3 % of the total container flow takes place between Germany and Belgium.

Table 2: Top 10 international country flows for transport of containers in 2015 - 1000 TEUkm

Loading country	Unloading county	Total	Share on total (%)
Germany	Belgium	243 270	20.3
Netherland	Germany	212 743	17.7
Germany	Netherland	194 842	16.2

Belgium	Germany	186 288	15.5
Netherlands	Belgium	70 441	5.9
Belgium	Netherlands	57 442	4.8
Netherlands	Switzerland	53 033	4.4
Switzerland	Netherlands	37 135	3.1
Switzerland	Belgium	33 747	2.8
Belgium	Switzerland	27 465	2.3
Other routes		84 768	7.1

Despite the low total share of container flow, a consideration of containers is reasonable. Considering the envisaged shift of transport from road and rail to inland navigation, container and RoRo cargo are most suitable. They can be easily transhipped from one mode to another. Further, the performance in respect to the five most important decision criteria are quite similar and the potential for modal shift is high, as it has been shown in Figure 4.

4.1.3 Fleet

The implementation of the VT concept will be incremental rather than a sudden, full-blown introduction. Thus, integration in the current inland navigation system can be made as follows:

Single vessel

- Self-propelled vessel

Pushed convoy

- Consists of a motor vessel plus one or up to three lighters without own propulsion system (at the most auxiliary drive for manoeuvring)
- Consist of a pusher plus one or several lighters

Towed convoy of craft

- Consists of a tug plus one or several crafts without own propulsion system

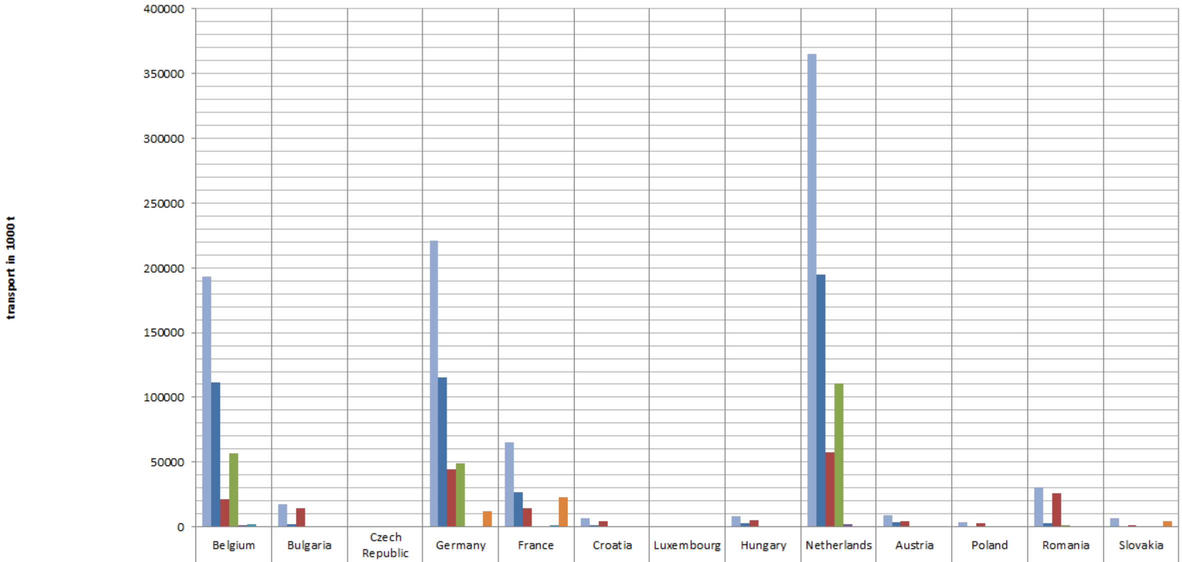
Vessel train (Virtual convoy)

- Consists of a leader vessel followed by one or more vessels with own propulsion systems
- Vessels are not mechanically connected, only electronically

The analysis of the fleet is important for the decision whether new specific vessels are needed or whether the vessel train concept can be integrated into the current system.

New build vessel can be designed specifically for the VT concept, thus can be optimized and more competitive. However, new vessels are a big investigation and the implementation of the VT will rather be a smooth transition than a sudden introduction. Therefore, it should also be possible to use the VT concept in the current fleet.

Figure 14 shows the amount of transported cargo by vessel type and country in thousand tonnes in 2016. The total transport is by far highest in the Netherlands, followed by Germany and Belgium. For all three countries, the majority is performed with self-propelled vessels barges or tanker barges. Not self-propelled barges do not contribute decisively.



	Belgium	Bulgaria	Czech Republic	Germany	France	Croatia	Luxembourg	Hungary	Netherlands	Austria	Poland	Romania	Slovakia
Total	192938	17467	832	221349	65162	6409		8224	365230	9071	3911	30484	6758
Self-propelled barge	111480	2179	321	115153	26762	1091		2481	195048	3703	457	2956	385
Not self-propelled barge	21174	14112	439	44241	14505	4526		4866	57616	4039	2870	26289	1628
Self-propelled tanker barge	57015	767		49352	2	425		548	110836	630	585	1027	68
Not self-propelled tanker barge	987	154		839		239		317	1698	700		177	
Seagoing vessel	2186	0			956								
Other goods carrying vessel	97	255	72	11763	22936	128		12	32			35	4677

Figure 14: Transport by type of vessel and by country in 2016

The fleet can also be analysed by number of vessels for different CEMT classes and countries. In Table 3 and Table 4, these data are summarized and further split into self-propelled vessels, and dumb and pushed vessels. Unfortunately, the data is selected and gathered for different years, mainly from 2011/2012 but contains also some older information. Thus, the total number of vessels might differ from the sum of all classes. Since the fleet structure does not change rapidly in the inland navigation sector, the data can be used for a rough analysis nevertheless.

In the Rhine region and in France, single driving vessels are much more represented than convoys. In the Rhine region, CEMT IV vessels are the most common, followed by CEMT III and V. Small vessels (CEMT I and II) as well as the larger vessels (CEMT VI/VII) are less represented. Whereas in France the fleet consists mostly of CEMT I vessels.

In the Danube region, dumb and pushed vessels account for the majority of the fleet. Among these dumb and pushed vessels are mostly CEMT IV and CEMT V vessels.

Table 3: Number of self-propelled barges per country

	Total	< 250 t	250-399 t	400-649 t	650-999 t	1000-1499 t	1500-2999 t	> 3000 t
			CEMT I	CEMT II	CEMT III	CEMT IV	CEMT V	CEMT VI/VII
Rhine region								
Belgium	874	32	203	99	130	244	203	111
Netherlands	3.703	336	297	556	778	768	716	252
Germany	1.168	192	195	824	596	763	536	16
Luxembourg	nD	nD	5	3	3	10	8	nD
Switzerland	13	nD	1	nD	1	22	61	5
Danube region								
Austria	nD	1	2	2	15	8	6	nD
Bulgaria	31	0	1	0	0	16	7	0
Croatia	19	2	3	nD	2	5	nD	nD
Slovakia	31	3	0	1	2	8	6	3
Hungary	70	5	10	18	24	9	6	0
Romania	107	0	0	0	0	0	5	0
France								
France	804	3	430	124	141	118	74	16
Other regions								
Czech Republic	32	0	1	18	23	38	0	0
Estonia	9	8	0	0	0	0	0	0
Italy	66	58	4	4	1	3	2	nD

Latvia	nD	0	0	0	0	0	0	0
Lithuania	35	27	0	2	1	1	0	0
Poland	67	0	0	38	15	17	0	0
Finland	153	141	7	1	1	2	1	0
United Kingdom	158	94	23	22	14	4	1	0

Table 4: Number of Dumb and Pushed Vessels per country

	Total	< 250 t	250-399 t	400-649 t	650-999 t	1000-1499 t	1500-2999 t	> 3000 t
			CEMT I	CEMT II	CEMT III	CEMT IV	CEMT V	CEMT VI/VII
Rhine region								
Belgium	263	17	34	34	11	23	68	62
Netherlands	796	121	32	69	39	46	389	100
Germany	861	83	82	2	142	55	223	7
Luxembourg	nD	nD	nD	nD	nD	0	nD	nD
Switzerland	nD	nD	nD	nD	1	1	6	1
Danube								
Austria	nD	10	15	25	16	18	63	1
Bulgaria	117	1	0	3	3	39	95	0
Croatia	111	26	17	2	13	40	5	0
Slovakia	104	1	1	11	3	16	116	0
Hungary	252	10	33	42	59	65	75	0
Romania	1.134	34	4	12	93	487	334	100
France								

France	363	3	36	21	81	24	139	5
Other regions								
Czech Republic	119	0	19	78	32	163	0	0
Estonia	3	1	0	132	0	0	0	0
Italy	81	79	1	2	0	1	3	nD
Latvia	nD	0	0	0	0	0	0	0
Lithuania	50	11	7	0	0	5	0	0
Poland	511	75	76	266	37	18	5	0
Finland	46	25	3	5	1	1	nD	0
United Kingdom	287	133	78	42	17	10	5	2

4.1.4 Labour market, crew regulations and modes of operation

Generalized costs per TEU and total logistic costs are stated as performance indicators. Labour cost, which are included in these costs, vary significantly depending on the type of vessel, respectively the number of crew members, salary levels in the country and other factors. However, their contribution to total costs can be quite high, varying around at least 30 % [5]. Thus, it is worse regarding a reduction of crewmember in the vessel train concept and evaluating the potential of cost reductions in this field.

First, an analysis of the labour market, current crew regulations and operating modes is performed. Since the topic of crew reduction is quite complex, including safety issues and regulative issues, a detailed examination will be addressed later in cooperation with other work packages. However, the analysis displayed here can serve as a basis for further discussions. To give a first impression of the crew reduction potential, several models are presented showing how these reductions might be achieved. These considerations are just meant as an outline of the potential, without taking any regulative issues into account.

The number of employees in the labour market of the IWT sector is steadily decreasing since 2006 from approximately 47 000 to 44 000 employees, as displayed in Figure 15. This decrease of around 6 % is mainly due to the decreasing demand for transportation. From that point of view, a reduction of crew members in a vessel train would, in the long term, lead to a further decline.

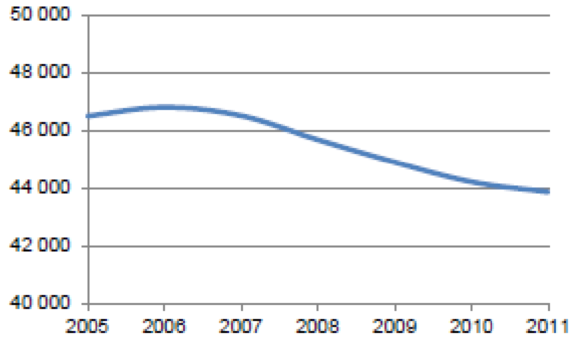


Figure 15: Development of the IWT labour market in Europe [6]

However, having a look at the age structure of employees in the leading countries Belgium (**Fehler! Verweisquelle konnte nicht gefunden werden.**), the Netherlands (Figure 17) and Germany (Figure 18) a crew reduction might become necessary anyway. The distribution of junior and old employees is critically especially in Belgium and Germany. The VT concept, with reduced crew, might fit quite well into this development and might be able to avoid the shift of transport to other modes.

Another possible scenario could be that the logistic concept of the vessel train increases the attractiveness of the profession and thus might stop the decrease in the labour market. The attractiveness might be increases by shorter journeys, due to changing of crew and thus a more regular stay at home.

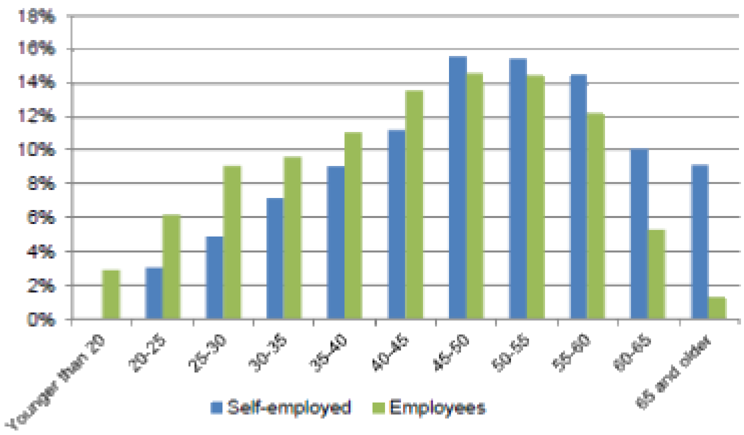


Figure 16: Structure of employees in Belgium [6]

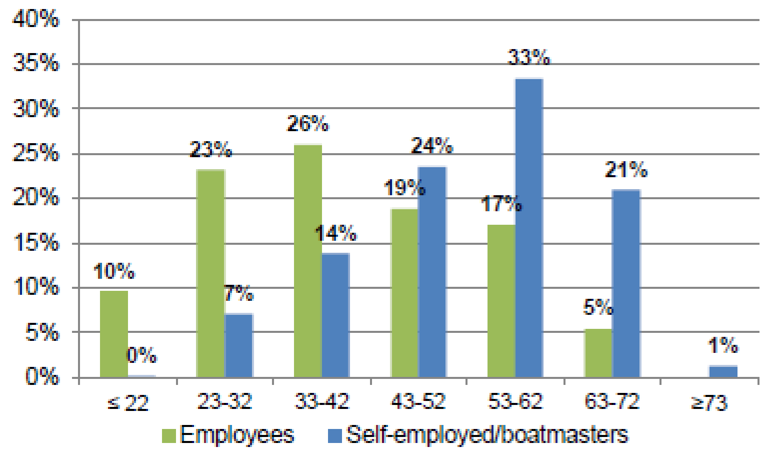


Figure 17: Structure of employees the Netherlands [6]

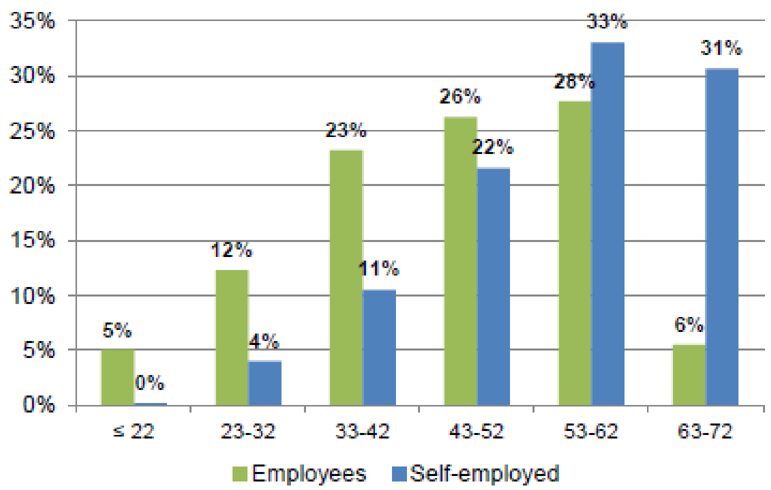


Figure 18: Structure of employees Germany [6]

In the inland navigation, different operating modes exist. Operating modes can slightly differ from country to country or even from waterway to waterway. Here, an example for the Rhine will be given. The operating modes on the Rhine are defined by the Central Commission for the Navigation of the Rhine (CCNR) [7]. For the Rhine, three different modes exist, which mainly differs in hours of navigation. These three forms can be distinguished into navigation for a maximum of 14 hours (A1), 18 hours (A2) or 24 hours (B) in a 24-hours period (

Table 5). Of course, further regulations, such as resting times, and exceptions are also specifically defined but will not be addressed here.

Table 5: Overview over operating modes

label	Maximum hours of navigation
A1	14 hours
A2	18 hours
B	24 hours

However, it is obvious, that the minimum of required crew members will depend on the operating mode. Besides the operation mode, the number of crew members depends on the type of vessel, the vessel length and the equipment standard. To stick to the example for the Rhine, crew regulations are also defined by the CCNR [7]. Table 6 and

Table 7 show the minimum crew for motor vessels and pushers, respectively, for rigid convoys and other rigid assemblies. This table only shows the standard rules for the crew, special rules and exceptions are not shown.

Table 6: The minimum crew for motor vessels and pushers

Group		Crew members	Number of crew members in operating mode A1, A2 or B and for equipment standard S1 or S2					
			A1		A2		B	
			S1	S2	S1	S2	S1	S2
1	L ≤ 70 m	boatmaster..............	1		2		2	2
		helmsman	-		-		-	-
		able boatman	-		-		-	-
		boatman..................	1		-		1	-
		apprentice	-		-		$1^{1)}$	$2^{1)\,3)}$
2	70 m < L ≤ 86 m	boatmaster..............	1 or 1	1	2		2	2
		helmsman	- -	-	-		-	-
		able boatman	1 -	-	-		-	-
		boatman..................	- 1	1	-		2	1
		apprentice	- 1	1	$1^{1)}$		-	1
3	L > 86 m	boatmaster..............	1 or 1	1	2	2	2 or 2	2
		helmsman	1 1	1	-	-	1 $1^{2)}$	1
		able boatman	-	-	-	-	- -	-
		boatman..................	1 -	-	1	-	2 1	1
		apprentice	- 2	1	$1^{1)}$	$2^{1)}$	- -	1

1) The apprentice or one of the apprentices may be replaced by a deckhand

2) The helmsman must hold a boatmaster's certificate specified by these regulations.

3) One of the apprentices must be over the age of 18.

Table 7: The minimum crew for rigid convoys and other rigid assemblies

Group		Crew members	Number of crew members in operating mode A1, A2 or B and for equipment standard S1 or S2					
			A1		A2		B	
			S1	S2	S1	S2	S1	S2
1	Dimensions of the assembly L ≤ 37 m W ≤ 15 m	boatmaster	1		2		2	2
		helmsman	-		-		-	-
		able boatman	-		-		-	-
		boatman	1		-		1	-
		apprentice	-		-		1[1)]	2[1)3)]
		engineer or engine-minder	-		-		-	-
2	Dimensions of the assembly 37 m < L ≤ 86m W ≤ 15 m	boatmaster	1 or 1	1	2		2	2
		helmsman	- -	-	-		-	-
		able boatman	1 -	-	-		-	-
		boatman	- 1	1	-		2	1
		apprentice	- 1	1	1[1)]		-	1
		engineer or engine-minder	- -	-	-		-	-
3	Pusher + 1 pushed barge of L > 86 m or Dimensions of the assembly 86 m < L ≤ 116.5 m W ≤ 15 m	boatmaster	1 or 1	1	2	2	2 or 2	2
		helmsman	1 1	1	-	-	1 1[2)]	1
		able boatman	- -	-	-	-	- -	-
		boatman	1 -	-	1	-	2 1	1
		apprentice	- 2	1	1[1)]	2[1)]	- -	1
		engineer or engine-minder	- -		-	-	- -	-
4	Pusher + 2 Pushed barges [*)] Motor vessel + 1 Pushed barge [*)]	boatmaster	1	1	2	2	2 or 2	2 or 2
		helmsman	1	1	-	-	1 1[2)]	1 1[2)]
		able boatman	-	-	-	1	- -	1 1
		boatman	1	-	2	-	2 2	- -
		apprentice	1[1)]	2[1)]	1[1)]	2[1)]	- -	1 1
		engineer or engine-minder	-	-	-	-	1 -	1 -
5	Pusher + 3 or 4 Pushed barges [*)] Motor vessel + 2 or 3 Pushed barges [*)]	boatmaster	1 or 1	1	2	2	2 or 2	2 or 2
		helmsman	1 1	1	-	-	1 1[2)]	1 1[2)]
		able boatman	- -	-	-	1	- -	1 1
		boatman	2 1	1	2	-	2 2	- -
		apprentice	- 2	1	1[1)]	2[1)]	1[1)] -	2 1
		engineer or engine-minder	1 1	1	1	1	1 1	1 1
6	Pusher + more than 4 Pushed barges*)	boatmaster	1 or 1	1	2	2	2 or 2	2 or 2
		helmsman	1 1	1	-	-	1 1[2)]	1 1[2)]
		able boatman	- -	1	-	1	- -	1 1
		boatman	3 2	1	3	1	3 3	1 1
		apprentice	- 2	1	1[1)]	2[1)]	1[1)] -	2[1)] 1
		engineer or engine-minder	1 1	1	1	1	1 1	1 1

1) The apprentice or one of the apprentices may be replaced by a deckhand.
2) The helmsman must hold a boatmaster's certificate specified under these regulations.
3) One of the apprentices must be over the age of 18.
*) Under this article the term "pushed barge" also refers to motor vessels not using their main engines and towed barges. Moreover, the following equivalence applies:
1 pushed barge = several barges of a total length not exceeding 76.50 m and a total width not exceeding 15 m.

The potential for crew reduction is highly depending on the vessel train constellation and technical circumstances. New monitoring systems might be necessary to ensure the safety of the vessel and remaining crew. Further, new regulations or adaptions to the resting times are most probably required. A detailed consideration, including legal and safety aspects will be performed later on, in cooperation with other work packages. In fictive scenarios, with six vessels in the vessel train and different plausible crew structure, the total crew in the train can be reduced by between 5 and 23 crew members compared to six single vessels.

4.1.5 Certificates

For the navigation on certain waterway sections a specific certificate is needed. A vessel train might offer the opportunity to navigate on this section even without a certificate. It would be conceivable, that the leading vessel must have a certificate, but a follower vessel, which is automatically guided by the leading vessel, might be allowed to navigate without certificate.

A grand certificate for all waterways, besides some exceptions with separate certificates (e.g. Weser, Elbe, Saale), requires four years of experience of journey time, special knowledge of the route and a 10-day workshop with one day of exam. The cost for the workshop is in the order of 1800 €. Additional extensions of certificates usually require a special knowledge of the route and one day of exam which costs around 300 €.

Instead of obtaining a certificate, external pilots can be hired for the according section. Hiring a pilot is a common methods and cost around 400 €.

It can be concluded, that the opportunity of sailing in a vessel train without having the required certificate for the section is not a big advantage over obtaining a certificate or hiring a pilot. For sure, this option might be a nice opportunity for some operators, but not a main driving advantage that can be stated for the vessel train.

Shortsea shipping

Available data for shortsea shipping (SSS) is not as extensive as for inland navigation. Further, the terminology is often not consistent. Maritime transport, shortsea shipping and sea-river shipping are often separated from each other inconsistently, making it difficult to gather and evaluate data and statistics. Additionally, the definition of shortsea shipping can vary locally. To clarify the meaning of shortsea shipping in the here presented context, the following EU definition is used:

'Shortsea shipping means the movement of cargo and passengers by sea between ports situated in geographical Europe or between those ports and ports situated in non-European countries having a coastline on the enclosed seas bordering Europe. Shortsea shipping includes domestic and international maritime transport, including feeder services along the coast, to and from the islands, rivers and lakes. The concept of shortsea shipping also extends to maritime transport between the Member States of the Union and Norway and Iceland and other States on the Baltic Sea, the Black Sea and the Mediterranean.' [8]

4.1.6 Shortsea shipping routes

In 2012, the SSS in the EU-28 was close to 1.8 billion tonnes of freight and represented 60% of total maritime transport of goods within Europe [9]. The distribution among different countries or sea area differs strongly, as can be seen in Figure 19.

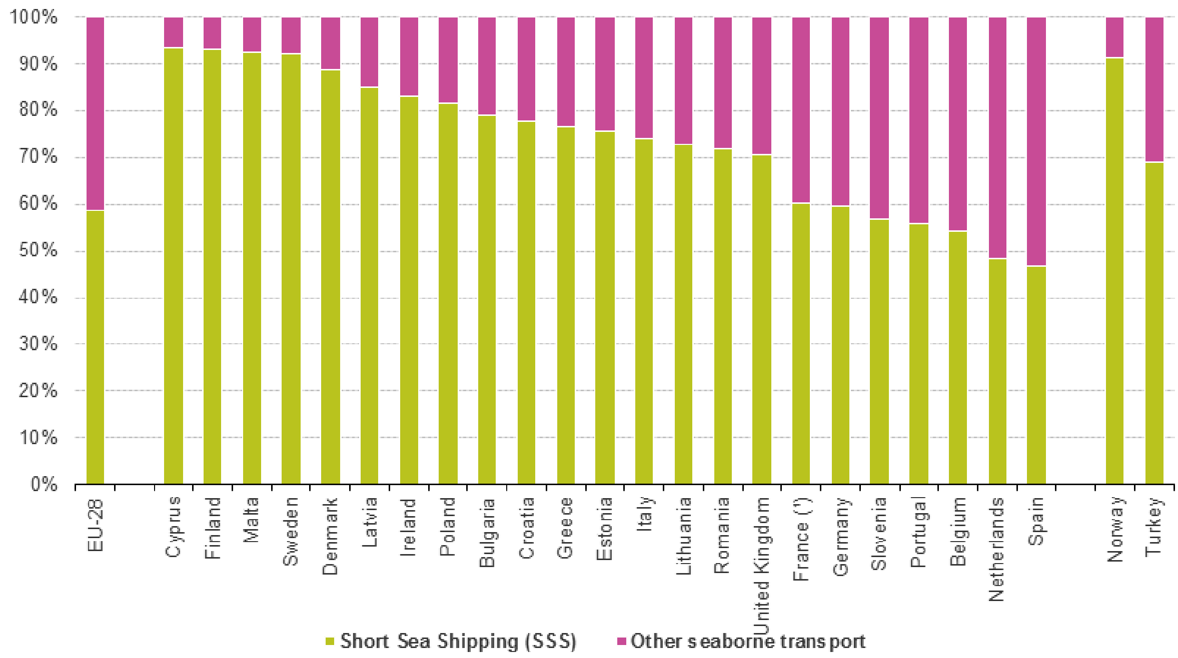


Figure 19: Percentage allocation of total maritime transport of goods by country

Figure 20 shows the distribution among the sea areas in 2012. Most freight transport takes place in the Mediterranean Sea with 29 %, followed by the North Sea (25.4 %) and the Baltic Sea (21.1 %). Only minor contributions are coming from the Atlantic Ocean (12.1 %) and the Black Sea (6.4 %).

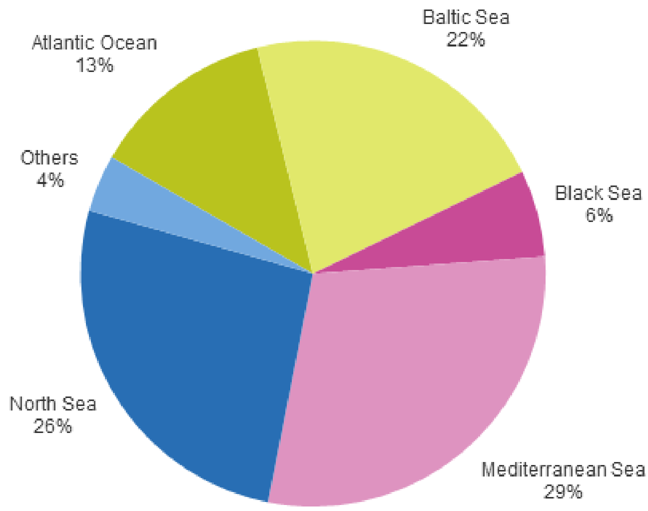


Figure 20: EU-28 short sea shipping of freight transport by sea region in 2012 [10]

Fehler! Ungültiger Eigenverweis auf Textmarke. shows a list of the main shortsea shipping routes, stating the countries of loading and unloading port as well as the amount of transported goods in million tonnes in 2009.

Table 8: Main routes in Intra-EU maritime transport (2009) [11]

Rank	Country of loading port	Country of unloading port	million tonnes transported
1	Italy	Italy	86.173
2	United Kingdome	United Kingdome	79.643
3	United Kingdome	Netherlands	40.187
4	Spain	Spain	39.471
5	France	United Kingdome	28.991
6	Greece	Greece	27.217
7	Netherlands	United Kingdome	24.937
8	United Kingdome	France	23.517
9	France	France	19.564
10	United Kingdome	Germany	14.389
11	Sweden	Germany	14.029
12	Denmark	Denmark	13.203
13	Belgium	United Kingdome	12.671
14	Denmark	Sweden	12.495
15	Sweden	Sweden	12.434
16	United Kingdome	Belgium	11.635
17	Germany	Sweden	11.243
18	United Kingdome	Ireland	11.153

19	Italy	Spain	11.017
20	Sweden	United Kingdome	10.363
21	Latvia	Netherlands	9.888
22	Finland	Germany	9.760
23	Spain	Italy	8.776
24	Sweden	Finland	8.736
25	Latvia	United Kingdome	8.443
26	Italy	Greece	8.042
27	Germany	Denmark	7.806
28	Denmark	Germany	7.592
29	Latvia	Germany	7.574
30	France	Spain	7.418
31	United Kingdome	Spain	7.168
32	Portugal	Portugal	7.115
33	Sweden	Denmark	6.998
34	Germany	United Kingdome	6.856
35	France	Netherlands	6.793
36	Finland	Sweden	6.500
37	Netherlands	Spain	6.424
38	Netherlands	France	6.717
39	Italy	United Kingdome	5.763
40	Netherlands	Germany	5.717

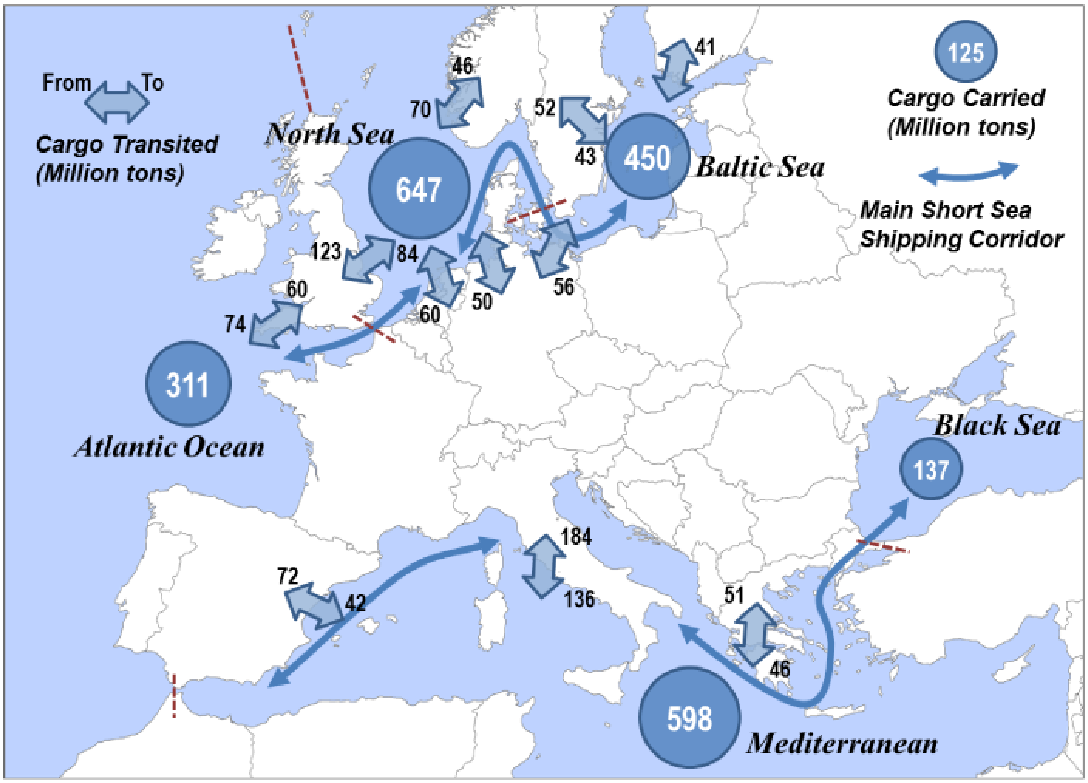


Figure 21: Main intra-European SSS cargo flows [source: SPC)

4.1.7 Cargo

The most common cargo in short sea shipping is liquid bulk and dry bulk cargo. Containers and RoRo-Cargo make 30 % of the total cargo transport with regional variations. The Black Sea reports the minimum with only 5 % and the Atlantic Ocean the maximum with 40 %. Due to the higher value of this boxed cargo the share of containers and RoRo cargo is significantly increased when it is based on value instead of tonnage.

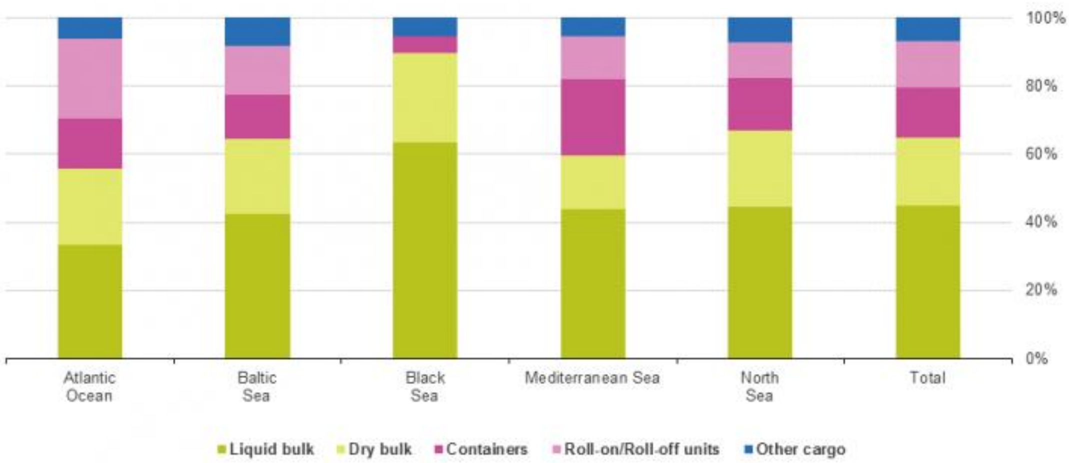


Figure 22: EU-28 Short Sea Shipping of goods by type of cargo for each sea region of partner ports in 2015 (in % of total gross weight of goods transported) [12]

4.1.8 Fleet

An overview over the shortsea shipping fleet is given in Figure 23. Russia holds the highest number of shortsea shipping vessels, followed by Germany and Norway. For the 12 listed countries the fleet consists of a total number of 7205 vessels.

Country of residence shipowner	# ships	# ships under national flag
Russia	1,265	1,241
Germany	1,199	192
Norway	930	448
Netherlands	737	591
Turkey	612	447
Greece	601	241
United Kingdom	522	435
Denmark	338	222
Italy	333	286
Ukraine	265	223
Spain	211	47
Sweden	192	129
Total	**7,205**	**4,502 (62%)**

Figure 23: SSS fleet overview [13]

Sea-river transport

Sea-river transports are possible on inland waterways of sufficient size with open access to the sea. The most important limiter is the allowable air draught under bridges and overhead cables followed by the water depth.

4.1.9 Sea-river routes

In Western Europe the following waterways are suited for sea-river transports [14]:

- Rhine (Netherlands, Germany)
- Thames, Humber, Forth (United Kingdom)
- Albert-Canal-Route (Belgium)
- Seine to Paris, Rhone to Lyon (France)
- Guadalquivir to Seville (Spain)

Further relations are:

- Göta Alv, Trollhättan and Södertälje Canal (Sweden)
- Saimaa Canal and Finnish Lakeland (Finland)
- Lower Danube (Romania)
- Sea of Azov and Black Sea, Caspian Sea with connected rivers

Figure 24 lists the above mentioned waterways and according waterway informations.

Belgium
Albert canal

- Length 134 m
- Width 12.5 m
- Draught 3.4 m
- Air Draught 6.7 m
- Tonnage 1.500/2.000

Belgium
Zeekanaal: Schelde - Ruisbroek Puurs

- Length 240 m
- Width 24 m
- Draught 8.80 m
- Air Draught 44 m
- Tonnage 10.000

Belgium
Zeekanaal: Ruisbroek - Brussels (voorhaven)

- Length 200 m
- Width 23 m
- Draught 5.80 m
- Air Draught 33.4 m
- Tonnage 4.500

United Kingdom
Humber - Goole

- Length 110 m
- Width 24.5 m
- Draught 5.5 m
- Air Draught na
- Tonnage 3.000/4.000

The Netherlands
Maas ; Juliana Canal

- Length 135 m; 135 m
- Width 12 m; 12 m
- Draught 3 m; 3 m
- Air Draught 6.8 m; 6.15 m
- Tonnage 1.000/1.500 ; 1.000/1.500

Portugal
Douro - Sardouro

- Length 87 m
- Width 111.4 m
- Draught 3.9 m
- Air Draught 7.5 m
- Tonnage 2.000/2.500

Sweden
Trolhattan canal ; Malaren Lake

- Length 88 m ; 135 m
- Width 13.2 m ; 19.6 m
- Draught 5.4 m ; 7.5 m
- Air Draught 27 m ; 41 m
- Tonnage 3.000/4.000 ; 9.000

Finland
Saima canal

- Length 82 m
- Width 11.8 m
- Draught 4.3 m
- Air Draught 24.5 m
- Tonnage 2.000/2.500

France
Seine - Gennevilliers (Paris)

- Length 120 m
- Width 15.5 m
- Draught 3.5 m
- Air Draught 8.7 m
- Tonnage 1.500/2.000

France
Rhone ; Saone

- Length 135 m ; 135 m
- Width 11.4 m ; 11.4 m
- Draught 3 m ; 3 m
- Air Draught 6.2 m ; 5.1 m
- Tonnage 1.000/1500 ; 1000/1500

Germany
Upper rhine ; Central Rhine

- Length 110 m ; 110 m
- Width 11.4 m ; 14 m
- Draught 2.5 m ; 2.5 m
- Air Draught 6.8 m ; 8.3 m
- Tonnage 1.000/1.500 ; 1.000/1.500

Germany
Lower Rhine

- Length 135 m
- Width 22.4 m
- Draught 3.5 m
- Air Draught 9.1 m
- Tonnage 2.000/4.000

Figure 24: Suitable sea-river waterways with according waterway details

4.1.10 Cargo

According to market analysis of the CCNR about 90-100 Mio. tonnes of cargo are transported annually by means of sea-river transport. Unfortunately, more detailed and recent data sources are not known. Transported cargo comprises agricultural and forest products, bulk cargo like coal, ores, salts, sands and construction materials. Also metal products, semi-finished products, papers, waste and scrap, project and heavy goods as well as dangerous goods are typically transported by low air-draught sea-river vessels. While today these transports only have a minor share in Western and Southern Europe, the importance is much higher in Russia. Boxed cargo is rare in sea-river cargo flows [14].

4.1.11 Fleet

Today 641 Russian-flagged sea-river vessels are registered in the Russian Maritime Register of Shipping. The average age is 32 years. Typical deadweight capacities of the sea-river vessels are in the order of 2000 dwt (excluding Eastern Europe). In Scandinavia ice classes may be required, while e. g. in the Rhine area liftable deckhouses are advantageous. In Russia the focus is on small draught ships [14].

Competitive modes of transport

The three main transport modes, road, rail and inland waterway transport in the traditional sense, have completely different operating conditions and, thus, completely different strengths and weaknesses. However, the vessel train concept brings up some similarities to rail and road concept. Thus, it is worth having a closer look to functioning of road and rail operation to analyse what might be learned from their experiences. In the following section an outline of road and rail transport will consider aspects that can be of value for the vessel train concept.

4.1.12 Railway

Railway freight transport has certain similarities to the desired vessel train concept, considering a locomotive with its wagons. Hence a detailed analysis of European rail freight transport is carried out with a focus on similarities and differences to the vessel train concept. A well-founded summary of important aspects in the analysis of logistical systems is given by Janić [15] and the therefore following list of aspects largely follows this publication.

In general the transport velocity for cargo by rail depends strongly on the distribution network and traffic volume. The transport velocity can be quite fast for direct connection, but is reduced by cargo handling for other distribution modes. Further, rail transport does not suffer from driving bans on Sundays or Holidays. However, freight and passenger transport shares an extensive amount of railways and restricts the freedom of tail freight transport, since passenger trains are usually take priority. Additionally, repair and maintenance works often take place in the nights, where freight transport is often operating. A further advantage of rail transport is the predictability, since transport is organised in plannable timetables. On the other hand, these timetables restrict the flexibility [1].

4.1.12.1 Railway infrastructure

A comprehensive summary of the historical development of the rail network up to the present day is given by Martí-Henneberg [16]. Starting in the middle of the 19th century against the background of the historical development of Europe, the development of the rail network was driven forward by the individual states for a long time. It is only since the last few decades that the European Union has been further developing the rail network in the form of common regulations. Nevertheless, the rail network remains historically grown and parts of the technical specifications have remained unchanged since the 19th century.

In the 1960s, the European rail network had reached its peak at around 230 000 kilometres. Since then, increasingly unprofitable lines have been closed down, so that the European rail network today has a length of about 195 000 kilometres [16]. Especially in Central Europe and Great Britain lines have been closed down, so that today rail transport to rural areas is no longer possible. The privatisation of railway companies and the necessary cost-cutting programmes (for example MORA-C in Germany [17]) have made a decisive contribution to this development. Figure 25 gives an impression of the current European railway network.

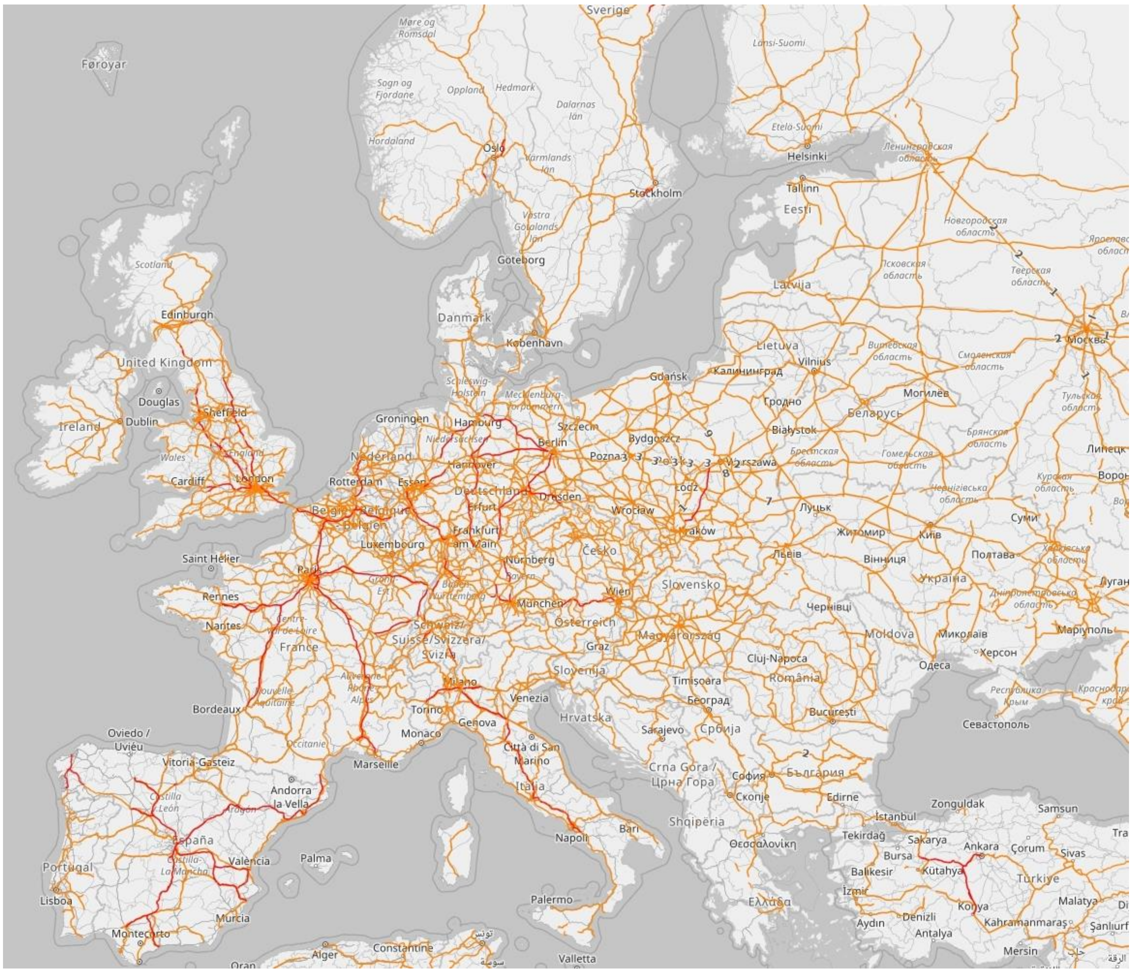


Figure 25: Railway network in Europe with main lines displayed in orange and high speed lines in red colour (Source: http://www.openrailwaymap.org)

With the fall of the iron curtain and the eastward enlargement of the EU, nowadays common developments at European level are being pursued. Within the trans-European networks (TENs), therefore, cross-border rail transport also plays a crucial role within the framework of the trans-European transport networks (TEN-T). As part of the further development of this project, nine TEN-T Core Network Corridors have been defined in 2013 with the EU regulation 1315/2013 [18]. Figure 26 shows the number of ports which are linked to the railway network in the member states and Figure 27 shows the planned and completed railway connections with additional port and rail road terminals (RRT).

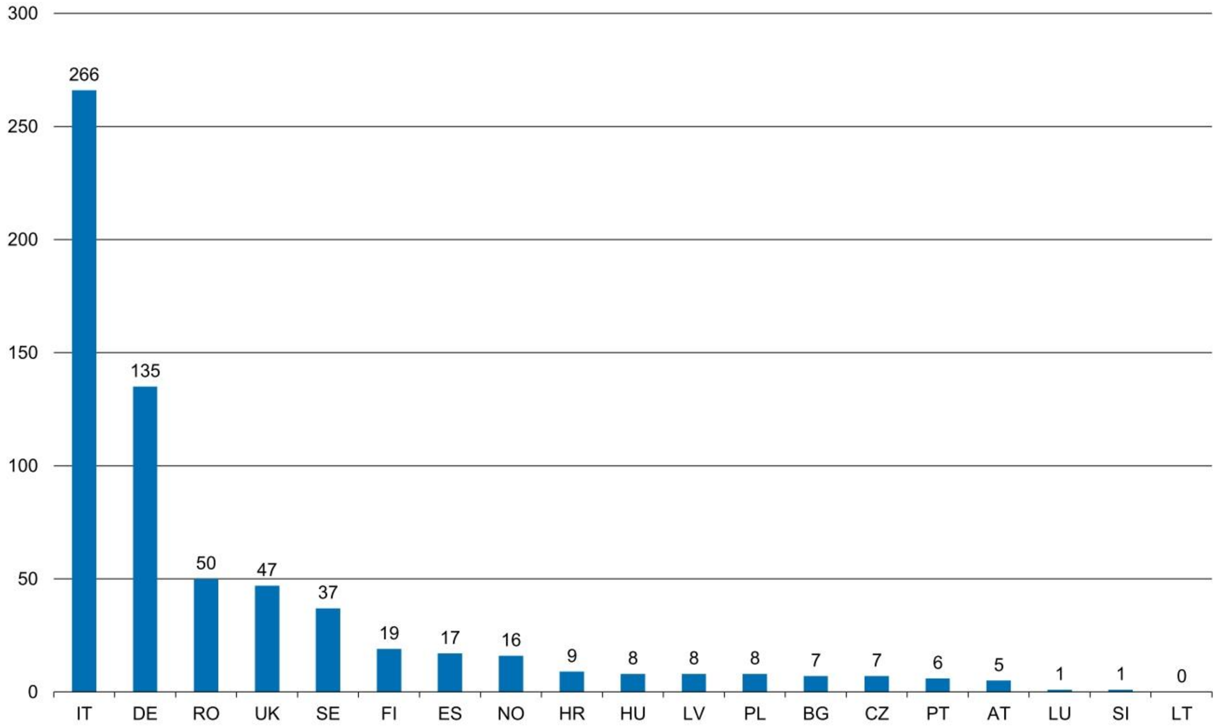


Figure 26: Number of maritime and port facilities linked to rail activities (2014), Source: RMMS, data 2014, FR and SK not relevant, Graph Notes: Data for NO include 6 port facilities without tracks and/or lifting capacity (see [2])

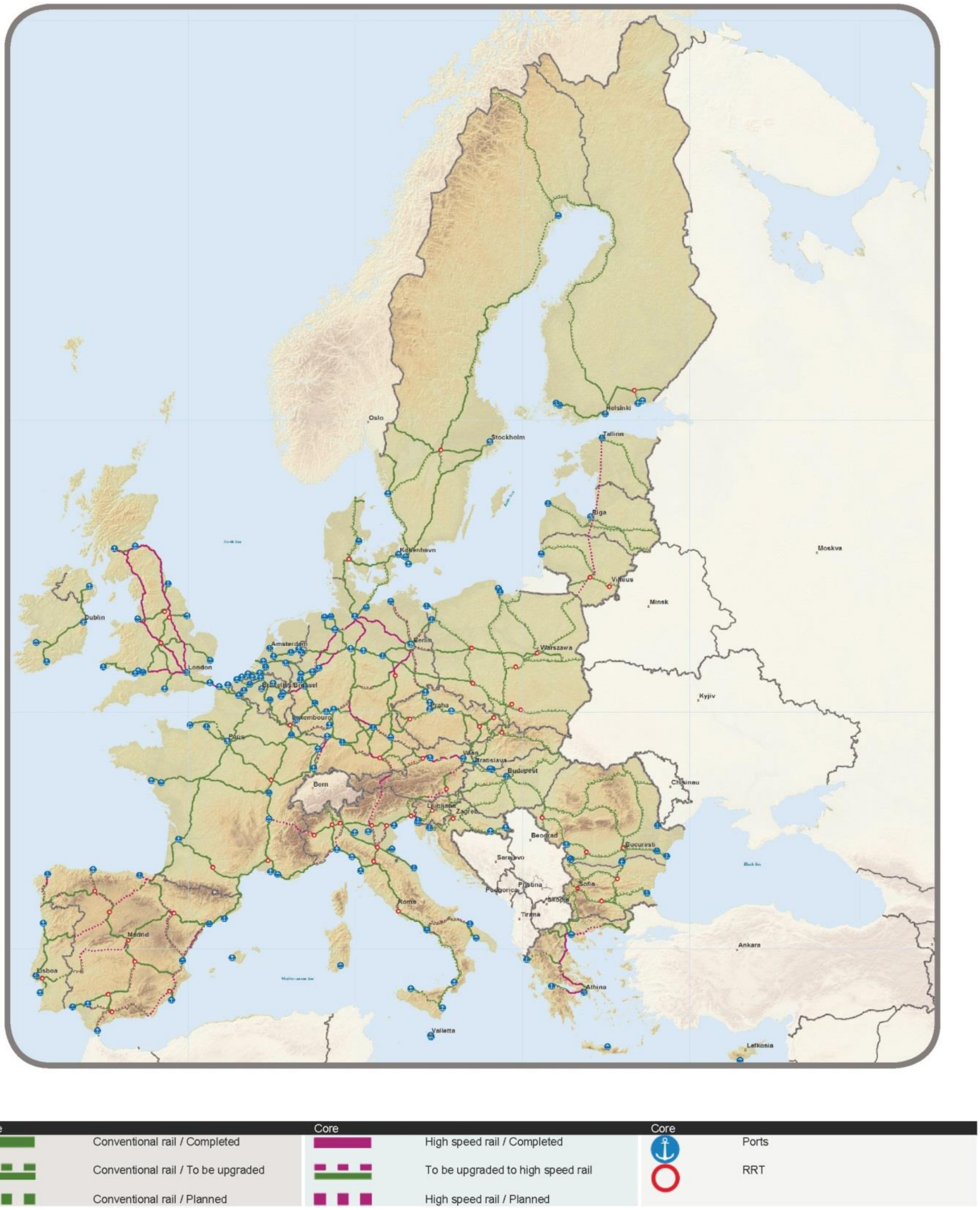


Figure 27: Existing and planned Core Network Corridors with connection to ports and rail road terminals (RRT) according to [18] (Source: [18])

4.1.12.2 Railway technology

In the course of the historical political development of Europe, different technical standards have become established in the various countries over the course of time, particularly with regard to track gauge, electrification and train protection systems. Basically, a distinction can be made between rail network technology and rail vehicle technology, but both are closely linked. Therefore, no strict distinction is made below.

An important parameter of the track network technology is the rail gauge, which can basically be divided into standard gauge (1435 mm), broad gauge and narrow gauge. With the exception of Spain, Portugal, Ireland, Finland and the Baltic States, the standard gauge is present in Europe and China. The division of the rail gauges in Europe is also described in [17], for example. The standard use of the broader gauge (1520mm) in North, Central and East Asia therefore allows for train connections to China, where the rail gauge only needs to be converted twice.

Since two- or multi-rail tracks mean an extensive reconstruction of the rail infrastructure, the rail gauge conversion of the rolling is nowadays a state of the art technology. Track gauge conversion means either a complete manually change of the wheelsets or the usage of new types of wheelsets, which allow an automatic change of the rail gauge during operation. However, this technology is mainly used in the more time-critical passenger traffic. In freight transport it is often easier to transfer the goods to other vehicles. In any case, the change of lane is associated with a time and financial expenditure.

In comparison to the rail gauge, there are various different electrification systems for rail traffic at European level. Both direct current (DC) and alternating current (AC) systems are used. With the exception of southern England, four systems have prevailed. For environmental reasons, an electric rail drive with regenerative power generation is preferable to diesel drive. In 2014, 52% of the EU's rail network was electrified on average. The proportions vary considerably from one Member State to another [19]. This is of particular interest for the future ecological consideration of rail transport.

In the meantime, multi-system locomotives have become state of the art technology, making it possible to travel on the entire European rail network (see for example [20]).

In principle, the electrical current can be supplied via overhead lines or conductor rails (third rail). Overhead lines are generally considered safer and easier to implement. However, they have a decisive disadvantage in rail freight transport: they do not permit efficient unloading from above, for example by means of gantry cranes. This disadvantage can only be compensated for by the less efficient horizontal loading and unloading or by a non-electrified line with diesel vehicles (see for example [21]).

Due to the technically complex and economically expensive pre- and post-carriage of trains and wagons and the transhipment of goods from road to rail, particularly intensive research and development is carried out in this area. These include innovative loading and unloading systems, automatic couplings and telematics systems for load monitoring. A meanwhile older summary and classification of different systems can be found in [22] and [23].

A major safety-related interoperability problem is the more than 20 different train control systems used at European level. Similar to road traffic, rail traffic is controlled by visual signals. If a train driver does not react correctly, the train is automatically slowed down. The European Train Control System (ETCS) as part of the European Rail Traffic Management System (ERTMS) is now mandatory on new lines throughout the EU, but upgrading existing lines is expensive and will therefore only progress slowly. In Germany, special international routes are and will be equipped with ETCS. This also includes the German part of the TEN-T corridors.

The maximum clearance gauge of a train is another restriction, especially due to overhead lines, bridges and tunnels. There are smaller differences across Europe, but a container transport with two layers, as used on routes in the United States, Canada, Australia, India, China and Panama, is not possible throughout Europe. In addition, there are interoperability problems with authorised train lengths, for example 750 m in France and 450 m in Spain, as well as different categories of authorised axle loads (see [24]).

Railway ferries, which are also used for freight transport to and from Scandinavia and Eastern Europe, are closing the rail network, particularly in the Baltic Sea region. In recent decades, however, their importance has declined sharply.

4.1.12.3 Freight collection and distribution networks

Goods are generally transported between a consignor and a consignee, or in other words from door to door. Within this supply chain there is a multitude of actors, depending on the type of logistics system and the choice of mode of transport. In principle, freight collection and distribution networks (CD networks) can be divided into five categories [15].

P-P – Point to point networks

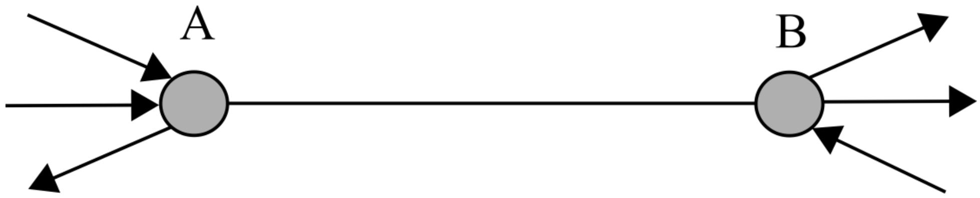


Figure 28: P-P network according to [15]

A P-P network is the simplest form of a CD network. Goods are transported by truck, for example from the consignor's door, to the intermodal origin terminal and loaded onto rail or inland waterway vessels that take them to the destination terminal. From there they are usually transported by truck to the door of the recipient. Goods are first and foremost cargo units, such as containers or swap bodies, which can be handled easily within general intermodal transport or in combined transport.

The specific form of block train traffic has certain similarities to a P-P network. In this case, large quantities of goods are transported exclusively by rail without pre- and post-carriage as well as further transhipment from A to B. These are mainly bulk goods of the coal and steel industry, petroleum products and building materials (see also [25]). For this purpose, long trains can be formed and the goods transported over long distances. The low specific energy consumption is in this case a system advantage of the railway and the transports can be offered at favourable conditions (see also [25]).

TCD – Trunk line with collection/distribution forks

A TCD network is similar to the P-P network, but contains upstream local terminals. Transport between the local and trunk terminals is organised via feeder services, which can also be provided by rail. The pre- and on-carriage is usually carried out again by truck (see also [25]).

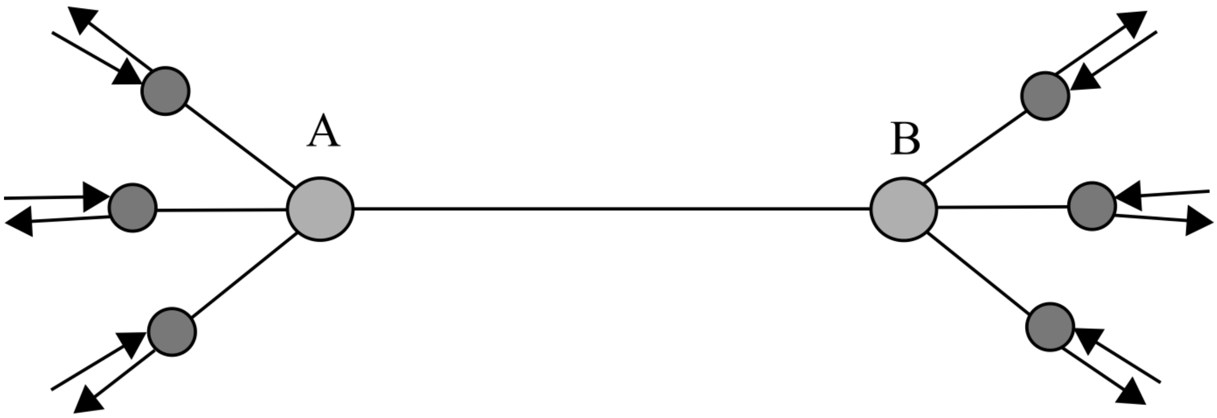


Figure 29: TCD network according to [15]

In terms of rail transport, local and trunk terminals are marshalling yards where goods are handled. The cost of handling depends on many factors of the equipment and personnel of these marshalling yards, as well as the speed of loading and unloading (see also [25]).

HS – Hub-and-Spoke(s)

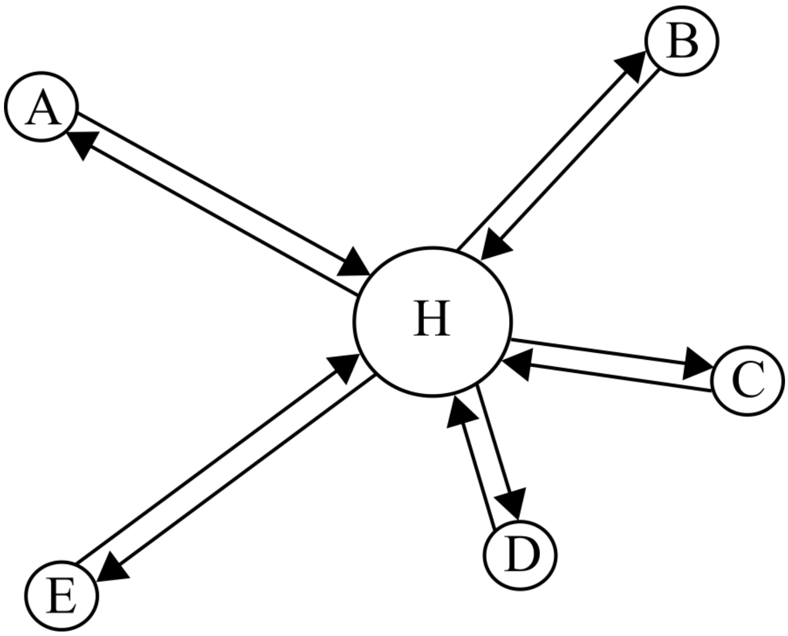


Figure 30: HS network according to [15]

A HS network consists of a central node (hub) and various spokes (spoke terminals). Goods normally enter and leave the spoke terminals by truck and are loaded onto rail or barge. In the hub, the goods are handled or even transported with other transport units. The connection between two spokes terminals is always made via the hub. In the case of rail traffic, the hub acts as a marshalling yard (see also [15]). Whereas in the past there may have been direct short rail connections between the spoke terminals, today's rail freight traffic runs via an extensive HS network.

The structure of the TCD and HS networks shows clear similarities to that of single wagon traffic by rail. For the transport of smaller quantities of goods, such as few containers or less, trains have to be assembled by several shippers. For this purpose train formation facilities are needed, which can be divided into different hierarchy levels.

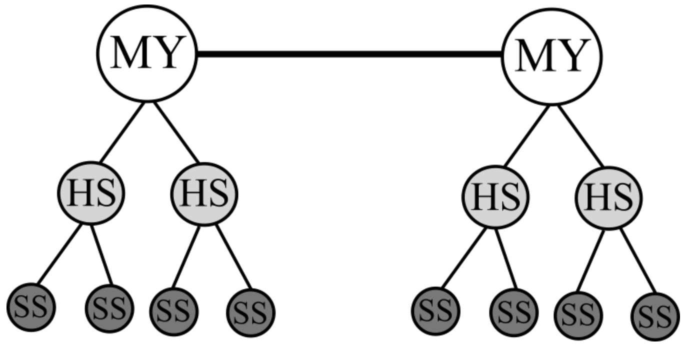


Figure 31: Schematic diagram of single wagon traffic according to [21]

Satellite stations (SS) are small track systems with few staff for the collection and distribution of local consignments. Hub stations (HS) are smaller marshalling yards for the first sorting of local consignments. Marshalling yards (MY) are the main interface between local and long-distance freight transport by rail (see also [21]). In the area of single wagonload transport, transport costs are therefore determined by the number and efficiency of transhipments. In relation to the distance transported, the costs are therefore concentrated on the pre- and on-carriage in the local marshalling yards.

A further development is the Train-Coupling- and Sharing System (TCS). Shorter trains from the local marshalling yards are coupled together instead of assembling the individual wagons into a new train. This saves on shunting operations at the start and finish, but requires vehicles with complex technical equipment (see also [26]).

L/R – Line or ring collection/distribution networks

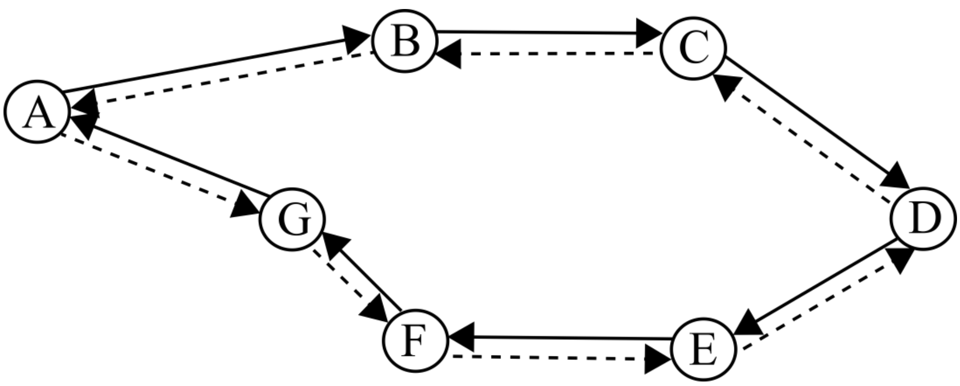


Figure 32: L/R network according to [15]

An L/R network consists of a ring or line structure with terminals at which the goods enter or leave the network. Rail and inland waterway vessels are the most suitable means of transport within the network. The pre- and post-carriage can be carried out with all modes of transport, although not all terminals must have the same capacities and switching modes (see also [15]).

M – Mixed network

An M-network usually consists of elements and combinations of the described network structures (see also [15]).

Operational performance parameters and operating procedure

Considering the goods receipt and goods issue in all network structures at the individual terminals via a complex pre- and post-carriage with different modes of transport, a complex logistical structure is created. According to Janic [15], the following parameters are of particular importance for the evaluation of performance:

- Size of the network
- Average route length
- Capacity of transport vehicles
- Service frequency
- Schedule delay
- Average transport speed
- Average transport time
- Average delivery distance
- Average delivery speed
- Average delivery time
- Punctuality
- Reliability
- Coefficient of terminal time
- Transport work
- Intensity of network services
- Technical productivity
- Costs
- Externalities

Following the liberalisation of the European market, railway undertakings are facing infrastructure undertakings. The latter sell train paths, which mean that a section of the line is occupied in time and space by a train. In international European rail traffic, therefore, the individual infrastructure companies of the member countries still have to be contacted in many cases. The nine transport corridors have recently become an exception. The EU regulation 913/2010 stipulates that Corridor One-Stop-Shops (C-OSS) coordinate the sale of the train paths for each individual corridor for the entire international route (see [24]).

There are basically two types of orders: Capacities can be ordered far in advance as part of the annual timetable or can be requested at short notice as part of the ad hoc procedure. However, this does not meet the needs of freight transport, as long-term planning is difficult to predict and suitable train paths are often no longer available in the short term. In addition, the competition can be distorted by ordering but not used train paths (see [24]).

In the context of mixed rail transport, i. e. the use of tracks for passenger and freight transport, freight transport is disadvantaged by the primacy of passenger transport. Accumulated delays in passenger transport affect freight traffic just as badly as maintenance measures on the route, which often take place at night in the slots of freight traffic (see [24]).

Despite efforts to create a single European railway sector, administrative and technical constraints remain which hamper the competitiveness of rail freight transport. These include lengthy procedures for registering vehicles and issuing safety certificates, which are still required by each individual member state in which a train is to run (see [24]).

The requirements placed on train drivers are a further obstacle. Unlike air traffic, there is no common language of operation, so it is imperative that train drivers master the language of the country in which the train operates (see [24]). For example a Duisburg/Antwerp journey requires a train driver that speaks German, French and Dutch.

The period of service is usually nine hours or, in some cases, ten hours. In contrast to trucks and inland waterway vessels, locomotives do not contain a sleeping cabin. Locomotive drivers therefore sleep at rest stops if necessary.

4.1.12.4 Labour market

From a social point of view, at least two points are problematic. On the one hand, the age structure of employees in the railway sector is above average in the 40-59 age group. There may be a shortage of skilled workers here in the next few years (see Figure 33).

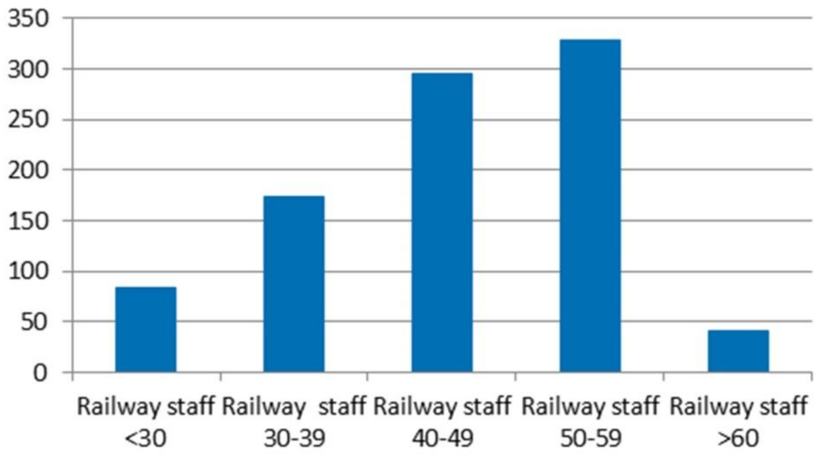


Figure 33: Age pyramid of workers in rail (thousand employees, 2012), Source: UIC 2012 (see [2])

4.1.13 Road

Freight transport by road is still the dominant method for the transportation of cargo. The transport velocity on the road is usually higher than for road and water transport. It is only limited by driving bans on Sundays or Holidays, or by traffic jams. Road transport is highly flexible and suitable for door-to-door delivery. On the other hand, the transport capacity is limited and, thus, transport costs are high. From the ecological point of view, road transport performs worst [1].

In the following section, the freight road transport should be analysed in respect to the vessel train concept. This analysis should yield insight into the logistic concept and technologies and should reveal aspects which might be interesting for the vessel train concept. The aim is not to compare both modes of transport and to state the well-known advantages and disadvantages, but to have a focused look what can be learned from road transport concepts for the vessel train concept.

Nevertheless, some general information will be given, to show the relevant similarities and differences. A special focus is laid on the truck platooning concept, which is quite similar to the vessel train concept.

4.1.13.1 Road Infrastructure

The road infrastructure is highly developed in Europe, since it in not only used for freight transport but also for private passenger traffic.

For the analysis of the fright transport, the focus is on the motorways. Figure 34 shows a map of motorways all over Europe. The total length of motorways in Europe is 73246 km, the distribution among countries is shown in Figure 35. Regarding the total length of motorways, Spain, France, Germany and Italy are the leading countries. For a better comparison, the road density can be compared, the results are summarised in Figure 36. The Netherlands, Belgium and Luxembourg are the countries with the highest road density.

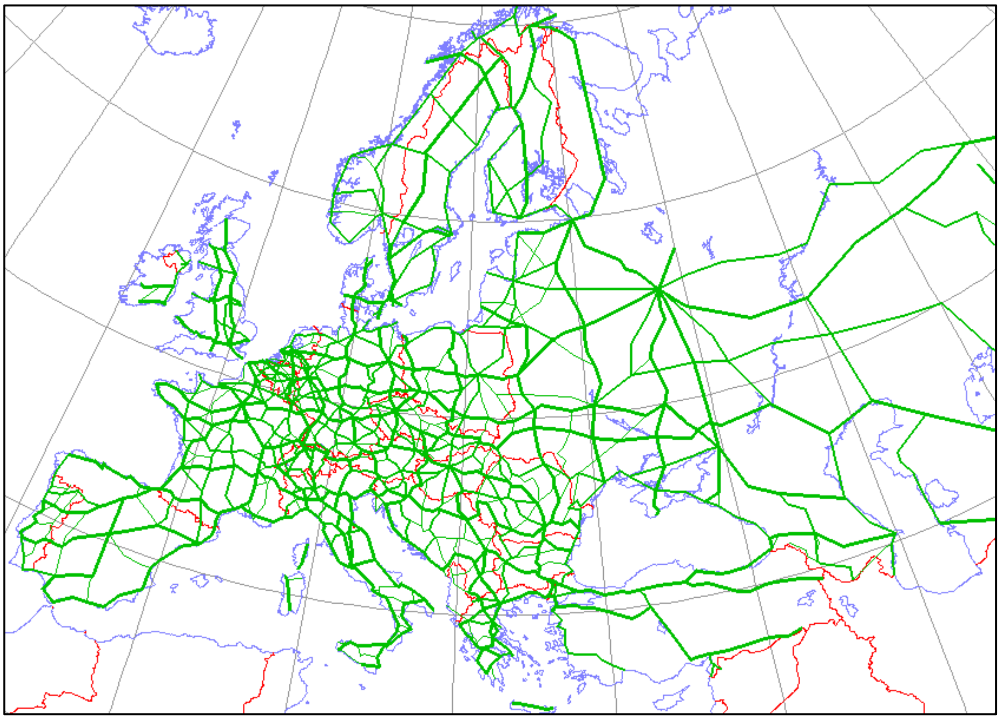
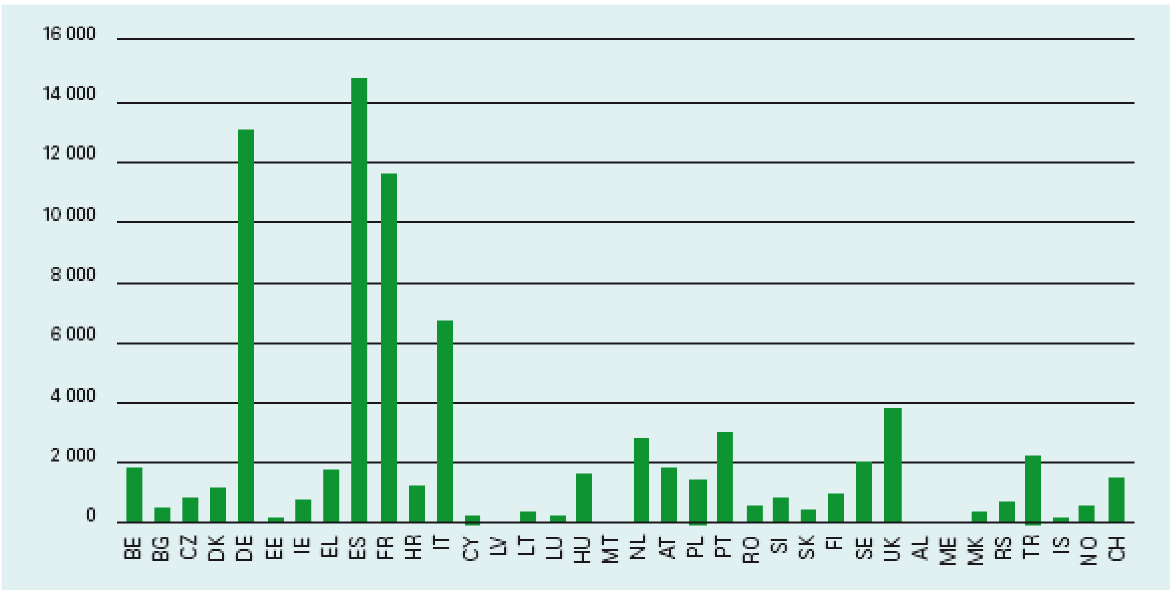
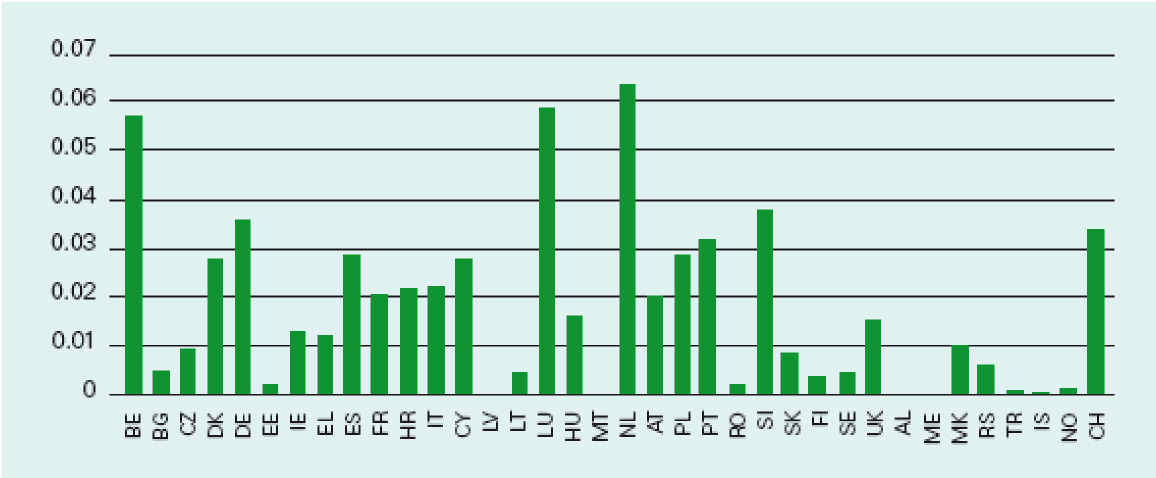


Figure 34: European motorway network



BE end of 2009 • **EL** end of 2010
UK 1st April 2013 • **IS** end of 2011

Figure 35: Length of motorway network by country, 2012 (km)



BE end of 2009 • EL end of 2010
UK 1st April 2013 • IS end of 2011

Figure 36: Density of motorways by country, 2012 (km motorway per km² land area)

It can be concluded, that the motorway infrastructure is well developed in Europe. Additionally, connecting and inner-city roads can be used for door-to-door delivery.

4.1.13.2 Freight collection and distribution network

In conventional road transport, several distribution networks have been established. The trend is heading towards larger distribution centres. However, some goods still require a three-tier distribution system, with regional, national and international distribution centres. Figure 37: Different forms of freight collection and distribution networks in road transportFigure 37 shows different freight collection and distribution networks.

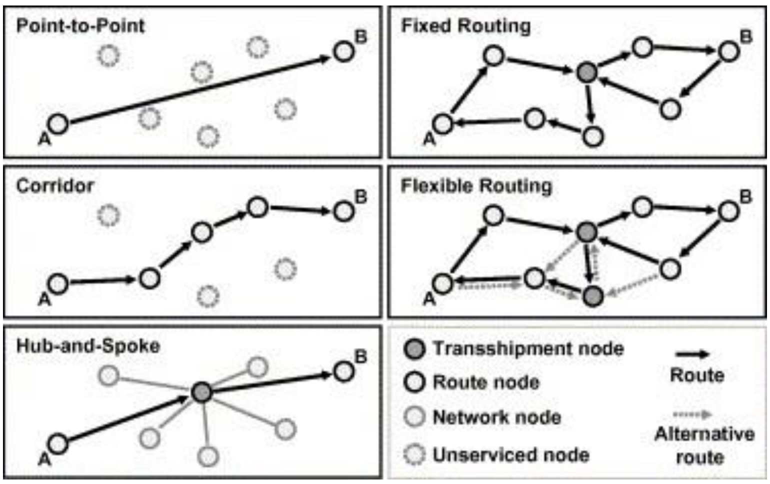


Figure 37: Different forms of freight collection and distribution networks in road transport [27]

Point-to-point distribution is used, when specialized and specific one-time orders have to be satisfied. For this form of distribution often less-than-full-load transports and empty returns occur, leading to an increase in costs and a decrease in efficiency. On the other hand, the logistic requirement is minimal. The corridor structure is an expanded point-to-point distribution, where the freight is loaded or unloaded at local/regional distribution centres, on a fixed route, or corridor. This form of distribution requires a good logistic planning. A third way of distributing freight is the hub-and-spoke network. This network requires large distribution centres with a high throughput of freight. This network can be quite efficient, when the distribution centre is logistically well organised and able to handle large amounts of time-sensitive consignments. A routing network can be divided into fixed routing and flexible routing. For both, freight is usually collected or distributed in a circular configuration, connecting specific hubs to each other. The fixed routing usually takes the same routes, whereas, flexible routing can change the route according depending on special requirements.

4.1.13.3 Road Platooning

Regarding collaborative travelling the road sector is pretty far ahead of the waterborne sector. In general, the idea of automatic driving on road came up quite early in the 1940's [28]. Since then, a lot of research for all kind of related topics came up, leading to a stepwise development of new technologies. Advanced driver-assistance systems (ADAS) such as Emergency Brake Assist or Active Brake Assist (EBA, ABA), Adaptive Cruise Control (ACC), Lane Departure Prevention or Lane Departure Warning (LDP,LDW), and Traffic Sign Recognition have been established quite well in the resent years, paving the way to automatic driving.

Regarding the technological developments and the prospective of automatic driving, the idea of connecting vehicles with each other is not far away. Around the year 2000 research on the so called vehicle-to-vehicle communication started and first field test have been performed in the recent years.

Provided that the technology works completely reliable these technologies have a huge improving impact on the safety on road. Besides the safety aspects collaborative travelling offers further advantages.

Especially for freight transport collaborative travelling, so called platooning, became quite attractive. Platooning describes a way of travelling in a convoy of several trucks, which are electronically connected, which is exactly the same idea for the vessel train.

Since some years many studies and projects had come up to investigate the concept of truck platooning and to develop the according technology. In 2015 the 'White Paper: Automated Driving and Platooning – Issues and Opportunities' has been published [28]. In this report a wide range of aspects needed to be considered for automated driving and platooning are examined and presented. One of the latest and quite successful projects in in Europe is the 'European Truck Platooning Challenge 2016' [29].

The European Truck Platooning Challenge 2016 is initiated by the Dutch Ministry of Infrastructure and the Environment, the Directorate General Rijkswaterstaat, the Netherlands Vehicle Authority (RDW) and the Conference of European Directors of Roads (CEDR). A large consortium composed of truck manufacturers, logistics service providers, research institutes and governments aimed to push truck platooning forward. The project covers legal aspects, technical requirements and developments, the impact on the mobility system, human factor issues as well as deployment aspects. Further, a large-scale, cross boarder field experiment, where different truck manufactures sent out trucks in a platoon from different destinations to the port of Rotterdam, has been performed [30].

Truck platooning can bring a branch of advantages over single driving trucks. The most prominent advantages are:

- Fuel saving and reduced emission
- Labour cost reduction
- Road space reduction
- Improvement of safety

Several studies have proven a high potential in fuel saving in truck platooning. Parts of the fuel saving potential can be attributed to the optimisation of accelerating and decelerating processes due to electronic coupling. Further improvements can be achieved by reducing the inter vehicle distance and taking advantage of the more favourable wake/slipstream of the vehicle in front. Accompanied by the reduced fuel consumption, is a reduced emission.

Several studies show a total fuel savings up to 12 %, depending on the inter vehicle distance and the number of trucks in the convoy. In general it can be stated: The more vehicles, the greater the saving. However, at some point, the effort to assemble a large number of trucks to one convoy exceeds the benefit of fuel saving.

Besides reduced fuel consumption, the reduction of the inter-vehicle spacing reduces the overall space consumption on the road. The mandatory distance between two trucks is 50 m when the spacing due to electrical coupling can be reduced to 4 m only a total space of 138 m can be saved in a platoon of four trucks.

From the technical point of view, the coupling of many trucks is uncritical. However, from practical and monetary point of view a coupling of more than 10 trucks in one convoy us not applicable.

A long term aim is a 24h operation of the fully automatically driving convoy and the building of a well-developed networking with custom authorities and forwarder companies. However, besides the need of a new legal framework and public acceptance, the implementation in respect to the integration into normal traffic and the development of new logistic concepts has to be prepared and performed.
Many studies have already addressed the transition to driverless road freight transport [31] and the comparison of different logistic concepts, such as the so called ‘timetable policy’ vs. ‘feedback policy’ [32]. In the ‘timetable policy’ trucks get together at a certain place and time to drive together to a specified aim, independently how many trucks are participate. In the ‘feedback policy’ trucks get together at a certain place where they are waiting for a specified number of trucks, before they leave as a convoy. Both methods bear advantages and disadvantages. The ‘timetable policy’ is more plannable, but savings might be reduced, due to a small number of trucks in the convoy. Whereas, the saving can be optimised for the ‘feedback policy’ when the number of trucks is set in advance, but the total transport might take longer and is less plannable due to unknown waiting times. Which kind of policy is suitable strongly depends on the type of cargo and the requirements of customers. Besides this planned formatting, a spontaneous formatting on the road is possible. However, the formatting on the road requires compatible technology among all trucks, as well as clear communication and identifying features. The logistic effort is quite high and a service and controlling system has to be established, to distribute the savings among the participating trucks in the convoy.

As already stated above, the integration into normal traffic is still an unsolved topic. For example, a long convoy makes it difficult for other vehicles to merge onto highway or leaving the highway. Thus, intelligent coupling and decoupling methods or automatically controlled regulations systems have to be developed and integrated into normal traffic.

Summary in respect to the vessel train concept:

The concept of freight platooning on the road and the vessel train concept seem to be quite similar for the first glance, but different on the second.

The main advantage of platooning on the road, mainly saving fuel and thus reducing emission is not valid for the waterborne transport. Further, the reduction of needed space due to the reduction of the inter-vehicle distance will be much more difficult on waterways, since not only the ship, but also the water is moving and the safety regulations will, for sure, be more strictly. Additionally, water transport does not suffer from a lack of available space and will not profit from reducing the inter ship distance.

From a technical point of view, the coupling of trucks is feasible, whereas, the technology have to be developed or transferred to vessels in the first place.

Challenges for the implementation of the new vessel train into the normal traffic will be similar to the implementation of truck platooning into normal road traffic. Suitable solutions for road traffic might be usable or at least partly transferable to the vessel train. Further, new logistic concepts developed for road platooning can be considered for a new logistic concept for the vessel train.

5 CURRENT CARGO FLOW

In order to research the market potential and the business applicability of the VT concept, cargo flows are needed to be taken into account. These cargo flows will serve two purposes:

- give a first insight into the potential market of the VT
- form the basis of the transport economics and welfare analysis.

Therefore, an origin destination (OD) matrix of containerized cargo for the first case study area needs to be developed.

The first case study area is called the “Antwerp case” in the proposal. The OD matrix should, preferably, include short sea flows (Scandinavia / Great Britain to Antwerp / Rotterdam) and IWT flows from the ports of Antwerp / Rotterdam to the Rhine, up to Basel).

Figure 38 gives an overview of the Antwerp case study area for the IWT and sea-river vessels. This study area goes along with the Rhine – Alpine corridor (RALP) of the EU TEN-T network.

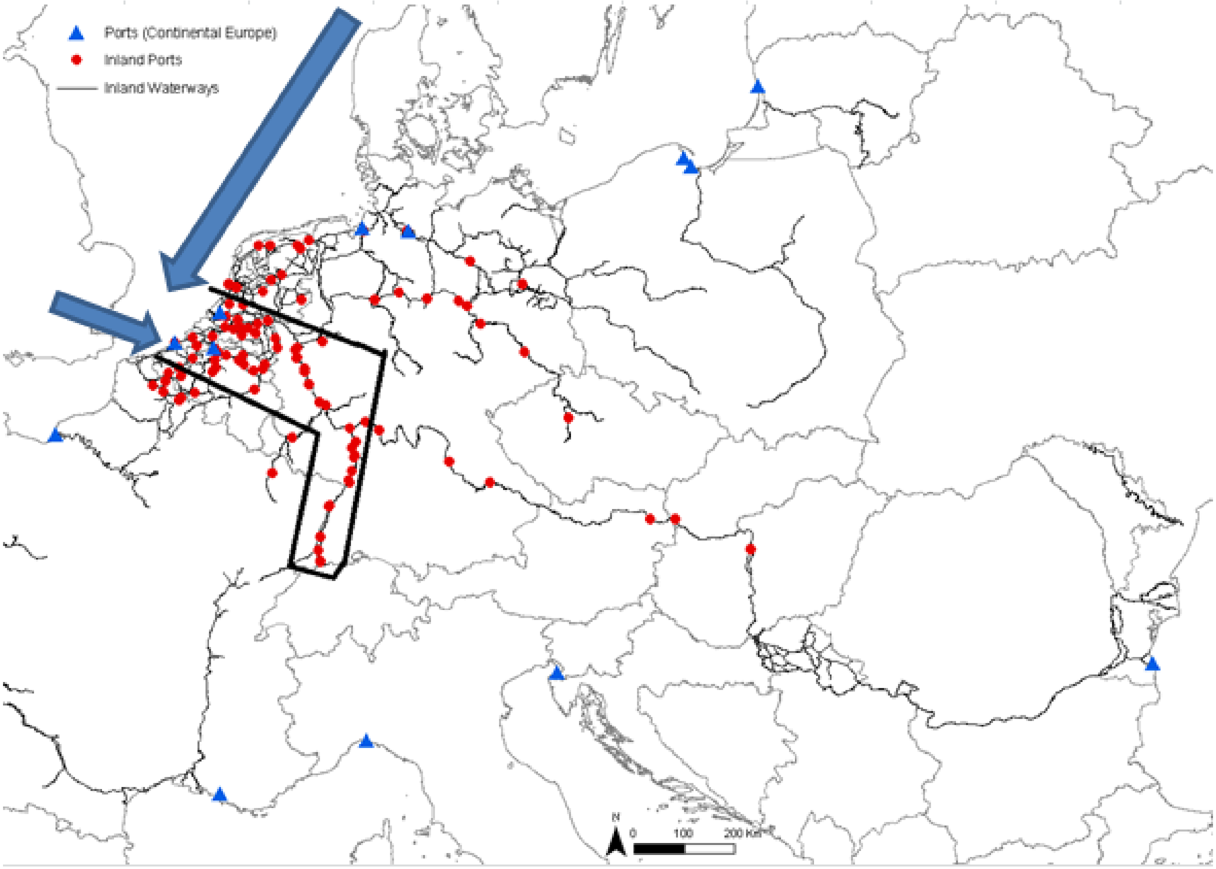


Figure 38: Geographical scope of the Antwerp case

Firstly, a review of different models and data sources is made. The main purpose is to select the most suitable data source. Secondly, the developed OD matrix is given. Thirdly, also a first rough sketch of a potential second case study area should be developed.

Review of existing methods/ data sources to set up the OD matrix

In this section, an overview is given of existing methods, data sources and models which can be used to develop the needed OD matrix for the Antwerp case.

EUROSTAT

Eurostat gives a lot of data related to different EU countries. Also at port level, there is a lot of information available. But there is, to our knowledge, no comprehensive data set of cargo flows data from specific origins to specific destinations. Therefore, EUROSTAT is not very suitable for the construction of the OD matrix.

TRANS-TOOLS 3

The objective of the TRANS-TOOLS3 project is to upgrade and further develop the current TRANS-TOOLS model to a new and improved European transport network model. The mission is to improve the methodological basis of the model, improve and validate its data foundation, deal with known deficiencies of the existing model, make the software more efficient, and focus on the user needs, model documentation and model validation.

With the model based on the tool-box approach from prior versions of the model, which ensures that the model can address the needs of many different types of users:

- Analyses of EU-wide transport policies.
- Analyses of TEN-T-projects.
- Detailed EU-wide sector analyses including freight, passenger transport and specific modes.
- Links to interregional and national project appraisals and use within the member states.

The model will be updated to the 2010 base year based upon ETISplus (see point 4) data and other data sources. The level of detail with regard to the rail, maritime and air transport modules will be increased. (TRANSTOOLS3 , 2017)

In TRANS-TOOLS3, for the base year, both the PC matrices and the OD matrices (for road, rail, inland waterways and sea transport) come from the ETISplus project. Matrices were delivered at both the NUTS2 and the NUTS3 levels, the former being the result of harmonizing available data whereas the latter were created synthetically by ETISplus. With respect to IWW, matrices in TRANS-TOOLS3 are based on ETISplus matrices. These matrices were constructed from NUTS2 data and further detailed at the NUST3 level by a synthetic disaggregated procedure. (Nielsen et al, 2015)

5.1.1 TRIMODE

The TRIMODE Consortium is developing an integrated transport model for passenger and goods transport in Europe. Core of the TRIMODE model will be a network and assignment model considering all modes in Europe as well as their interconnection with intercontinental transport. Spatial disaggregation is at NUTS3 level. An economic model of each European country as well as of other world regions will be coupled with the transport model. Models of vehicle fleets will enable to describe the diffusion of new technologies as well as the estimation of transport energy demand and emissions. (M-Five, 2017)

5.1.2 ETIS+

In the EU funded ETIS and ETIS+ projects, a large comprehensive database was built upon data of EUROSTAT and complemented with data from other national or international databases. The main purpose of starting the ETIS+ project was the on-going requirement by DG MOVE for good quality input data to support models, evaluation methodologies and indicator frameworks. Without information integration, DG MOVE lacks a consistent transport data source, and encounters problems of data interpretation arising from the heterogeneous methodologies associated with the available data sources. This is a fundamental and widespread problem, requiring effort and innovation in terms of knowledge management as well as data collection, storage and retrieval. This has led to the concept of a common database to be used by modellers and policy makers, as first implemented through the framework project ETIS in 2005. ETIS is a European Transport policy information system, combining data, analytical modelling with maps (GIS), and a single interface for accessing the data. It aims therefore to provide a bridge between official statistics and application within the transport policy theme. (ETIS, 2013)

In the database, it is possible to determine some OD flows for IWT transport at NUTS2 level, while the freight data is reported in NST07 (see Figure 39). In order to come to cargo flows of containerized cargo, several ratios need to be used to transform the NST07 data.

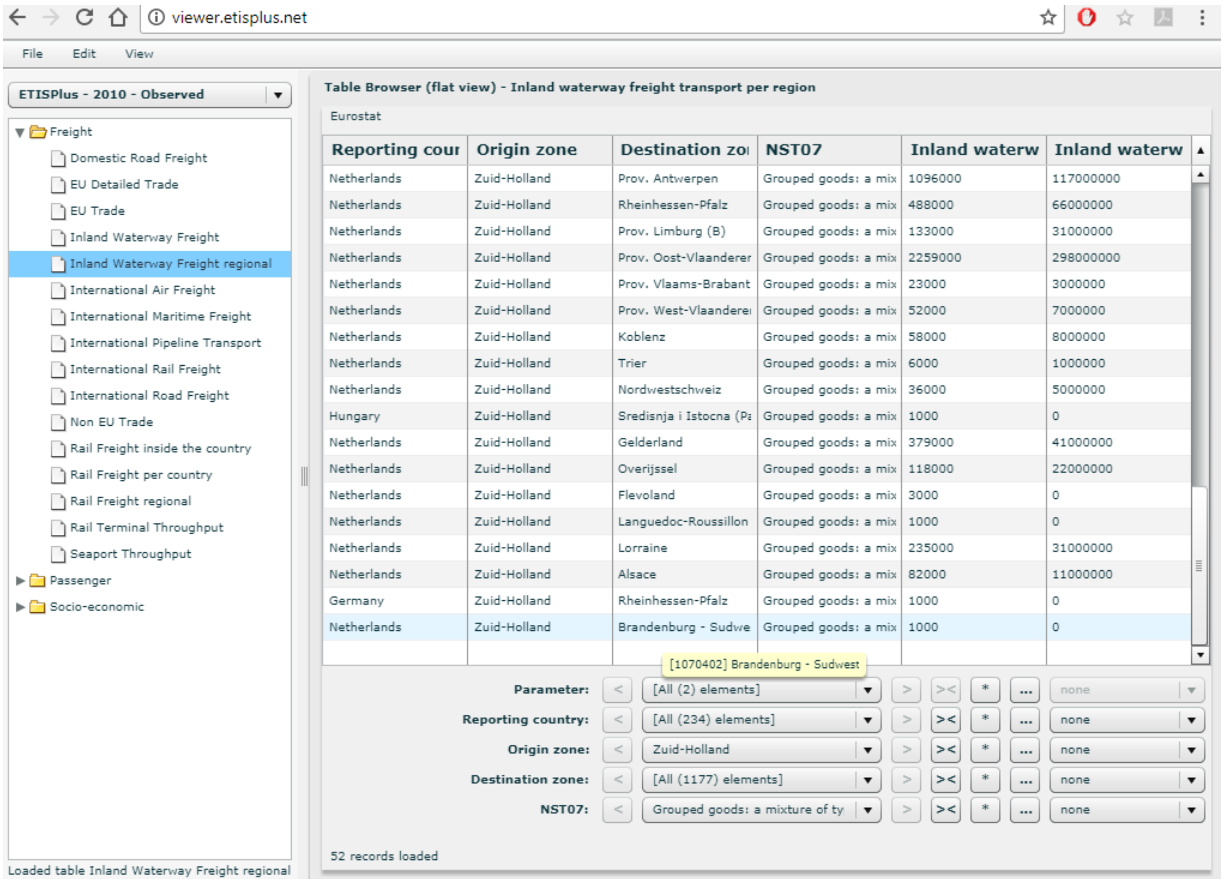


Figure 39: Screen shot of the ETIS+ database ETIS+ (2017)

It needs to be mentioned that for link counts, observed data is used if link load statistics are available, and estimated/modelled data if only counts at locks are available (applicable for NL, part of DE and BE). (ETIS+, 2013b)

5.1.3 MDS Transmodal

MDS Transmodal is a consultancy which provides analysis and advice on strategic, commercial and economic issues mainly related to freight transport and logistics. There work is based on the development and maintenance of a unique and comprehensive set of databases and transport models as well as the expertise of their consultants. (MDS, 2017)

The company has trade data available, including container and RoRo shipping but excluding IWT transport. Also, they have a strong focus on the UK.

5.1.4 Prognos

Prognos is an interdisciplinary research consultancy firm with, among other research/expertise fields, a strong level of expertise in transport and infrastructure. Their work focuses on analysing and forecasting the requirement for goods and passenger transport, associated with questions of meeting long-term demand through pre-existing or planned system capacities, networks and transport routes.

In all areas of infrastructure, Prognos bases its work on extensive databases and forecast models that undergo continuous further development to reflect a wide range of variables for the investigation parameters. Its results provide public and private decision makers with sound bases for taking decisions on investments and strategic processes. (Prognos, 2017)

5.1.5 Unece

The United Nations Economic Commission for Europe (UNECE) is one of the five United Nations regional commissions, administered by the Economic and Social Council (ECOSOC). In UNECE, there is the UNECE Sustainable Transport Division which has the secretariat of the Inland Transport Committee (ITC). ITC publishes a yearly report about inland freight statistics in Europe (including road, rail, IWT and pipeline). (UNECE,2017)

The statistics in the publication are compiled by the secretariat of UNECE on the basis of replies to questionnaires submitted by member States and from official national and international sources. To collect transport statistics, the Sustainable Transport Division in coordination with Eurostat and the International Transport Forum (ITF) administers a Web Common Questionnaire website where designated country contacts from national statistics offices may send available transport data. The countries are requested to provide the latest available statistics. For this publication, an additional questionnaire was sent by email to member States to ensure that the data was as recent as possible. The data provided here are exclusively official data provided by national authorities and have been reviewed by the secretariat, but not independently verified. Missing data have either not been provided or do not exist. (UNECE,2017)

5.1.6 ITF/OECD

The International Transport Forum at the OECD is an intergovernmental organisation with 59 member countries. It acts as a think tank for transport policy and organises the Annual Summit of transport ministers. ITF is the only global body that covers all transport modes. The ITF is administratively integrated with the OECD, yet politically autonomous. (ITF, 2017)

ITF provides also a freight transport statistics which can be used by the different OECD member states.

5.1.7 ASTRA MODEL

If a complete set of cargo flow data is needed, the ASTRA model can be used. The ASTRA (ASsessment of TRAnsport Strategies) model is a system dynamics model at the European scale developed since 1997 by three partners (Fraunhofer-ISI, IWW Karlsruhe and TRT Trasporti e Territorio) for the strategic assessment of policy scenarios, taking into account feedback loops between the transport system and the economic system. The ASTRA model consists of eight inter-linked modules. For a detailed description of the ASTRA structure, see Schade (2005). (Fiorello et al, 2010)

Astra gives the cargo flows for 10 NST freight categories at NUTS-2 level[1].

In the ASTRA model, the Regional Economics Module (REM), calculates the generation and distribution of freight transport volume. This freight transport is driven by two mechanisms (Schade & Krail, 2006):

- National transport depends on the sectoral production value of the 15 goods producing sectors where the monetary output of the input output table calculations are transferred into volume of tons by means of value-to volume ratios.
- International freight transport i.e. freight transport flows that are crossing national borders are generated from monetary intra-European trade flows of the 15 goods producing sectors. Again, transfer into volume of tons is performed by applying value-to-volume ratios that are different from the ones applied for national transport. In that sense, the export model provides generation and distribution of international transport flows within one step on the basis of monetary flows.

This makes that the transport volumes are not observed but are calculated values.

Overview of the main data sources

Table 9 gives an overview of the reviewed data sources.

Table 9: Overview of the main data sources (1)

	1	2	3	4
Data source	EUROSTAT	TRANS-TOOLS 3	TRIMODE	ETIS/ETiS++
O-D data?	No	Yes	?[2]	Yes

[1] The Nomenclature of territorial units for statistics, abbreviated NUTS (from the French version Nomenclature des Unités Territoriales Statistiques) is a geographical nomenclature subdividing the economic territory of the European Union (EU) into regions at three different levels (NUTS 1, 2 and 3 respectively, moving from larger to smaller territorial units). Above NUTS 1, there is the 'national' level of the Member States. (EC, 2017)

[2] ? = no data available

Level of detail of regions	NUTS2	Mostly NUTS3, some raw data NUTS2	?	Countries
Scope of transport data	EU	EU (worldwide import/export to EU)	EU	EU (export worldwide)
Type of data (TEU or tonne)	TEU/tonne	TEU/tonne	?	tonne
Modes of transport			Work in progress so unkown to public	
IWT	Yes	Yes		
Rail	Yes	Yes		Yes
Road	Yes	Yes		Yes
Sea-River	?	?		Yes
Short Sea Shipping				
Containers	Yes	Yes		?
RoRo vessels	Yes	Yes, for access contact Thomas Ross Pedersen [ross @dtu.dk]		No
Data freely available	Yes	Yes	European Commission will decide it in 2019	Yes
Link to data	http://ec.europa.eu/eurostat	http://www.transportmodel.eu/	http://www.trt.it/en/PROGETTI/trimode_project/	http://viewer.etisplus.net/

Table 9: Overview of the main data sources (continued)

	5	6	7	8	9
Data source	MDS Transmodel	Prognos	Unece	ASTRA	ITF/OECD
O-D data?				Yes	
Level of detail of regions				NUTS-2 level	
Scope of transport data				EU	
Type of data (TEU or tonne)				tonne	
Modes of transport					
IWT				Yes	
Rail				Yes	

Road Sea-River Short Sea Shipping Containers RoRo vessels				Yes Yes No Yes	
Data freely available		NO		n.a.	
Link to data	http://www.mdst.co.uk/		https://www.unece.org/fileadmin/DAM/trans/main/wp6/publications/2017_INLAND_TRANSPORT_STATISTICS.pdf	http://www.astra-model.eu/structure-overview.htm	https://www.itf-oecd.org/search/statistics-and-data?f%25255B0%25255D=field_publication_type%3A648&f%5B0%5D=field_publication_type%3A648

Expert insights on selected cargo flows

Besides the theoretical models, which contain cargo flow data, also “real” cargo flow data can be obtained from, for instance:

- Transport companies
- Logistics service providers
- Freight forwarders
- Etc.

These experts can provide detailed insights on certain cargo flows, while the models provide a more aggregate overview. Therefore, the role of these experts is twofold:

- To validate if the constructed OD matrix is in line with their expertise.
- To provide detailed insights at a much more disaggregate level than the freight models

The main project partners that can contribute to this task are:

- **Van Moer Groep**
- **Marlo**
- **Duisburg Port**
- **Touax**
- **Plimsoll (mainly for the Danube case and not for ”the Antwerp case”)**

Each organization will provide an overview of the data that is available for the Antwerp case, as indicated in Figure 38.

Main observations:

There are no observed OD databases in Europe available. There are several synthetic (calculated) OD matrices available from different EU freight model projects. The main purpose of the synthetic OD matrices is to identify the main cargo flows. Because data from the ASTRA-model are available, this OD matrix is used for the Antwerp case. For further detailed cargo flows, in order to make a micro assessment, use will be made of the detailed cargo flow information of the different expert insights.

Main OD matrix of the Antwerp case

After the review of the different data sources, the conclusion can be made that it is very difficult to obtain a complete and detailed OD matrix containing real observed cargo flow data. This leads to the conclusion that there are two levels of detail with respect to the cargo flows:

- The aggregate cargo flows based on freight transport models with a synthetic OD matrix (ASTRA)
- Disaggregate cargo flow data which can be obtained from expert insights and knowledge

For a concrete case study, detailed cargo flows at micro level are needed to perform the necessary transport economics analysis especially for the assessment of cargo flows going to and from urban areas. For the main cargo flows going to and from the Rhine region, more disaggregated cargo flow data can be used. For the cargo flows going from Antwerp region to the German hinterland (Rhine transport) a more disaggregate level of data can be used.

So for the Antwerp case, two levels of detailed cargo flows can be used. Disaggregate for those flows in a close proximity to the port of Antwerp, where the waterway network is much more fine than in the Rhine region. Also there are much more variations in the waterway infrastructure (CEMT II to CEMT VI waterways) including different types of locks, tide and interactions with sea going vessels (port of Antwerp area). Therefore a more disaggregate cargo flow distribution need to be used in the proximity of the port of Antwerp and a more aggregate cargo flow distribution can be used in the Rhine region.

With respect to the setup of the aggregated OD matrix, the following elements need to be taken into account:

- **Variables:**
  - Detailed cargo flows in tonnes and/or TEU equivalents at micro level for the cargo flows close to the Port of Antwerp.
  - Cargo flows of unitized cargo in tonnes and/or TEU equivalents, preferably at NUTS2 level for all regions around the Rhine for continental cargo flows.
  - Country-level data for short-sea cargo flows.

- **Data:**
  - Cargo flow data
  - Land flows (including IWT, Road, Rail)
  - Short sea data flows (containers and RoRo (if possible))

In the analysis, containers (unitised) cargo flows in tonnes (which can be converted to loaded containers) are taken from the ASTRA model.

The “Antwerp case” corresponds with the Rhine Alpine corridor which is built up from the following NUTS-2 regions:

- BE25 (Zeebruges), BE23 (Ghent), BE21 (Antwerp), BE22, BE24, BE10 (Brussels) and BE33
- NL34, NL33 (Rotterdam), NL32 (Amsterdam), NL31,NL22, NL41 and NL42
- DEA1 and DEA2 (NRW)
- DEB1, DEB3, DE71, DE12 and DE13 (South-West Germany)
- CH03 (Basel, Switzerland)

The different NUTS-2 regions are plotted in the map in Figure 40.

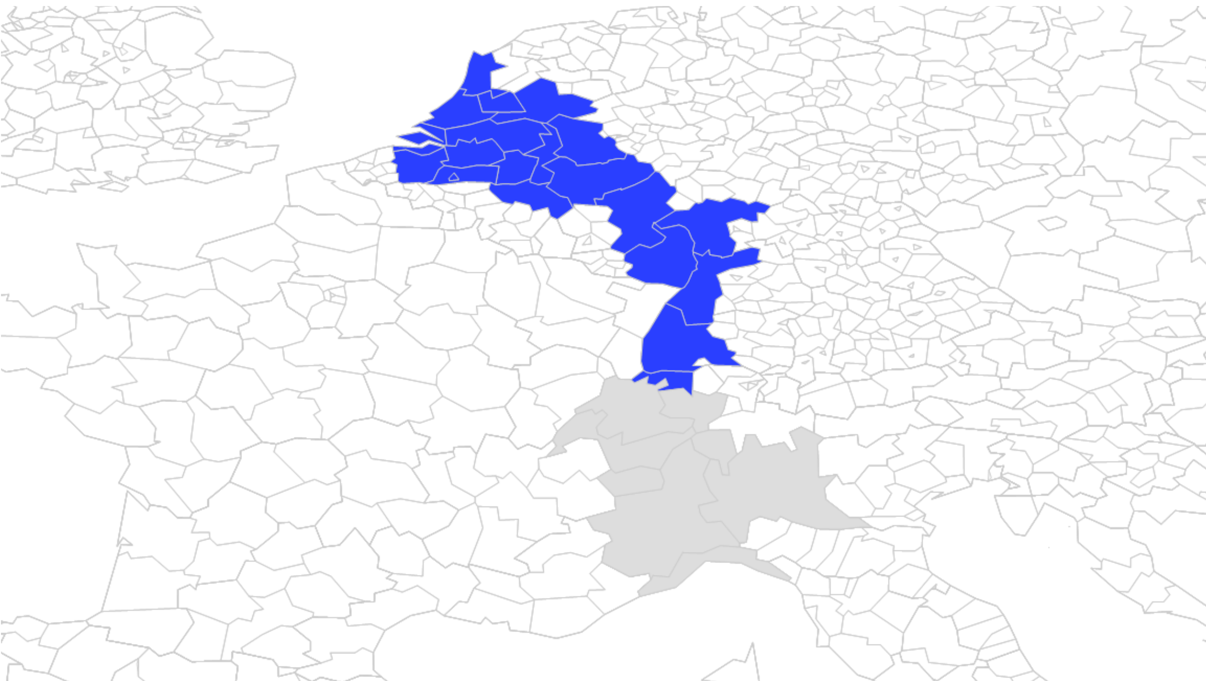


Figure 40: Overview of the geographical regions included in the Antwerp case (IWT flows)

5.1.8 Land transport cargo flow data

In total, the OD matrix is a 22 by 22 matrix, as shown in Table 10. This matrix gives the cargo flows between the different NUTS-2 regions for IWT transport. The data is for the base year 2010, but also data future cargo flows in 2020 and 2030 are available[3].

Table 11 gives the data for rail transport, while Table 12 presents the road data.

[3] In the data, no containerized IWT cargo flows are found to and from Brussels

All figures feature both the volumes in tonnes of containerized cargo and the volumes in loaded containers (10 tonnes per TEU).

Table 13 presents the modal share of IWT per OD-pair for the considered transport corridor. From this figure, those OD pairs can be observed which have an IWT share higher then 40%. Those OD pairs can be the starting point of testing the VT concept.

Most of these cargo flows have an origin or destination at either:

- Port of Antwerp
- Port of Rotterdam
- Port of Amsterdam
- Port of Duisburg

Table 10: IWT cargo flows at NUTS2 level in tonnes (left) and TEU (right)

IWT	BE25	BE23	BE21	BE22	BE24	BE10	BE33	NL34	NL33	NL32	NL31	NL22	NL41	NL42	DEA1	DEA2	DEB1	DEB3	DE71	DE12	DE13	CH03
BE25	22,025	13,706	732,313	2,022	3,593	-	1,736	20,022	50,046	7,602	7,795	1,361	8,003	1,110	19,561	-	1,190	204	-	75	75	-
BE23	322,348	115,548	250,206	13,063	111	-	71,557	205,258	315,143	149,409	96,147	60,404	124,179	46,115	41,040	2,403	1,064	15,016	9,953	15,158	-	29,381
BE21	1,187,169	343,508	3,070,884	145,162	70,088	-	268,764	578,018	7,072,341	2,402,929	258,349	91,086	820,546	284,342	594,013	133,790	102,971	698,993	63,650	210,187	22,272	197,560
BE22	4,060	12,794	305,571	79,202	494	-	11,881	28,770	96,857	16,417	12,603	31,255	115,276	66,188	-	-	-	5,286	5,021	529	-	5,514
BE24	1,014	8,437	-	1,545	-	-	-	21,737	15,525	571	-	-	51,574	-	5,814	-	-	-	-	-	-	-
BE10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BE33	41,527	171,700	487,789	147,239	18,567	-	203,967	123,885	54,473	109,127	1,163	39,993	86,350	87,074	6,739	-	-	949	-	75	-	265
NL34	293,935	1,118,143	599,583	140,394	38,150	-	73,290	718,743	575,372	38,054	56,977	116,432	230,301	10,772	84,237	4,992	-	10,064	70	6,326	6,664	124,972
NL33	505,588	1,652,461	9,798,243	258,888	116,339	-	794,647	331,861	164,284	740,326	312,602	507,869	1,036,495	383,745	2,507,053	211,597	57,836	1,043,596	120,866	82,506	11,995	878,739
NL32	346,265	373,818	1,066,031	125,047	16,005	-	128,059	56,026	1,244,954	1,134,532	196,340	792,183	884,237	148,201	429,917	30,810	25,510	71,153	52,793	203,646	13,822	820,435
NL31	15,965	7,099	12,194	21,809	501	-	12,382	11,237	783,150	47,800	25,675	176,017	58,302	2,847	4,513	-	-	-	-	-	4,080	1,902
NL22	18,090	14,493	69,015	759	1,134	-	4,707	37,944	334,361	214,555	104,736	229,641	176,804	54,604	2,565	1,287	652	45,343	24,620	14	12,820	7,086
NL41	23,060	95,573	641,209	43,420	5,765	-	24,634	67,724	1,352,733	105,390	260,853	243,178	505,560	101,736	1,318	42,707	29,536	79,556	246	14,735	18,298	31,655
NL42	30,699	201,539	544,401	209,462	6,121	-	137,680	44,755	577,001	72,644	106,758	191,619	399,587	147,043	1,434	6,356	-	6,441	-	412	5,100	7,086
DEA1	140,402	48,532	1,491,138	34,096	9,627	-	41,499	84,375	1,508,570	341,201	23,821	330,924	453,312	61,838	357,933	5,612	43,920	4,210	33,607	7,574	1,858	4,963
DEA2	2,089	371	242,356	-	-	-	-	49,860	162,676	1,910	-	101,167	914	-	33,345	1,862	1,238	16,130	-	2,045	31	1,053
DEB1	10,648	7,747	336,115	4,176	1,363	-	465	-	140,985	6,415	4,578	49,382	13,976	56,161	35,329	2,578	529	1,222	962	2,245	2,384	9,357
DEB3	4,712	5,110	729,655	183	-	-	-	-	340,498	523	-	13,668	10,581	4,554	27,117	1,167	8,237	255,956	260,023	159,161	2,593	7,267
DE71	465	12,008	60,499	232	-	-	2,914	-	197,850	3,047	-	2,360	47,081	1,176	30,290	381	11,078	21,072	-	1,686	778	-
DE12	5,749	24,918	275,313	3,275	-	-	7,139	27,223	53,536	10,757	134,632	88,752	42,120	-	32,823	11,360	5,159	30,892	116,986	160,693	14,002	8,785
DE13	232	15,666	104,739	1,125	-	-	-	22,414	226,800	93,692	35,418	101,174	311,691	15,294	17,806	698	7,512	17,500	156,718	29,278	22,921	34,764
CH03	247	621	272,365	-	-	-	-	1,097	180,862	16,036	2,107	1,296	20,034	1,994	4,060	1,262	6,208	17,064	1,489	2,123	3,134	-

IWT	BE25	BE23	BE21	BE22	BE24	BE10	BE33	NL34	NL33	NL32	NL31	NL22	NL41	NL42	DEA1	DEA2	DEB1	DEB3	DE71	DE12	DE13	CH03
BE25	2,203	1,371	73,231	202	359	-	174	2,002	5,005	760	780	136	800	111	1,956	-	119	20	-	8	8	-
BE23	32,235	11,555	25,021	1,306	11	-	7,156	20,526	31,514	14,941	9,615	6,040	12,418	4,611	4,104	240	106	1,502	995	1,516	-	2,938
BE21	118,717	34,351	307,088	14,516	7,009	-	26,876	57,802	707,234	240,293	25,835	9,109	82,055	28,434	59,401	13,379	10,297	69,899	6,365	21,019	2,227	19,756
BE22	406	1,279	30,557	7,920	49	-	1,188	2,877	9,686	1,642	1,260	3,125	11,528	6,619	-	-	-	529	502	53	-	551
BE24	101	844	-	154	-	-	-	2,174	1,552	57	-	-	5,157	-	581	-	-	-	-	-	-	-
BE10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BE33	4,153	17,170	48,779	14,724	1,857	-	20,397	12,389	5,447	10,913	116	3,999	8,635	8,707	674	-	-	95	-	8	-	26
NL34	29,393	111,814	59,958	14,039	3,815	-	7,329	71,874	57,537	3,805	5,698	11,643	23,030	1,077	8,424	499	-	1,006	7	633	666	12,497
NL33	50,559	165,246	979,824	25,889	11,634	-	79,465	33,186	16,428	74,033	31,260	50,787	103,650	38,374	250,705	21,160	5,784	104,360	12,087	8,251	1,200	87,874
NL32	34,626	37,382	106,603	12,505	1,601	-	12,806	5,603	124,495	113,453	19,634	79,218	88,424	14,820	42,992	3,081	2,551	7,115	5,279	20,365	1,382	82,043
NL31	1,597	710	1,219	2,181	50	-	1,238	1,124	78,315	4,780	2,567	17,602	5,830	285	451	-	-	-	-	-	408	190
NL22	1,809	1,449	6,901	76	113	-	471	3,794	33,436	21,455	10,474	22,964	17,680	5,460	256	129	65	4,534	2,462	1	1,282	709
NL41	2,306	9,557	64,121	4,342	576	-	2,463	6,772	135,273	10,539	26,085	24,318	50,556	10,174	132	4,271	2,954	7,956	25	1,473	1,830	3,166
NL42	3,070	20,154	54,440	20,946	612	-	13,768	4,476	57,700	7,264	10,676	19,162	39,959	14,704	143	636	-	644	-	41	510	709
DEA1	14,040	4,853	149,114	3,410	963	-	4,150	8,438	150,857	34,120	2,382	33,092	45,331	6,184	35,793	561	4,392	421	3,361	757	186	496
DEA2	209	37	24,236	-	-	-	-	4,986	16,268	191	-	10,117	91	-	3,334	186	124	1,613	-	205	3	105
DEB1	1,065	775	33,611	418	136	-	46	-	14,098	641	458	4,938	1,398	5,616	3,533	258	53	122	96	225	238	936
DEB3	471	511	72,965	18	-	-	-	-	34,050	52	-	1,367	1,058	455	2,712	117	824	25,596	26,002	15,916	259	727
DE71	46	1,201	6,050	23	-	-	291	-	19,785	305	-	236	4,708	118	3,029	38	1,108	2,107	-	169	78	-
DE12	575	2,492	27,531	327	-	-	714	2,722	5,354	1,076	13,463	8,875	4,212	-	3,282	1,136	516	3,089	11,699	16,069	1,400	879
DE13	23	1,567	10,474	112	-	-	-	2,241	22,680	9,369	3,542	10,117	31,169	1,529	1,781	70	751	1,750	15,672	2,928	2,292	3,476
CH03	25	62	27,237	-	-	-	-	110	18,086	1,604	211	130	2,003	199	406	126	621	1,706	149	212	313	-

Table 11: Rail cargo flows at NUTS2 level in tonnes (left) and TEU (right)

Rail	BE25	BE23	BE21	BE22	BE24	BE10	BE33	NL34	NL33	NL32	NL31	NL22	NL41	NL42	DEA1	DEA2	DEB1	DEB3	DE71	DE12	DE13	CH03
BE25	10,546	4,628	580,235	-	502	648	-	-	-	-	-	-	-	-	74	3	-	-	-	5,150	-	53
BE23	11,191	-	16,300	-	-	-	-	25,122	-	-	-	-	-	-	4,871	6,448	962	1,426	2,057	4,541	736	691
BE21	1,328,786	25,877	1,336,981	336,700	2,715	6,914	84,422	675	32,951	190	18	-	17,196	2,625	78,906	46,406	619	69,553	20,819	7,088	9,977	98,640
BE22	28,796	50,360	32,164	1,742	235	5,773	5,343	-	-	-	-	-	-	-	1,788	2,702	1,998	175	-	-	-	-
BE24	2,638	434	1,244	567	286	3,252	-	-	-	-	-	-	-	-	-	0	-	-	80	-	-	-
BE10	8,497	6,615	9,307	1,460	2,874	6,223	2,829	-	-	-	-	-	-	39	95	181	-	-	-	-	-	-
BE33	2,557	-	142,093	9,363	2,044	1,778	1,668,714	-	-	-	-	-	-	-	30,544	1,482	1,306	-	0	-	-	-
NL34	-	10	-	-	-	-	-	-	10	-	-	-	61	476	8,334	2,784	60	1,351	2,801	-	-	-
NL33	-	-	15,562	-	-	-	-	-	2,393	300	598	-	224,200	204,012	258,017	10,964	372	87,926	59,350	56,083	2,855	11,302
NL32	-	-	-	-	-	-	-	-	48	74,051	25	482	-	1,058	177,480	1,694	188	1,622	-	6,535	366	52
NL31	-	-	-	-	-	-	-	-	179	564	-	-	-	-	-	-	-	-	-	-	-	-
NL22	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-
NL41	-	-	350	-	-	-	-	-	175,504	10	66	-	112,382	-	-	-	-	-	-	-	-	-
NL42	-	-	4	-	-	-	-	-	671,256	-	-	-	17,728	39,691	-	-	-	-	-	-	-	-
DEA1	2,265	-	26,073	-	18	2,308	2,257	405	94,235	72,462	-	-	-	-	-	465,704	131,366	-	-	-	4,345	77,085
DEA2	50	-	14,046	2,340	-	-	62	4,226	44,864	3,271	-	-	-	-	210,652	959,412	5,103	9,278	28,848	10,547	41,747	19,867
DEB1	-	-	1,322	87	-	-	2	-	1,244	-	-	-	-	-	8,933	12,427	8,819	-	10,694	-	-	-
DEB3	-	-	17,175	-	-	-	-	-	118,924	-	-	-	-	-	-	5,107	-	-	41,111	38,585	3,816	8,002
DE71	4,139	-	10,089	-	-	-	-	7	-	-	-	-	-	-	-	41,862	-	5,262	32,697	-	4,105	502
DE12	4,148	-	8	-	-	-	-	-	35,184	-	-	-	-	-	-	2,685	-	-	7,479	9,013	30,059	20,232
DE13	327	-	50	-	-	-	-	-	31,747	-	-	-	-	-	-	-	-	820	-	-	-	-
CH03	-	-	44,175	-	-	-	-	-	20,979	-	-	-	-	-	2,957	2,592	-	719	327	-	6,260	199,146

Rail	BE25	BE23	BE21	BE22	BE24	BE10	BE33	NL34	NL33	NL32	NL31	NL22	NL41	NL42	DEA1	DEA2	DEB1	DEB3	DE71	DE12	DE13	CH03
BE25	1,055	463	58,023	-	50	65	-	-	-	-	-	-	-	-	7	0	-	-	-	515	-	5
BE23	1,119	-	1,630	-	-	-	-	2,512	-	-	-	-	-	-	487	645	96	143	206	454	74	69
BE21	132,879	2,588	133,698	33,670	272	691	8,442	68	3,295	19	2	-	1,720	262	7,891	4,641	62	6,955	2,082	709	998	9,864
BE22	2,880	5,036	3,216	174	24	577	534	-	-	-	-	-	-	-	179	270	200	17	-	-	-	-
BE24	264	43	124	57	29	325	-	-	-	-	-	-	-	-	-	0	-	-	8	-	-	-
BE10	850	661	931	146	287	622	283	-	-	-	-	-	-	4	10	18	-	-	-	-	-	-
BE33	256	-	14,209	936	204	178	166,871	-	-	-	-	-	-	-	3,054	148	131	-	0	-	-	-
NL34	-	1	-	-	-	-	-	-	1	-	-	-	6	48	833	278	6	135	280	-	-	-
NL33	-	-	1,556	-	-	-	-	-	239	30	60	-	22,420	20,401	25,802	1,096	37	8,793	5,935	5,608	285	1,130
NL32	-	-	-	-	-	-	-	-	5	7,405	2	48	-	106	17,748	169	19	162	-	654	37	5
NL31	-	-	-	-	-	-	-	-	18	56	-	-	-	-	-	-	-	-	-	-	-	-
NL22	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-	-	-	-
NL41	-	-	35	-	-	-	-	-	17,550	1	7	-	11,238	-	-	-	-	-	-	-	-	-
NL42	-	-	0	-	-	-	-	-	67,126	-	-	-	1,773	3,969	-	-	-	-	-	-	-	-
DEA1	227	-	2,607	-	2	231	226	40	9,423	7,246	-	-	-	-	-	46,570	13,137	-	-	-	435	7,709
DEA2	5	-	1,405	234	-	-	6	423	4,486	327	-	-	-	-	21,065	95,941	510	928	2,885	1,055	4,175	1,987
DEB1	-	-	132	9	-	-	0	-	124	-	-	-	-	-	893	1,243	882	-	1,069	-	-	-
DEB3	-	-	1,717	-	-	-	-	-	11,892	-	-	-	-	-	-	511	-	-	4,111	3,858	382	800
DE71	414	-	1,009	-	-	-	-	1	-	-	-	-	-	-	-	4,186	-	526	3,270	-	410	50
DE12	415	-	1	-	-	-	-	-	3,518	-	-	-	-	-	-	269	-	-	748	901	3,006	2,023
DE13	33	-	5	-	-	-	-	-	3,175	-	-	-	-	-	-	-	-	82	-	-	-	-
CH03	-	-	4,418	-	-	-	-	-	2,098	-	-	-	-	-	296	259	-	72	33	-	626	19,915

Table 12: Road cargo flows at NUTS2 level in tonnes (left) and TEU (right)

Road	BE25	BE23	BE21	BE22	BE24	BE10	BE33	NL34	NL33	NL32	NL31	NL22	NL41	NL42	DEA1	DEA2	DEB1	DEB3	DE71	DE12	DE13	CH03
BE25	9,252,446	1,978,697	1,028,607	261,452	494,009	220,803	447,546	49,411	220,887	71,350	48,864	174,774	273,274	173,597	92,702	90,749	18,450	14,290	25,630	28,666	30,075	3,720
BE23	2,578,187	9,278,299	2,388,400	386,487	893,639	135,225	404,192	60,057	260,772	81,938	57,112	193,579	317,574	191,881	114,918	115,723	22,681	17,705	33,305	38,629	37,716	3,553
BE21	1,275,197	2,314,593	12,298,628	1,304,360	1,802,066	295,543	489,132	94,079	499,878	148,410	106,837	350,034	564,513	346,649	205,128	200,752	41,854	33,290	65,619	65,863	67,809	9,031
BE22	418,552	478,717	1,730,014	4,529,822	690,656	76,374	292,562	35,495	172,363	54,019	37,277	129,432	197,193	136,810	82,081	83,773	18,190	12,427	23,568	25,831	28,018	2,618
BE24	478,620	1,053,105	1,577,429	319,026	373,236	689,905	423,637	15,690	80,351	24,940	17,584	63,731	101,367	60,710	36,260	34,682	7,028	5,284	10,263	10,966	11,438	1,340
BE10	75,975	78,438	149,594	20,407	373,236	357,028	25,023	4,340	18,178	5,663	3,983	11,910	19,694	13,423	9,695	10,153	2,372	1,514	2,624	2,505	2,491	200
BE33	496,866	452,545	479,244	488,008	289,930	84,612	2,553,596	33,478	148,822	49,760	34,112	119,031	187,499	123,665	79,975	80,370	17,142	15,379	22,196	25,529	27,895	2,388
NL34	91,193	70,923	156,940	61,188	37,386	13,388	43,904	2,052,382	663,231	271,599	189,541	22,613	622,314	25,028	91,176	70,430	13,965	12,784	18,530	22,477	24,062	2,672
NL33	402,076	357,781	836,891	287,794	190,578	57,503	205,931	741,453	25,990,118	3,566,119	1,435,887	1,794,492	3,488,332	723,098	386,883	311,253	67,939	75,099	106,253	104,846	113,316	16,785
NL32	130,551	113,396	258,706	99,310	61,536	20,506	70,236	135,645	2,981,128	12,287,735	952,860	779,365	1,094,630	312,072	122,166	97,297	20,941	17,575	30,389	31,418	34,736	4,675
NL31	57,556	52,109	117,035	42,781	28,208	9,139	31,919	51,447	1,561,003	1,144,752	5,481,166	1,337,957	788,782	134,668	58,658	48,495	10,639	9,235	15,805	15,907	17,287	2,324
NL22	199,747	171,990	387,914	145,931	97,764	31,913	112,201	73,904	2,087,030	1,127,605	1,419,421	13,532,561	2,485,146	626,298	221,756	177,092	38,101	31,884	56,676	58,210	65,596	7,911
NL41	364,687	327,120	711,250	264,257	170,974	56,811	205,574	1,008,746	4,274,891	1,728,345	899,347	2,792,856	23,129,740	2,225,830	392,069	322,750	66,319	64,703	97,522	105,254	113,137	13,456
NL42	219,132	184,426	419,823	163,052	100,528	33,453	118,403	61,596	683,454	293,626	153,481	642,623	2,393,248	7,380,036	257,800	217,971	45,354	38,807	63,636	70,034	75,359	8,229
DEA1	127,684	139,579	296,142	134,618	67,063	24,650	94,700	90,752	430,001	137,791	97,416	384,041	555,242	423,297	27,359,481	6,148,063	744,444	62,374	203,675	29,507	2,767	68,010
DEA2	112,404	118,950	258,525	115,882	57,738	21,777	79,859	55,898	269,004	84,450	62,333	231,174	349,563	289,795	5,687,417	22,653,325	1,676,954	173,458	418,377	63,629	6,086	54,308
DEB1	26,605	30,035	61,567	30,527	14,490	5,599	21,051	16,476	74,387	23,836	17,661	64,422	93,600	79,411	748,433	1,943,528	9,157,157	1,043,498	1,575,472	315,537	29,751	20,263
DEB3	17,697	16,710	43,332	16,121	8,433	3,453	13,871	9,395	52,785	14,523	12,364	41,395	64,553	51,607	41,248	142,320	896,589	8,998,954	2,911,785	2,958,689	444,976	20,170
DE71	22,978	26,075	57,213	23,458	12,876	4,269	15,772	11,430	65,158	18,521	15,133	50,453	76,107	57,172	111,900	341,964	1,195,792	2,587,735	16,808,958	2,245,205	206,286	22,153
DE12	37,406	42,266	87,160	34,963	18,772	6,497	26,725	16,318	88,755	26,355	21,016	74,809	114,662	84,607	11,342	39,874	229,723	3,213,928	2,166,116	14,013,787	1,744,087	40,542
DE13	43,411	48,553	102,308	42,826	21,344	7,378	32,939	19,476	99,122	29,944	22,939	86,067	124,697	96,196	497	2,194	13,326	296,536	125,666	1,478,449	14,859,526	95,915
CH03	6,976	7,841	16,131	4,838	4,048	1,070	3,298	1,320	8,038	1,928	1,563	5,087	7,948	5,090	41,890	37,803	10,542	10,920	19,192	24,634	38,680	8,928,890

Road	BE25	BE23	BE21	BE22	BE24	BE10	BE33	NL34	NL33	NL32	NL31	NL22	NL41	NL42	DEA1	DEA2	DEB1	DEB3	DE71	DE12	DE13	CH03
BE25	925,245	197,870	102,861	26,145	49,401	22,080	44,755	4,941	22,089	7,135	4,886	17,477	27,327	17,360	9,270	9,075	1,845	1,429	2,563	2,867	3,008	372
BE23	257,819	927,830	238,840	38,649	89,364	13,522	40,419	6,006	26,077	8,194	5,711	19,358	31,757	19,188	11,492	11,572	2,268	1,771	3,331	3,863	3,772	355
BE21	127,520	231,459	1,229,863	130,436	180,207	29,554	48,913	9,408	49,988	14,841	10,684	35,003	56,451	34,665	20,513	20,075	4,185	3,329	6,562	6,586	6,781	903
BE22	41,855	47,872	173,001	452,982	69,066	7,637	29,256	3,549	17,236	5,402	3,728	12,943	19,719	13,681	8,208	8,377	1,819	1,243	2,357	2,583	2,802	262
BE24	47,862	105,310	157,743	31,903	37,324	68,990	42,364	1,569	8,035	2,494	1,758	6,373	10,137	6,071	3,626	3,468	703	528	1,026	1,097	1,144	134
BE10	7,597	7,844	14,959	2,041	37,324	35,703	2,502	434	1,818	566	398	1,191	1,969	1,342	970	1,015	237	151	262	250	249	20
BE33	49,687	45,255	47,924	48,801	28,993	8,461	255,360	3,348	14,882	4,976	3,411	11,903	18,750	12,366	7,997	8,037	1,714	1,538	2,220	2,553	2,790	239
NL34	9,119	7,092	15,694	6,119	3,739	1,339	4,390	205,238	66,323	27,160	18,954	2,261	62,231	2,503	9,118	7,043	1,396	1,278	1,853	2,248	2,406	267
NL33	40,208	35,778	83,689	28,779	19,058	5,750	20,593	74,145	2,599,012	356,612	143,589	179,449	348,833	72,310	38,688	31,125	6,794	7,510	10,625	10,485	11,332	1,679
NL32	13,055	11,340	25,871	9,931	6,154	2,051	7,024	13,565	298,113	1,228,773	95,286	77,936	109,463	31,207	12,217	9,730	2,094	1,758	3,039	3,142	3,474	467
NL31	5,756	5,211	11,704	4,278	2,821	914	3,192	5,145	156,100	114,475	548,117	133,796	78,878	13,467	5,866	4,849	1,064	923	1,580	1,591	1,729	232
NL22	19,975	17,199	38,791	14,593	9,776	3,191	11,220	7,390	208,703	112,761	141,942	1,353,256	248,515	62,630	22,176	17,709	3,810	3,188	5,668	5,821	6,560	791
NL41	36,469	32,712	71,125	26,426	17,097	5,681	20,557	100,875	427,489	172,834	89,935	279,286	2,312,974	222,583	39,207	32,275	6,632	6,470	9,752	10,525	11,314	1,346
NL42	21,913	18,443	41,982	16,305	10,053	3,345	11,840	6,160	68,345	29,363	15,348	64,262	239,325	738,004	25,780	21,797	4,535	3,881	6,364	7,003	7,536	823
DEA1	12,768	13,958	29,614	13,462	6,706	2,465	9,470	9,075	43,000	13,779	9,742	38,404	55,524	42,330	2,735,948	614,806	74,444	6,237	20,367	2,951	277	6,801
DEA2	11,240	11,895	25,853	11,588	5,774	2,178	7,986	5,590	26,900	8,445	6,233	23,117	34,956	28,979	568,742	2,265,333	167,695	17,346	41,838	6,363	609	5,431
DEB1	2,661	3,004	6,157	3,053	1,449	560	2,105	1,648	7,439	2,384	1,766	6,442	9,360	7,941	74,843	194,353	915,716	104,350	157,547	31,554	2,975	2,026
DEB3	1,770	1,671	4,333	1,612	843	345	1,387	940	5,278	1,452	1,236	4,139	6,455	5,161	4,125	14,232	89,659	899,895	291,179	295,869	44,498	2,017
DE71	2,298	2,608	5,721	2,346	1,288	427	1,577	1,143	6,516	1,852	1,513	5,045	7,611	5,717	11,190	34,196	119,579	258,773	1,680,896	224,521	20,629	2,215
DE12	3,741	4,227	8,716	3,496	1,877	650	2,673	1,632	8,876	2,636	2,102	7,481	11,466	8,461	1,134	3,987	22,972	321,393	216,612	1,401,379	174,409	4,054
DE13	4,341	4,855	10,231	4,283	2,134	738	3,294	1,948	9,912	2,994	2,294	8,607	12,470	9,620	50	219	1,333	29,654	12,567	147,845	1,485,953	9,591
CH03	698	784	1,613	484	405	107	330	132	804	193	156	509	795	509	4,189	3,780	1,054	1,092	1,919	2,463	3,868	892,889

Table 13: IWT modal share on the considered NUTS2 cargo flows

IWT		Zeebrugge		ANT					VLIS	ROT	Amst					DUISP							
		BE25	BE23	BE21	BE22	BE24	BE10	BE33	NL34	NL33	NL32	NL31	NL22	NL41	NL42	DEA1	DEA2	DEB1	DEB3	DE71	DE12	DE13	CH03
Zeebrugge	BE25	0%	1%	31%	1%	1%	0%	0%	29%	18%	10%	14%	1%	3%	1%	17%	0%	6%	1%	0%	0%	0%	0%
	BE23	11%	1%	9%	3%	0%	0%	15%	71%	55%	65%	63%	24%	28%	19%	26%	2%	4%	44%	22%	26%	0%	87%
ANT	BE21	31%	13%	18%	8%	4%	0%	32%	86%	93%	94%	71%	21%	59%	45%	68%	35%	71%	87%	42%	74%	22%	65%
	BE22	1%	2%	15%	2%	0%	0%	4%	45%	36%	23%	25%	19%	37%	33%	0%	0%	0%	30%	18%	2%	0%	68%
	BE24	0%	1%	0%	0%	0%	0%	0%	58%	16%	2%	0%	0%	34%	0%	14%	0%	0%	0%	0%	0%	0%	0%
	BE10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	BE33	8%	28%	44%	23%	6%	0%	5%	79%	27%	69%	3%	25%	32%	41%	6%	0%	0%	6%	0%	0%	0%	10%
VLIS	NL34	76%	94%	79%	70%	51%	0%	63%	26%	46%	12%	23%	84%	27%	30%	46%	6%	0%	42%	0%	22%	22%	98%
ROT	NL33	56%	82%	92%	47%	38%	0%	79%	31%	1%	17%	18%	22%	22%	29%	80%	40%	46%	86%	42%	34%	9%	97%
Amst	NL32	73%	77%	80%	56%	21%	0%	65%	29%	29%	8%	17%	50%	45%	32%	59%	24%	55%	79%	63%	84%	28%	99%
	NL31	22%	12%	9%	34%	2%	0%	28%	18%	33%	4%	0%	12%	7%	2%	7%	0%	0%	0%	0%	0%	19%	45%
	NL22	8%	8%	15%	1%	1%	0%	4%	34%	14%	16%	7%	2%	7%	8%	1%	1%	2%	59%	30%	0%	16%	47%
	NL41	6%	23%	47%	14%	3%	0%	11%	6%	23%	6%	22%	8%	2%	4%	0%	12%	31%	55%	0%	12%	14%	70%
	NL42	12%	52%	56%	56%	6%	0%	54%	42%	30%	20%	41%	23%	14%	2%	1%	3%	0%	14%	0%	1%	6%	46%
DUISP	DEA1	52%	26%	82%	20%	13%	0%	30%	48%	74%	62%	20%	46%	45%	13%	1%	0%	5%	6%	14%	20%	21%	3%
	DEA2	2%	0%	47%	0%	0%	0%	0%	45%	34%	2%	0%	30%	0%	0%	1%	0%	0%	8%	0%	3%	0%	1%
	DEB1	29%	21%	84%	12%	9%	0%	2%	0%	65%	21%	21%	43%	13%	41%	4%	0%	0%	0%	0%	1%	7%	32%
	DEB3	21%	23%	92%	1%	0%	0%	0%	0%	66%	3%	0%	25%	14%	8%	40%	1%	1%	3%	8%	5%	1%	21%
	DE71	2%	32%	47%	1%	0%	0%	16%	0%	75%	14%	0%	4%	38%	2%	21%	0%	1%	1%	0%	0%	0%	0%
	DE12	12%	37%	76%	9%	0%	0%	21%	63%	30%	29%	86%	54%	27%	0%	74%	21%	2%	1%	5%	1%	1%	13%
	DE13	1%	24%	51%	3%	0%	0%	0%	54%	63%	76%	61%	54%	71%	14%	97%	24%	36%	6%	55%	2%	0%	27%
	CH03	3%	7%	82%	0%	0%	0%	0%	45%	86%	89%	57%	20%	72%	28%	8%	3%	37%	59%	7%	8%	7%	0%

The other intermediate regions are also interesting to be taken into account because they can be coupled to the main backbone of the VT which can be formed on these large cargo flows (see for the IWT cargo flow data Table 10).

5.1.9 Short sea shipping and sea river cargo flow data

For the Short Sea / RoRo traffic, with origin or destination in Europe, use could be made of data of the ASTRA model. Cargo flows which are transhipped in either Antwerp or Rotterdam and are transported with feeder vessels are not available in Astra. Here, another source is needed.

With respect to the short sea flows with an origin or destination in Europe two different cases are selected:

- UK
- Scandinavia

For both cases, the cargo flows from selected origins / destinations to the same NUTS-2 regions as for the land based transport flow matrix are used.

From the UK, the following regions are selected as origin/ destination: Greater London (including Dover and London Gateway), Liverpool (port), Southampton (port) and Immingham (RoRo port).

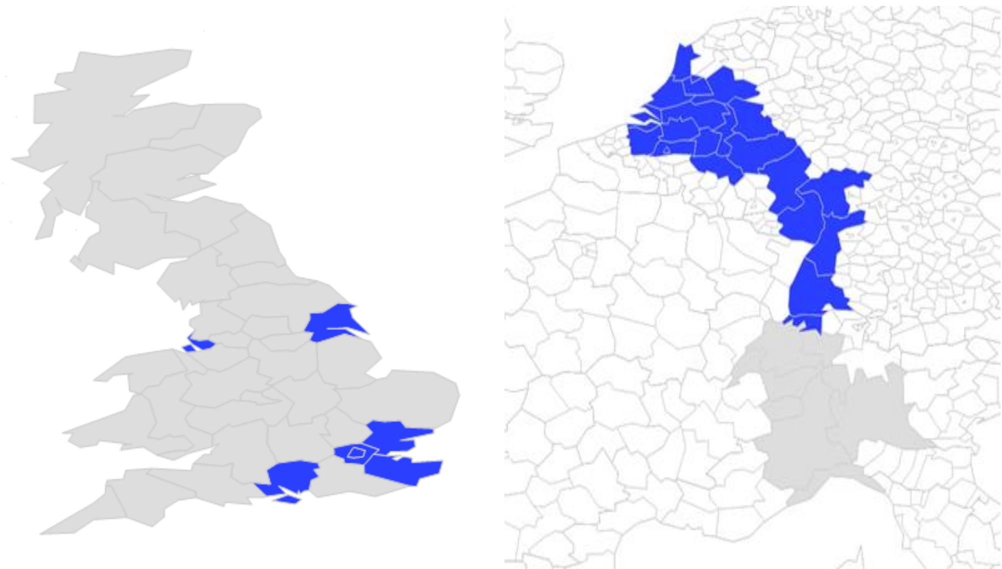


Figure 41: Origins / destinations between the UK and the EU mainland

For Scandinavia, the following regions are selected: Goteborg (port) and Stockholm. The regions of Bergen and Oslo are interesting to include, but no data for Norway is available in ASTRA.

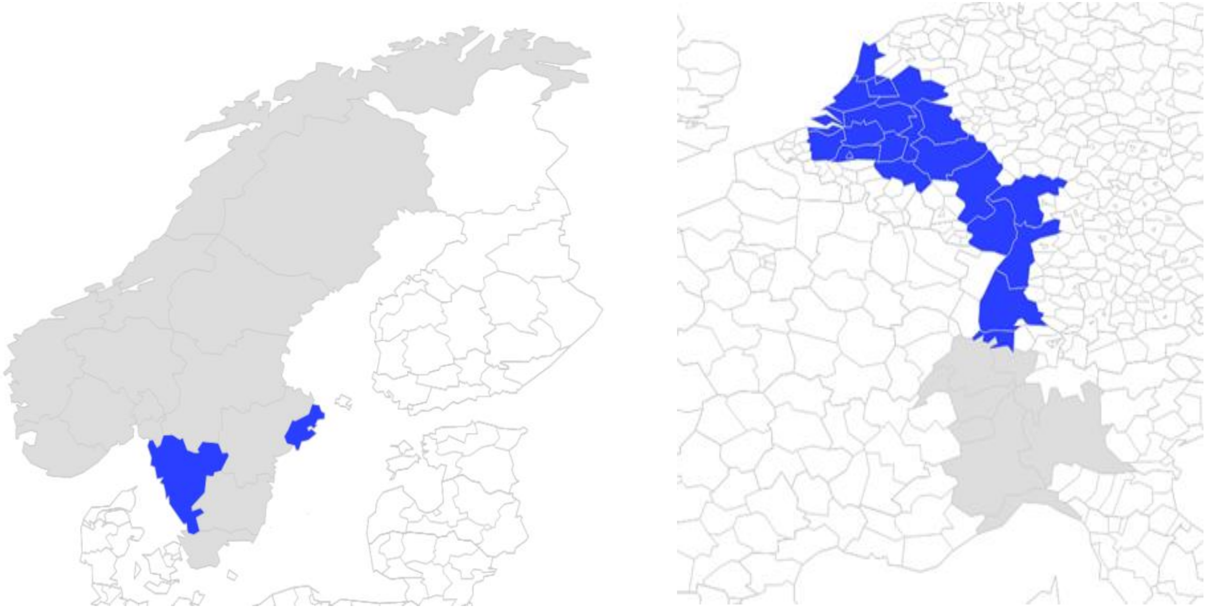


Figure 42: Origins / destinations from Scandinavia to EU mainland

Table 14: Selected UK regions to the EU main land cargo flows on NUTS2 level in tonnes (left) and TEU (right)

	Road	BE25	BE23	BE21	BE22	BE24	BE10	BE33	NL34	NL33	NL32	NL31	NL22	NL41	NL42	DEA1	DEA2	DEB1	DEB3	DE71	DE12	DE13	CH03
FROM	UKD5	332	4,787	1,719	2,088	953	2,548	1,116	1,810	638	805	3,162	407	3,061	1,852	1,283	1,307	211	147	497	548	617	97
	UKE1	992	14,166	5,103	7,229	2,829	7,437	3,531	4,556	1,517	2,063	6,794	1,086	7,577	4,654	4,042	4,341	681	561	1,487	1,893	1,941	386
	UKH3	870	12,180	4,539	5,554	2,368	6,067	3,029	4,032	1,452	2,022	6,312	885	6,798	4,179	3,570	3,681	651	530	1,360	1,614	1,815	293
London	UKI1	990	10,361	3,800	5,167	2,464	5,397	3,018	6,020	2,157	2,560	8,783	1,512	9,386	5,915	4,651	4,275	911	657	1,628	1,819	2,217	323
	UKI2	832	11,255	4,102	5,812	2,316	5,617	2,770	3,848	1,429	1,853	5,716	854	6,594	4,033	3,436	3,742	603	476	1,332	1,598	1,594	313
	UKj3	444	6,342	2,330	2,826	1,247	3,074	1,500	2,394	883	1,139	4,059	519	4,078	2,445	1,844	1,899	297	211	715	802	898	143
	UKJ4	2,243	31,161	11,504	15,423	6,220	16,571	8,070	9,580	3,136	4,475	13,156	2,168	15,559	9,808	8,878	9,551	1,795	1,490	3,346	4,295	4,725	786
TO	UKD5	134	6,894	2,005	2,906	1,024	2,670	1,800	1,720	535	1,311	3,772	751	3,168	1,798	2,437	1,947	386	284	538	829	1,100	121
	UKE1	195	9,564	2,874	5,019	1,608	4,226	2,825	2,762	809	1,932	5,894	1,420	5,178	3,013	4,742	4,224	796	566	1,043	1,988	2,185	215
	UKH3	337	16,418	4,747	7,699	2,383	6,392	4,408	3,678	1,170	2,920	7,853	1,512	7,005	3,901	6,699	6,116	1,234	972	1,699	2,843	3,198	392
London	UKI1	837	32,380	9,951	16,112	6,152	15,936	10,139	10,607	3,072	7,043	19,544	3,994	18,821	10,607	16,764	12,384	3,265	2,263	3,505	5,557	7,332	778
	UKI2	344	15,162	4,501	7,770	2,619	6,783	4,516	3,812	1,152	2,681	6,881	1,362	7,116	3,878	6,801	6,104	1,221	865	1,555	2,831	3,107	324
	UKj3	129	6,748	1,960	2,983	998	2,614	1,784	1,633	516	1,241	3,527	624	3,053	1,687	2,539	2,198	418	264	583	997	1,200	110
	UKJ4	793	35,032	11,195	17,241	5,953	15,857	10,627	9,386	2,857	6,847	17,509	3,830	17,444	9,768	15,728	13,317	3,015	2,401	3,395	6,062	7,904	878

	Road	BE25	BE23	BE21	BE22	BE24	BE10	BE33	NL34	NL33	NL32	NL31	NL22	NL41	NL42	DEA1	DEA2	DEB1	DEB3	DE71	DE12	DE13	CH03
FROM	UKD5	33	479	172	209	95	255	112	181	64	80	316	41	306	185	128	131	21	15	50	55	62	10
	UKE1	99	1,417	510	723	283	744	353	456	152	206	679	109	758	465	404	434	68	56	149	189	194	39
	UKH3	87	1,218	454	555	237	607	303	403	145	202	631	88	680	418	357	368	65	53	136	161	182	29
London	UKI1	99	1,036	380	517	246	540	302	602	216	256	878	151	939	591	465	428	91	66	163	182	222	32
	UKI2	83	1,125	410	581	232	562	277	385	143	185	572	85	659	403	344	374	60	48	133	160	159	31
	UKj3	44	634	233	283	125	307	150	239	88	114	406	52	408	244	184	190	30	21	72	80	90	14
	UKJ4	224	3,116	1,150	1,542	622	1,657	807	958	314	447	1,316	217	1,556	981	888	955	179	149	335	430	473	79
TO	UKD5	13	689	201	291	102	267	180	172	53	131	377	75	317	180	244	195	39	28	54	83	110	12
	UKE1	20	956	287	502	161	423	282	276	81	193	589	142	518	301	474	422	80	57	104	199	218	22
	UKH3	34	1,642	475	770	238	639	441	368	117	292	785	151	700	390	670	612	123	97	170	284	320	39
London	UKI1	84	3,238	995	1,611	615	1,594	1,014	1,061	307	704	1,954	399	1,882	1,061	1,676	1,238	326	226	350	556	733	78
	UKI2	34	1,516	450	777	262	678	452	381	115	268	688	136	712	388	680	610	122	87	155	283	311	32
	UKj3	13	675	196	298	100	261	178	163	52	124	353	62	305	169	254	220	42	26	58	100	120	11
	UKJ4	79	3,503	1,119	1,724	595	1,586	1,063	939	286	685	1,751	383	1,744	977	1,573	1,332	301	240	340	606	790	88

Table 15: Selected Scandinavia regions to the EU main land cargo flows on NUTS2 level in tonnes (left) and TEU (right)

	Road	BE25	BE23	BE21	BE22	BE24	BE10	BE33	NL34	NL33	NL32	NL31	NL22	NL41	NL42	DEA1	DEA2	DEB1	DEB3	DE71	DE12	DE13	CH03
FROM	SE11	89	1,711	587	741	436	659	329	2,315	1,322	1,420	5,822	704	5,613	3,585	2,588	2,382	564	486	1,098	978	994	646
	SE23	411	7,424	2,614	3,983	1,825	3,041	1,633	9,924	5,764	6,548	24,181	3,772	26,999	16,171	12,910	13,009	2,564	1,846	5,060	5,186	4,468	1,631
TO	SE11	68	3,299	952	1,504	461	1,032	656	4,020	1,169	2,302	8,945	980	6,321	3,424	7,736	5,584	1,642	1,638	2,064	2,684	2,651	-
	SE23	214	9,189	2,700	5,230	1,191	3,645	2,165	9,557	2,687	5,470	18,898	2,800	14,711	8,797	24,031	18,609	4,655	3,290	5,915	7,732	8,033	-

	Road	BE25	BE23	BE21	BE22	BE24	BE10	BE33	NL34	NL33	NL32	NL31	NL22	NL41	NL42	DEA1	DEA2	DEB1	DEB3	DE71	DE12	DE13	CH03
FROM	SE11	9	171	59	74	44	66	33	232	132	142	582	70	561	359	259	238	56	49	110	98	99	65
	SE23	41	742	261	398	183	304	163	992	576	655	2,418	377	2,700	1,617	1,291	1,301	256	185	506	519	447	163
TO	SE11	7	330	95	150	46	103	66	402	117	230	895	98	632	342	774	558	164	164	206	268	265	-
	SE23	21	919	270	523	119	364	216	956	269	547	1,890	280	1,471	880	2,403	1,861	465	329	591	773	803	-

5.1.10 Expert insights of cargo flow data

With the identification of the aggregate cargo flows between the different NUTS2 regions, a more in-depth analysis of the cargo flows is given by expert insights.

First, the result of the validation of the main aggregated cargo flows by different experts is given. Secondly, the identification of the specific data sources is given, which can be used if detailed cargo flows (at a disaggregate level) are needed in the analysis.

5.1.11 Validation of constructed aggregated OD – Matrix

The constructed OD matrix is validated by the following expert partners: Van Moer Groep, Marlo and Duisburg Port, Touax and Plimsoll. Each partner will check if the matrix on the following parameters:

- The size of the cargo flows
- The direction of the cargo flows ((in)balance of the different OD pairs)
- The modal share of IWT cargo flows
- The structure of the OD matrix

Van Moer Groep

The Van Moer Groep is has very good insights on the cargo flows in region where it is active (Benelux). With respect to the more aggregate view of the cargo flows going to the Rhine region, VMG can conclude that the values same to more or less align with the overall feeling that they have with their expert opinion.

Marlo

Marlo has no real comments on nor additions to the compiled data base and agrees with the data that was found.

Duisburg Port

It is difficult for Duisburg Port to validate the data in the OD-Matrix, because the region DEA1 does not only contain transport volumes of the Port of Duisburg. Duisburg Port can provide figures mainly for the IWT and rail cargo flows, but it is difficult to calculate the road traffic. In their view, the modal share of IWT seems to be to high (Antwerp 68%, Rotterdam 80%). Transport by rail to these seaports plays a significant role . But this can be different to other ports / terminals that belong to the DEA1 region as well.

Touax

Touax point if views is that it is very hard to find one system or source that provides all detailed data of transported goods from origin to destination by the different modes. There suggestion is to also look at data provided by other sources such as the statistical departments of the Ports of Rotterdam and Antwerp even if it is only supportive to the other data.

5.1.12 Detailed cargo flow data

The aggregate OD matrix of the Antwerp case is set up and it will give a first insight into main cargo flows. The insights of the different experts are used to come to a more disaggregated level. Each of the different partners will provide an overview of the data that is available including:

- Origin of the flow
- Destination of the flow
- Mode of transport
- Size of the flow
- Type of transport (Containerized or RoRo)

Van Moer Groep

Van Moer Groep has detailed data for the cargo movements in the Antwerp case study Area. There is data available (company anonymous) on the axis Zeebruges – Antwerp – Brussels including a branch to the region of Leuven (Class II inland waterway) and the city of Brussels (both urban areas).

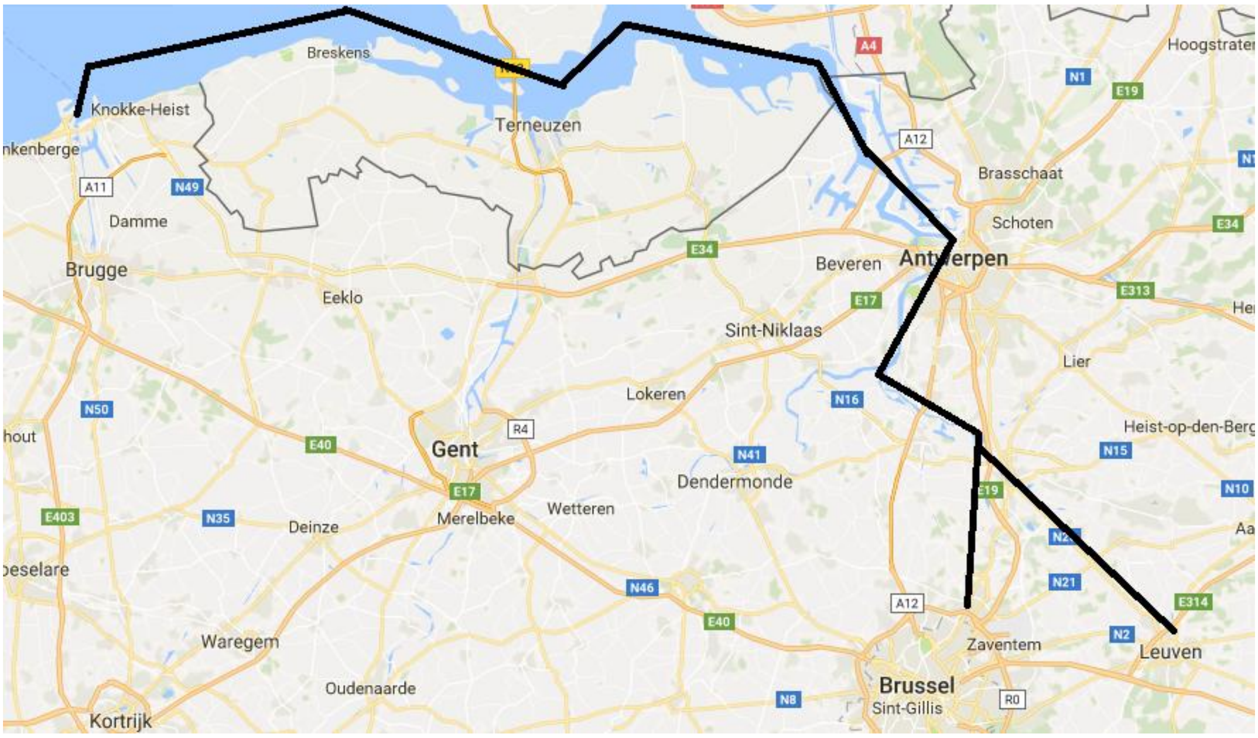


Figure 43: Zeebrugges – Antwerp – Brussels axis

On this axis, both inland vessels, sea-river (or estuary vessels) and short sea ships are present including several different infrastructural characteristics. This means that in order to assess the viability of the VT, this axis can be seen as one of the most complex in the whole region in North-Western Europe. It is also possible to link this transport axis to the river Rhine where now the bulk of the IWT transport is taken place. Therefore this region is very suitable for the assessment of the VT concept because there is on the one hand the complexity of the infrastructure and on the other hand there is the density of the waterway network, which makes that a lot of companies are in close proximity of a waterway which makes that it is possible, due to the data of Van Moer Groep, to developed real concrete business cases.

The main data will be collected and structured in task 2.2.3 (see project proposal).

Marlo

Marlo says it has no additional expert insight that can be added to the cargo flow data.

Port of Duisburg

Duisburg port can provide detailed vessel data for departures or arrivals in Duisburg to or from different locations. Especially for the Antwerp case information about the number of ships and their departure or arrival times is available. This data can be very well used for the connection between the transport axis Zeebruges – Antwerp – Brussels and the river Rhine.

Duisburg port also has direct short-sea transport connections from Duisburg to Norway, mainly to Bergen (ca. 150 vessels per year) and some to Oslo (but only small number compared to barge transports to the sea ports). For Sweden, only a few vessels are coming from Stockholm or have the destination Stockholm when leaving Duisburg.

Vessel data for the Port of Duisburg with the following information is available:

- Origin of the cargo flow (for vessels arriving in Duisburg)
- Destination of the cargo flow (for vessels with origin Duisburg)
- Type of vessel (container, push boat with lighter, dry cargo vessel, liquid product vessel, RoRo,…)
- Size of vessel
- Arrival and Departure date and time in Duisburg
- Cargo handling in Duisburg (yes/no)

The main data will be collected and structured in task 2.2.3 (see project proposal).

Determining the geographical scope of the second case study area

The first scoping of the geographical scope of the second case study area is based on several meetings and suggestions with the different project partners. This second case study area will be a rough sketch without the detailed data. The data is collected in task 2.1.5.3.

The main idea is that the second case study area should be the Danube region.

The main advantages of choosing for the Danube region is that:

- It is a completely different region/situation as the Rhine region both in terms of vessels operating on the river and the navigational characteristics which makes that the assessment of the VT concept is completely different then from the Antwerp case. for instantance:

  - This area could suffer a lot from changing circumstances such as water level, ice but also the number of locks. These different circumstances may impact the viability of the VT concept and therefore it is worthwhile to research.
  - Moreover, due to a different economic environment may impact the VT concept. So can the savings on reducing the crews not compensate the increase of investment for a VT because the boatmen's salaries are much lower than on northern Europe

- It is also possible to link sea-river and short sea shipping to the IWT network via the port of Constanta
- The current IWT tonnages are relatively low compared to the tonnages on the Rhine which makes that there is a lot of room of improvement
- The Danube is also part of the TEN-T network (Rhine-Danube corridor) which makes that it is viable part of the larger EU transport infrastructure network.

Conclusion/summary of the results

In this chapter the data is collected to develop an OD matrix which can be used in the Antwerp case. These data base will consist out of a disaggregated cargo flows on the axis Zeebrugges – Antwerp – Brussel (to deal with different types of infrastructure, and interactions on that part of the network) and a more aggregated cargo flows for the cargo flows to the Rhine. Also a first rough sketch of a potential second case study area is given.

6 PERFORMANCE INDICATORS

In order to research the viability of the Vessel Train (VT) concept, a (limited) set of performance indicators (PIs) need to be developed. Based on these PIs, conclusions can be drawn on the introduction of the VT as a new logistics system in the short, sea-river and IWT markets. The developed PIs are needed for the model that will be further developed in task 2.2. The main outcome of this subtask is a list of PIs and parameters that need to be calculated by the model.

Using PIs for performance measurement ensures that you are always evaluating business activity against a static benchmark. PIs provide visibility of business performance and allow objective quantitative and qualitative evaluation. (Logistics Bureau, 2013)

This means that two situations need to be evaluated:

- The transport system without the VT (base case)
- The transport system including the VT (future scenario)

It is not the purpose to develop an endless list of PIs to evaluate the VT concept but we need to stick

with the main goals and objectives (Logistics Bureau, 2013). Therefore a very good definition of the main objective of the PIs need to be developed. The main objective is:

"The evaluation of the transport system (including the VT) based on the broad economic, environmental, energy and social requirements. "

These elements need to be included in the Performance Indicators (PIs) and their values that benchmark the VT concept transport characteristics.

The main purpose of WP2 is to research the business economics aspects of the VT. Therefore, the focus will be on the development of business economic performance indicators. The welfare economic indicators will be developed in WP1, because that WP will take all the welfare effects into account.

In order to determine the main PIs, the following structure will be followed. At first, a short overview of existing PI methods will be given. Based on the review, a first version of the PIs will be made which will be checked and validated by people and institutions with business knowledge. Also, a list of variables and data needs will be given. Finally, a short summary of the main findings will be given.

Review of existing methods to determine PI

In this section a literature review is conducted with respect to the supply chain performance measures in order to identify potential appropriate business economic measures/performance indicators that can be applied for evaluating the transport system with and without the VT.

Developing key performance indicators for measuring the supply chain performance is broadly considered a challenge because often there is a lack of guidelines on how to develop them and also the list appears to be inexhaustible. Bongsug (2009) defines the Supply Chain Management (SCM) performance as a group of metrics (Key Performance Indicators-KPIs) and processes that are used to evaluate how accurate the planning is and how well the execution takes place. Thus the ultimate goal in performance measurement is to minimize the gap between what is planned and what is finally executed and also identify and correct potential problems, giving a feedback necessary for the survival of a system or an organization. This is not an easy task in terms of the planning because of the uncertainty of what the future will bring.

According to Bongsug (2009), the ‘Supply-chain operations reference’ (SCOR) helps in developing KPIs for measuring the performance of the supply chain. The KPIs that will be developed should be critical for each of the four of the ‘Supply-chain operations reference’ (SCOR) processes, which are ‘plan, source, production and delivery’ (Table 16). The author points out that only a small number of KPIs should be developed and used by the companies, the most necessary ones and suggests the categorization of the KPIs based on their significance in primary and secondary. The primary KPIs show the overall supply chain performance, which should be monitored regularly and the secondary ones are metrics that show why the primary metrics have high or low values, offering a more detailed view of the supply chain.

For the success of the key performance indicators, it is important that the roles and responsibilities (R&R) of organizational members, units or teams are clearly defined, thus knowing which KPI is the responsibility of which organizational unit and communicated on a regular basis (Bongsug, 2009).

Krauth et al. (2017) conducted a literature review focusing on the areas of general management, supply chain management, logistics service supervision and warehousing and based on this, they developed performance indicators and empirically evaluated their usefulness. What is important to mention is that the step that comes before the development of the performance indicators is the definition and classification of the different forms of logistics service providers; the distinction of the warehouses in dedicated and public and the distinction of the relationship of a logistics service provider with his client based on an open book or closed book approach. In the following Table 16, the findings of literature according to Krauth et al. (2017) are presented per area under examination.

Table 16: Literature review findings about performance measurement for the areas of 1) general management, 2) supply chain management, 3) logistics service providers and 4) warehouse management.

Area under examination	Frameworks of performance measurement/KPIs	Further details	Authors
General management	Balanced scoreboard	Measuring companies performance in an integrated manner.	Brewer and Speh, (2000) (Kaplan et al., (1992) Kleijnen and Smits, (2003)
	Logistics service provider’s performance model (related to market, customer satisfaction and loyalty)	Rational performance Operational performance Cost performance	Stank et al., (2003)
	Financial performance indicators	Measuring if the company’s strategy, implementation, and execution contribute to bottom-line improvement.	Chapman, et al. (2003), Lemoine and Dagnaes., (2003)

Supply chain management	Aligning logistics service providers with the serving supply chain	Measuring flexibility, efficiency and responsibility (1st step).	Christopher and Towill (2002)
	Hierarchical model	Measuring supply chain agility.	Weber (2002)
	SCOR model	Originally developed for manufacturing processes, thus it might be not directly applicable to logistics service provision. (Lai et al. 2004)	Supply Chain Council, (2003); Stewart, (1995)
	Partnership evaluation criteria	-Level and degree of information sharing. - Buyer-vendor cost saving initiatives. - Extent of mutual co-operation leading to improved quality. Entity and stage at which supplier is involved. Extent of mutual assistance in problem solving efforts.	Gunasekaran et al., (2001) Mason-Jones and Towill, (1997), Thomas and Griffin, (1996) Graham et. al., (1994) Toni et al., (1994) Maloni and Benton, (1997)
	Partnership evaluation only for the key supply chain partners, not all	Otherwise having strong collaboration with all supply chain partners is not feasible and profitable.	Kemppainen and Vepsaelaeinen (2003)
	Information quality (information systems supporting integration of inter-organizational processes (Hammer, 2001)	IT investment (impact on better coordination in the value chain).	Ross (2002)
Logistics service provider	Performance related to transport activities of logistics service provider (Van Donselaar et al. 1998)	Timeliness and accuracy Delivery performance. Personnel scheduling and safety measures.	Bromley, (2001); Johnson, (2001) Stewart, (1995) Crum and Morrow, (2002); Mejza et al., (2003)
	Customer relationships (Knemeyer et al., 2003)	Customer satisfaction and loyalty.	Stank et al., (2003)

Warehouse management	Indicators for selecting a specific logistic service provider to outsource warehousing	Responding to service requests. General management and ethical issues.	Moberg and Speh (2004)
	Use of information technology for measuring the performance of warehouses		Rogers et al. (1996)
	Indicators for assessing whether a warehouse management system fits the respective company examined.	Indicatively: "Product range, user environment and system characteristics, basic functions such as order processing, inventory management, means of transport and typology of storage."	Fraunhofer Institut für Materialfluss und Logistik (2005)

Source: Krauth et al. (2017), own composition

Krauth et al. (2017) developed their own framework and based on the literature review they classified the performance indicators based on the perspectives of different stakeholders: manager, employee, customer and society. Under the managerial perspective the following performance categories are clustered: effectiveness, efficiency, satisfaction, IT & innovation. From the perspective of the customer three performance indicators mainly matter: costs, performance and flexibility. Costs are measured as costs per stored unit; performance is measured as On-Time and In-Full (OTIF) and flexibility measures the ability to accommodate decreases and increases in the flow of goods. Important performance indicators are also the ones related to personnel because labor costs often can be very high. For the evaluation of their framework, the authors consulted an industry expert, visited the planning department of a logistics service provider, conducted an interview with an expert of warehouses and focused on the customer perspective of logistics service providers.

Balfaqih et al (2016) conducted a review of literature of supply chain performance measurement systems and used 83 out of 374 related articles from 1998-2015. They point out that during the recent years the focus shifted from the internal business processes management level (manufacturing management level) to the enterprise management level of the supply chains due to the globalization, outsourcing, information technology etc. Measuring the performance of the supply chain is necessary in order to manage the supply chain efficiently, to achieve SC excellence and maintain sustainable competitive advantage.

A drawback in performance measurement system is the existence of several conflicting measures. Also what is necessary is that the performance measurement criteria should have a clear definition of scope and focus on suitable data and calculation methods. There are also many different reasons for developing a performance measurement system (PMS), thus the purpose of developing a PMS should be clearly stated and it is also significant to consider the SC as a whole when designing a supply chain management performance measurement system (Balfaqih et al, 2016).

The 83 papers under review are categorized under three approaches that Balfaqih et al (2016) propose as a typology of the performance measurement systems; the perspective, process or hierarchical based approaches. Almost 63% of the articles that were reviewed applied a **perspective-based approach**. This approach gathers both generic performance measures and cause and effect hypotheses, thus specifying the interrelations among the performance measures.

The 2nd approach, the process-based approach was used by 41% of the papers reviewed and focuses on understanding the activities and main processes of a SC. The most widely used model by the papers was the supply chain operation reference (SCOR) model, which concludes five main processes: plan, source, make, deliver and return and contains five main performance characteristics: responsiveness, reliability, flexibility, cost and asset attributes. This model was used also in combination with other models such as the BSC and methods such as the DEA.

The 3rd approach, the hierarchical based approach, evaluates the performance of the SC at three different hierarchical levels, strategic, tactical and operational so as to help managers to take the right decisions. Almost 35% of the papers used a hierarchical-based approach to evaluate the SC performance. This approach was also combined with other frameworks such as the SCOR model and the BSC. A technique that is used is the fuzzy two-stage data development analysis (FTSDEA).

A key recommendation of Balfaqih et al (2016) is for decision makers to be aware that there are no SCPMS or sets of performance indicators that can be applied equally well under all conditions and organizations. Thus decision makers should select performance measurement approaches, methods and indicators that suit their SCs. Also the authors point out the steps to develop a PMS for a CS: 1) define the objectives of the SC; 2) Select suitable approach, technique, criteria and indicators; 3) Prioritize the performance criteria and indicators; 4) Receive feedback from the stakeholders and make respective modifications on the PMS; 5) Reach a consensus on the PMS and 6) show the PMS to all stakeholders for evaluation purposes.

Lai, Ngai and Cheng (2002) conducted a study for constructing an instrument to measure the supply chain performance in transport logistics. They used the SCOR model as a conceptual background and based on the statement that SCP measures should focus on both the effectiveness and efficiency of the SC, and not to each of them alone, in order to reflect SCP in transport logistics, they identified three dimensions: 1) Service effectiveness for shippers (SES), 2) Operations efficiency for transport logistics service providers (OE), 3) Service effectiveness for consignees (SEC).

Stank, Keller and Daugherty (2001) pointed out the importance of integration not only among the internal operations but also with the customers and suppliers (external operations). The authors focus on one out of the three perspectives of integration, the collaborative perspective; the other two perspectives are a series of interactions and a composite of both perspectives. Collaboration is a decision making process among independent parties. Authors created a conceptual model which tests three hypotheses: *"H1: Internal collaboration has a positive influence on logistical service performance outcomes; H2: External collaboration has a positive influence on logistical service performance outcomes; H3: Internal collaboration and external collaboration are positively related."* They used the questionnaire that was designed for the 1995 World Class Logistics Research at the Michigan State University as the basis for the research. In summer 1997 they completed cases studies of 26 firms to make the measures broader into a SC perspective and they developed questionnaire items to assess logistics process performance. In 1998 a survey population was selected from the membership list of the Council of Logistics Management (CLM) and thus one questionnaire was sent to supply chain or senior logistics executives in every firm that was based in North America (Canada, Mexico and United States). The response rate was 11.5%, meaning that out of the total sample of the 2,680 firms that received the questionnaire, only 306 firms provided complete replies, however these provide sufficient data for confirming the conceptual framework. The items of the questionnaire were selected based on literature and refined based on the 26 case studies. Principal components analysis and confirmatory factor analysis are used to assess unidimensional characteristics for each factor. Also in order to test how collaboration is related to firm performance an analysis that used structural equations modeling via Lisrel 8 has been conducted. Results show that H1 and H3 are supported but not H2. This means that it is found that internal collaboration is related to higher levels of logistics services performance (H1) and that external and internal collaboration are correlated significantly. However, it is found that external collaboration does not lead directly to higher performance of the logistics service. The non-anticipated results (lack of support of H2 and at the same time support of H3) led to further analysis in order to examine if the internal collaboration plays an intermediary role in affecting a logistics service of a firm, meaning that external collaboration may affect internal collaboration and thus indirectly affect the logistics service of a firm. Thus, a three-step regression analysis was used and the findings showed that internal collaboration is necessary if a firm wants to improve its external collaboration with customers and suppliers.

Gunasekaran and Kobu (2007) conducted a review of recent literature (1995-2004) of papers about the performance measures and metrics in logistics and supply chain management in order to create a short list of key performance measures and metrics that are related with organizational performance in a SCM system. The literature has been reviewed and classified based on the following criteria: *(i) balanced score card perspective; (ii) components of measures; (iii) location of measures in supply chain links; (iv) decision levels; (v) nature of measures; (vi) measurement base; and (vii) traditional vs. modern measures*

The literature review revealed about 80-90 performance measures, however after omitting all the overlapping measures and repeats, at the end there were 27 measures, called KPIs, as presented in Figure 44.

	A				B				C					D			E		F		G			
Metrics	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	1	2	1	2	1	2	Total	Percentage
01 Accuracy of scheduling		X			X				X							X		X	X		X		7	32
05 Bid management cycle time		X			X				X					X				X	X		X		7	32
06 Capacity utilization		X	X			X					X				X	X		X	X		X		9	41
07 Compliance to regulations		X	X				X		X	X				X				X	X	X		X	10	45
08 Conformance to specifications		X		X			X			X	X					X		X	X			X	9	41
18 Delivery reliability		X		X	X		X						X			X		X	X			X	9	41
24 Forecasting accuracy				X	X		X		X						X	X		X	X			X	9	41
29 Inventory costs	X	X				X		X	X	X	X	X	X			X	X		X		X	X	14	63
33 Labor efficiency			X			X					X				X	X		X	X		X		8	36
35 Lead time for procurement				X	X					X					X			X	X		X		7	32
36 Lead time manufacturing		X		X	X						X				X	X		X	X		X		9	41
39 Obsolescence cost	X			X	X		X		X								X		X			X	8	32
44 Overhead cost	X	X			X	X			X		X					X	X		X			X	10	42
46 Perceived quality				X			X	X					X					X		X		X	7	32
47 Perceived value of product				X			X						X					X		X		X	6	27
50 Process cycle time		X			X			X	X		X	X			X	X		X	X		X		11	50
51 Product development time		X	X		X				X					X				X	X		X		8	36
54 Product/service variety	X		X	X			X	X	X					X				X		X		X	10	45
55 Production flexibility		X	X		X	X	X	X			X					X		X		X	X		11	50
62 Return on investment	X					X			X					X			X		X			X	7	32
63 Selling price	X			X		X	X						X	X			X		X			X	9	41
68 Stock out cost	X			X			X	X					X				X		X			X	8	32
71 Supply chain response time		X	X		X			X	X					X	X	X		X	X		X		11	50
76 Transportation cost	X					X						X			X	X	X		X			X	8	32
77 Value added	X			X		X					X		X		X	X	X		X			X	10	45
81 Warranty cost	X			X			X		X								X		X			X	7	32
Total	10	13	7	13	12	9	12	7	13	4	9	3	7	7	9	14	9	17	22	5	11	16		
Percentage	38	50	27	50	46	35	46	27	50	15	35	12	27	27	35	54	35	65	85	19	42	61		

A. Balance score perspectives: 1. Financial, 2. Internal process, 3. Innovation and improvement, 4. Customers. **B**. Components of performance measures: 1. Time, 2. Resource utilization, 3. Output, 4. Flexibility. **C**. Location of measures in supply chain links: 1. Planning and product design, 2. Supplier, 3. Production, 4. Delivery, 5. Customer. **D**. Decision level: 1. Strategic, 2. Tactical, 3. Operational. **E**. Financial base: 1. Financial, 2. Nonfinancial. **F**. Measurement base: 1. Quantitative, 2. Nonquantitative. **G**. Traditional vs. Modern: 1. Function based, 2. Value based.

Figure 44: Metrics used to measure performance in SCM systems and their relations to categories and factors suggested by researchers. Gunasekaran and Kobu (2007)

However, selecting the key metrics and measures from the 27 measures presented above should be made based on the different characteristics, needs and objectives of each individual organization. Another recommendation of the authors is that key performance measures and metrics should use a proactive rather than a reactive approach. Also, the 27 KPIs presented in Figure 44 can be applied for both manufacturing and services but when it comes to individual companies, such as transportation, some additional measures may be required such as customer service level and utilization of transportation resources. Also it is noted that a regular and continuous updating of PIs is necessary because the enterprise environment changes. Finally, the authors point out the importance of using nonfinancial measures and intangibles.

Maestrini et al (2017) conducted a literature review of 92 papers of 40 different peer-reviewed journals published from 1998-2015 focusing on external SCPMSs as their main goal but also taking into consideration the internal SPMSs as a dimension of a wider framework in order to point out the integration of the external and internal SC activities. The majority of the articles (72 out of 92) belong to the domain of operations technology and management, however the last five years there is a growing attention also about corporate social responsibility and sustainability management. Almost half of the papers in the sample (41 out of 92) are theoretical studies that they provide a conceptual framework for measuring the performance of the SC and 51 papers are empirical works mostly using as methodologies, case studies and surveys. Most of the empirical studies are exploratory following the theory building paradigm, some refine an existing theory or they are illustrative and some adopt a theory-testing approach.

The focus is also on the SCPMS life cycle (design, implement, use and review) and specifically mostly in the phase of design (62 out of the 92 papers). However, a good SCPMS design is not sufficient to guarantee a successful adoption since failures can occur because of the poor quality in the other three phases. The methods that are used for metric selection in the SCPMS design phase are the following four in the sample of papers reviewed: 1) Analytical hierarchy process (AHP), 2) Questionnaires, 3) Analytical network process (ANP) and 4) Technique for order preference by similarity to ideal solution (TOPSIS), which is a method used for final ranking and normalization. It can be used to compensate for the inaccurate ranking of the AHP. It is also found that the frameworks that are most often used in the papers reviewed are the 1) Supply chain balanced scorecard (SCBSC), 2) SCOR-based, 3) Resource output flexibility (Resource: various dimensions of cost; output: various dimensions of customer service; flexibility: ability to an environment that changes) and 4) Process-based, for which the unit of analysis is the supply chain process (Maestrini et al, 2017).

So as to sum up the papers that are reviewed with respect to the supply chain performance measurement systems showed that the focus is on clearly defining what is the key terms they are working with, such as PMS, SCPMS, metrics etc., on providing recommendations on how to develop own key performance measures, on categorizing the SCPM that are most widely used, on presenting also the existing SCPMS frameworks and the techniques that are used. Therefore less attention is paid on the specific existing performance measures as such.

Lessons learned from the literature review

- Less is better (with respect to the number of the indicators to be used).
- Categorize KPIs in primary and secondary.
- Develop KPIs for each of the critical operations of the Supply Chain (see four SCOR processes).
- From a logistic service providers point of view, performance is measured through timeliness and accuracy, delivery performance, personnel scheduling, safety measures, customer satisfaction and loyalty.
- Consider developing performance indicators based on the perspectives of the different stakeholders in the vessel train system (based on the framework of Krauth et al., 2017) (except the perspective of the society which will be examined in WP1 and not in WP2).
- Effectiveness, efficiency, satisfaction, IT & Innovation are key performance overall categories for measuring performance from a management point of view (based on the framework of Krauth et al., 2017).
- From the perspective of the customer, three performance indicators mainly matter: costs, performance and flexibility. Costs are measured as costs per stored unit; performance is measured as On-Time and In –Full (OTIF) and flexibility measures the ability to accommodate decreases and increases in the flow of goods.
- Keep in your mind the change of the environment: the level to which supply chain management takes place shifted from an internal business level to the enterprise management level of the SC. Thus it is significant to consider the SC as a whole when designing a supply chain management performance measurement system.

- It is critical that PIs are based on a clear definition of scope and on suitable data and calculation methods.
- A key recommendation of this paper is for decision makers to be aware that there are no SCPMS or sets of performance indicators that can be applied equally well under all conditions and organizations. Thus decision makers should select performance measurement approaches, methods and indicators that suit their SCs.

With these main lessons taken into account, the performance indicators for the Novimar project will be developed. The main purpose of the VT system is:

“to adjust the waterborne transportation such that it can make optimal use of the existing short-sea and inland waterways and vessels, while benefitting from a new system of waterborne transport operations that will expand the entire waterborne transport chain up and into the urban environment .”

So, from a supply chain point of view, the VT will not change items like:

- Sales forecast
- Procurement and suppliers

In order to develop the KPI of the VT, only those elements that are influenced by the implementation of the VT are to be taken into account. Therefore, the PI to assess the VT needs to include at least:

- Transport cost
- Total Transport time (including delays and waiting times at deepsea and inland terminals)
- Transport reliability
- Inventory cost (both in-transit and in a warehouse)
- Flexibility
- External cost will be part of WP1 (Welfare assessment of the VT)

Setup of main PIs for the VT concept

In WP2, the main focus is on the business economic aspect of the VT. Therefore the main performance indicators will also be related to this.

One of the main features of the VT is that cargo flows are combined which have different origins and destination pairs, because the VT has an impact on multiple cargo flows. This means that the evaluation of the VT needs to be determined for each cargo flow with origin and destination (OD).

The first PI that will be based on a more macro-based approach in which the **difference in generalized cost** for the movement of a containerized load (TEU) from the base case and the new situation in which the VT is implemented is taken.

$$\Delta GC_{i,j} = GC_{i,j}(IWT/SSS) - GC_{i,j}(VT) \quad (1)$$

In which:

$GC_{i,j}$(IWT/SSS) is the current generalized cost per TEU for IWT or SSS transport between origin i and destination j.

$$GC_{i,j} = \overline{OPC_{i,j}} + \left[\overline{T_{i,j}} + \sqrt{VAR(T_{i,j})}\right].VoT \quad (2)$$

In which $GCi_{,j}$ is generalized cost per TEU from i to j, $OPC_{i,j}$ is the out of pocket cost per TEU from i to j, $T_{i,j}$ is the average transport time from i to j , VoT is the value of time per TEU, $\sqrt{VAR(Ti,j)}$ is the standard deviation of the total transport time from i to j[4].

If the PI turns out to be positive, then the VT concept leads to a lower GC per transported container. This will result in modal shift for all containerized cargo flows from origin i to destination j.

Therefore the second PI will be the **increase in modal share** for the different cargo flows which are linked to the VT.

$$\Delta P_{Waterborne,i,j} = P_{SSS/IWT+VT,i,j} - P_{SSS/IWT,i,j} \quad (3)$$

In which $P_{SSS/IWT}$ is the modal share of the waterborne transport from origin I to destination j in the current situation while $_{SSS/IWT+VT}$ is the modal share of waterborne transport including the vessel train. The modal share of the waterborne transport can be calculated with the following formula:

$$P_{SSS/IWT,i,j} = \frac{e^{-\lambda GC_{SSS/IWT,i,j}}}{e^{-\lambda GC_{SSS/IWT,i,j}} + e^{-\lambda GC_{Road,i,j}} + e^{-\lambda GC_{Rail,i,j}}} \quad (4)$$

In which λ is the spreading factor, $GC_{Roadi,j}$ the generlised cost for road transport from origin I to destination j and $GC_{Rail,i,j}$ the generalized cost of rail transport from i to j.

A third merit to determine the performance of the VT is to look more at a micro level (company level). For this approach the following PI is determined:

$$\Delta TLC_{i,j} = TLC_{i,j}(IWT/SSS) - TLC_{i,j}(+VT) \quad (5)$$

In which ΔTLCi,j is the **difference in total logistics cost** from origin I to destination j. $TLC_{i,j}$(IWT/SSS) is the total logistics cost from origin i to destination j for the current situation and $TLC_{i,j}$(+VT) is the total logistics cost when the VT is included.

[4] The variation in time can be determined via a Monte Carlo Simulation (see for more info task 2.2)

The TLC can be calculated based on the following formula (Blauwens et al (2006)):

$$TLC = TC + \left(\frac{1}{R}.\frac{Q}{2}.v.h\right) + \left(L.v.\frac{h}{365}\right) + \left(\frac{1}{R}.v.h.k.\sqrt{(L.d)+(D^2.l)}\right) \quad (6)$$

In which:

Goods flow parameters		Transport mode parameters	
Annual volume (units)	R	Transportation costs (/unit)	TC
Average daily demand (units/day)	D	Loading capacity (units)	Q
Variance of daily demand (units^2/day)	d	Average lead-time (days)	L
Value of the goods (€/unit)	v	Variance of lead-time (days^2)	l
Holding cost (% per year)	h		
Safety factor	K		

The main advantage of this PI is that a change in the transport system is reflected on a company level (both in-transit and warehouse inventory cost). Only specific data requirements are needed to make this calculation.

A fourth method to assess the potential of RoRo potential in a VT is the "**number of the wheeled cargo**[5] **that is actually used over the maximum possible wheeled cargo that could be transferred in a certain vessel train**" that travels from point A to point B. Since there are different types of wheeled cargo, with different sizes, we can use as unit of measurement each time the different type of wheeled cargo that is used in the RORO ships.

This indicator can be calculated with the following formula:

$$PWC_{i,j} = \frac{WC_{i,j,VT}}{WC_{i,j,MAX,VT}} \quad (7)$$

In which $PWC_{I,J}$ is the percentage of wheeled cargo from origin I to destination j on a VT. $WC_{i,j,VT}$ is the number of wheeled cargo units to be transported on a VT (calculated) and $WC_{i,j,VT,MAX}$ is the maximum capacity of wheeled cargo units in a VT.

A fifth method to assess the performance of the VT concept is about having economies of scale not via the big ships that carry big quantities of cargo but via a higher number of multiple smaller vessels that can still carry a high volume of cargo in an aggregate way. Thus the **volume of cargo transported by small vessels**[6] can be a performance indicator of the VT concept.

This indicator can be calculated with the following formula:

$$\Delta Volume\_SIW_{i,j} = Volume\_SIV_{i,j,+VT} - Volume\_SIV_{i,j,IWT} \quad (8)$$

[5] Wheeled cargo: cars, trucks, semi-trailer trucks, trailers, and railroad cars.
[6] IWT CEMT classes II and III

In which ΔVolume_SIW$_{I,J}$ is the change in volume cargo transport by small inland waterway vessels between origin i to destination j on a VT. Volume_SIW$_{,j,+VT}$ is volume of cargo transported by small inland vessels in a vessel train between origin i and destination j. And Volume_SIW$_{,j,IWT}$ is the volume of cargo transported by small inland without the VT between origin i and destination j.

In Table 17 an overview of the developed PI is given.

Table 17: Overview of proposed Performance indicators

PI	Calculation	Meaning	Impact
Gen cost	$\Delta GC_{i,j} = GC_{i,j}(IWT / SSS) - GC_{i,j}(VT)$	Difference in generalized cost per TEU	Attractiveness of the new transport system on a aggregated level.
Modal share	$\Delta P_{Waterborne,i,j} = P_{SSS/IWT+VT,i,j} - P_{SSS/IWT,i,j}$	Increase of modal share	Effective use of waterborne infrastructure (also in urban areas)
TLC	$\Delta TLC_{i,j} = TLC_{i,j}(IWT / SSS) - TLC_{i,j}(VT)$	Difference in Total logistics cost	Attractiveness of the VT at Micro level to assess the VT on a company level
% Wheeled cargo	$PWC_{i,j} = \frac{WC_{i,j,VT}}{WC_{i,j,MAX,VT}}$	Potential of RoRo cargo for the VT concept	Attractiveness of the VT For RoRo traffic
% of cargo transport by small vessels	$\Delta Volume\_SIW_{i,j} =$ $Volume\_SIV_{i,j,+VT} - Volume\_SIV_{i,j,IWT}$	Potential of small inland vessels	Attractiveness of the VT concept for small inland vessels

Possible other PI such as external cost and other social requirements are allocated in WP1. Where the welfare evaluation of the VT will be done.

These main parameters/ indicators are used to assess different constellations of the VT[7] . Based on a sensitivity analysis the main impact of changes to the VT system can be assessed (Task 2.2.4) and those VT solutions that have the best scores on the developed performance indicators can be developed into concrete business cases. The first three PI can also be used in the construction of the business case.

[7] VT can be composed from vessels of the same size/type to VT of different vessel types to VT build from newly designed vessels.

List of required data and inputs

In order to calculate the developed PIs several variables are needed. Firstly a transport network with different regions/ areas is needed with the following components:

- Transport network
  - Different origins and destinations (ODs) in the "Antwerp" case study area
    - Fine mesh in the region around the port of Antwerp
    - A less fine mesh for cargo flows going to the Rhine
  - Inland terminals in the different hinterland areas
  - Location of urban areas in the different Origins and destinations
  - Sea ports with the different container and roro terminals.

Secondly on the network different transport modes are needed. These modes of transport are:

- Modes of transport (including intermodal transport)
  - IWT
    - Current IWT vessels
    - VT concept
  - Road
  - Rail
  - Short sea
    - Current SSS vessels
    - VT concept

Thirdly for each mode of transport the logistic cost need to be determined. In order to calculate this the following variables are needed:

- Logistics cost
  - Cost
  - Time
  - Value of Reliability
  - Inventory cost
  - In transit inventory cost
  - Value of Time and depreciation cost of cargo

With respect to data needs to compute the PI, the following is needed:

a. Cost data of all modes (the starting point of the cost structures can be taken from van Hassel et al (2016) and can be updated in the course of the Novimar project.
b. Cargo-related data (depreciation and value, data from project partners)
c. The transport network and transport modes are also taken from van Hassel et al (2016) which need to be updated and adopted to the needs of the Novimar project.

Summary

This chapter has an overview of existing PI methods has been given. Based on the review, a first set of PIs are developed which were checked and validated by project partners. Also, a list of variables and data needs has been developed.

7 CONCLUSION

The NOVIMAR project researches the vessel train, a waterborne platooning concept featuring a manned lead ship and a number of follower ships that follow at close distance by automatic control. The vessel train concept is a totally new approach for inland waterway navigation transport. Thus, the setting of requirements is crucial. The initial requirements set in work package 1 served as a starting point. An analysis of the current situation in inland waterway transport, shortsea shipping and sea-river transport have been analysed to identify current gaps. A lot of data on waterway structures, fleets and transported cargo can be found for inland waterway navigation, but hardly for shortsea shipping and river sea transport. The collected data was analysed with respect to the relevance for the vessel train concept.

Further, the working principle of rail and road transport have been analysed to transfer knowledge and experiences to the new vessel train concept. Rail transport is quite different form the vessel train concept and the transfer of relevant information is difficult. Whereas in the road transport sector truck platooning is currently investigated and already highly developed. Knowledge might be gained from a technical and logistic point of view.

Further, detailed cargo flows were determined as preparation for the first and second case study. The first case study is already set to consider for the Antwerp region. The region for the second case study will be set later. Advantages and disadvantages for the Danube region are discussed.

The output of this deliverable serves as a basis for the transport system model. For the evaluation of the vessel train concept, based on this model, performance indicators have been determined.

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ANNEXES

A 1. Annex A: Public summary

The NOVIMAR project researches the vessel train, a waterborne platooning concept featuring a manned lead ship and a number of follower ships that follow at close distance by automatic control. The vessel train concept is a totally new approach for inland waterway navigation transport. Thus, the setting of requirements is crucial. The initial requirements set in work package 1 served as a starting point. An analysis of the current situation in inland waterway transport, shortsea shipping and sea-river transport have been analysed to identify current gaps. A lot of data on waterway structures, fleets and transported cargo can be found for inland waterway navigation, but hardly for shortsea shipping and river sea transport. The collected data was analysed with respect to the relevance for the vessel train concept.

Further, the working principle of rail and road transport have been analysed to transfer knowledge and experiences to the new vessel train concept. Rail transport is quite different form the vessel train concept and the transfer of relevant information is difficult. Whereas in the road transport sector truck platooning is currently investigated and already highly developed. Knowledge might be gained from a technical and logistic point of view.

Further, detailed cargo flows were determined as preparation for the first and second case study. The first case study is already set to consider for the Antwerp region. The region for the second case study will be set later. Advantages and disadvantages for the Danube region are discussed.

The output of this deliverable serves as a basis for the transport system model. For the evaluation of the vessel train concept, based on this model, performance indicators have been determined.

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