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CONTENTS

List of symbols and abbreviations

BM	Business Model
FV	Follower Vessel
IT	Information Technology
IWT	Inland Waterway Transport
kn	Knot or one nautical mile per hour (1.852 km/h)
LV	Leader Vessel
MMMS	MIXMOVE Match Solution
nm	Nautical miles
PI	Performance Indicator
RoRo	Roll on Roll off
TC	Transportation Cost
T/F ratio	Total to full ratio of vessel
TLC	Total Logistic Cost
ToR	Terms of Reference
VO	Vessel Owner
VT	Vessel Train

1. EXECUTIVE SUMMARY

1.1 Problem definition

The vessel train (VT) could 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 this deliverable has as main objective to identify the basic conditions for successful implementation of VT's. Based on these conditions decision trees are developed which are used both the VT handbook (T.1.7) and in the Vessel train Roadmap to market uptake (T6.4).

1.2 Technical approach and work plan

This deliverable has developed the decision trees which can be used to investigate potential other use areas of the VT concept. In order to do this the definition of the basic conditions and key success factors for VT's are determined. Next to that 3 different potential areas for VT-operations in Europe are studied. These three cases are:

1. IWT application on the Rhine – Alpine corridor
2. A short sea shipping case on the North Sea-Baltic corridor
3. An IWT case on the Rhine Danube corridor.

These three cases are used to test the viability for VT-operations in potential areas and identification of problems. And for the identified problems, recommendations of possible measures are determined.

Based on the gained insights three different decision trees are developed:

1. One for the short sea application
2. One for the IWT application
3. One for the IWT application in urban areas.

1.3 Results

In this deliverable, the main objective was to develop three decision trees where the VT concept can be applied [1]. These decision trees are based on a detailed analysis of different VT cases. With respect to the short sea shipping application the following four main attributes are taken into account:

- The potential cost savings for the vessel owner by applying the VT concept
- The available fleet and cargo flows that could be used to make a VT

[1] The actual decision trees are used in the VT handbook and in the market uptake of the VT concept.

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- The type of vessel (slow or fast sailing vessels)
- The option of the vessel owner to change its business model (adopt slow steaming principles as they become part of the VT).

From the analysis of the IWT application the main elements that need to be taken into account in the decision trees are:

- Available fleet and cargo flow in the studied region
- The type of freight market (concentrated with larger shipping companies, or fragmented with a lot of small and medium-sized shipping companies)
- The potential cost savings due to crew reduction
- The sailed distance of FV in the VT
- Possible obstacles which the VT needs to pass (locks, bridges, etc.)

Finally, for the urban case application we come to the following main elements:

- Vessel dimensions (can the vessel fit on the urban IWT network)
- Bridges and the amount of traffic making use of these bridges
- The possibility to schedule a VT operation outside rush hours.

With these decision trees, it is possible to assess if a VT can be set-up in a specific region. If it turns out that the VT gets a positive evaluation, then the transport model, developed in WP2, can be used to make a more in-depth analysis.

The three studied cases were all cases in which it was possible to develop an economic viable VT.

1.4 Conclusions and recommendation

In this deliverable three main decision trees (short sea shipping, IWT and IWT in an urban context) are developed. These decision trees are based on detailed analysis of different VT cases (IWT cases on the Rhine and Danube and a short sea case on the North Sea).

With these generic decision trees, it is possible to assess if a VT can be set-up in a specific region. This means that also other regions, which are not yet studied in detail, can be assessed by making use of the decision trees. The decision trees can therefore be used in T.1.7 (Vessel Train handbook) and T.6.4 (Vessel Train roadmap).

If it turns out that the VT gets a positive evaluation from the decision trees, then the transport model, developed in WP2, can be used to make a more in-depth analysis.

There are no corrective measures in this deliverable.

2 INTRODUCTION

2.1 Task/Sub-tasks

The task objectives are:

- Definition of the basic conditions and key success factors for VT's
- Identification of potential areas for VT-operations in Europe
- Assessment of viability for VT-operations in potential areas and identification of problems
- Recommendations for possible measures to foster VT-applications in problem areas.

Envisaged activities are:

- *Sub-task T1.4.1*: Identify basic conditions and success factors for VT-application. Validate these by benchmarking against the showcases from Chapter 1 Task T2.6
- *Sub-task T1.4.2*: Identify at least three potential VT-application cases using the European TEN-T corridors as a starting point, of which applications from the short sea, sea-river and IWT
- *Sub-task T1.4.3*: Assess/investigate the identified potential cases for VT-applications. Identify shortcomings with respect to the basic conditions and success factors
- *Sub-task T1.4.4*: Define possible solutions for the identified shortcomings, such as infrastructural adaptation, organisational measures, regulatory measures, vessel adaptation, etc.
- *Sub-task T1.4.5*: Using the outcome of sub-tasks T1.4.2-T1.4.4 to develop a simple decision tree diagram for determining the potential of VT-application in a selected area.
- *Sub-task T1.4.6*: Prepare the draft report (deliverable) for the task.

2.2 Analysis

The NOVIMAR project researches the VT concept which is a waterborne platooning concept featuring a manned lead ship and a number of follower ships that follow at a close distance under automatic control. Deliverable 1.4 includes the analysis to determine other implementation areas, in Europe, for the VT concept. In this deliverable, the main qualitative and quantitative factors (taken from the work of WP2) which will impact the successful implementation of the VT will be researched. Based on this decision trees will be developed which can be used to determine potential areas in which the VT can be successful implemented.

2.3 Approach

Task 1.4 is the fourth task under Work Package (WP) 1 'Requirements and assessment'. It started in month twenty-five of the project and runs until month frothy two. The deliverable is due end of month frothy three. In this task three successful VT cases are analysed. Based on these detailed analysis three generic decision trees (IWT, short sea and VT in urban area) are developed. These decision trees can be used in the vessel train handbook and the vessel train roadmap. The work was distributed according to the sub-tasks to different partners.

3 PLAN

The main objective of this deliverable is to develop decision trees on the applicability of the VT in other application areas.

3.1 Objectives

While WP2 deals with two VT-train specific cases this task investigates the wider potential of VT-application along the main freight corridors in Europe. At first, the basic conditions for successful implementation of VT's are identified. Qualitative and quantitative factors will be involved, for example, cargo flow volumes, waterborne infrastructures linking short sea- inland-urban areas, shortcomings of current situations, the current cost of transport etc. The TEN-T corridors will be the starting point to identify potential VT-application areas.

3.2 Planned activities

The planned activities of this deliverable are:

- *Sub-task T1.4.1*: Identify basic conditions and success factors for VT-application. Validate these by benchmarking against the showcases from Chapter 1 Task T2.6
- *Sub-task T1.4.2*: Identify at least three potential VT-application cases using the European TEN-T corridors as a starting point, of which applications from the short sea, sea-river and IWT.
- *Sub-task T1.4.3*: Assess/investigate the identified potential cases for VT-applications. Identify shortcomings with respect to the basic conditions and success factors
- *Sub-task T1.4.4*: Define possible solutions for the identified shortcomings, such as infrastructural adaptation, organisational measures, regulatory measures, vessel adaptation, etc.
- *Sub-task T1.4.5*: Using the outcome of sub-tasks T1.4.2-T1.4.4 to develop a simple decision tree diagram for determining the potential of VT-application in a selected area.
- *Sub-task T1.4.6*: Prepare the draft report (deliverable) for the task.

3.3 Resources and involved partners

The distribution of the activities among the project partners in task T1.4 is the following:

UANTW (leader) with TUD define the basic conditions/success factors, identify, and assess potential VT-application cases, define possible solutions, prepare the first draft of the decision tree, TUD finalises.

3.4 Timeline

According to the Description of Action (DoA), Task 1.4 starts at month twenty-four and ends with deliverable 1.4 at month forty-three. The development of the content of the first version of this deliverable was finished at project month forty-four. In the Gannt chart below the detailed planning of this deliverable can be seen.

Table 1: **Gannt Chart D.1.4**

Project month	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Sub-task T1.4.1	■	■	■																
Sub-task T1.4.2				■	■	■													
Sub-task T1.4.3							■	■	■	■									
Sub-task T1.4.4											■	■							
Sub-task T1.4.5													■	■	■	■	■		
Sub-task T1.4.6																		■	■

4 PLAN EXECUTION

4.1 Introduction

In this section, the short description of the performed activities of deliverable 1.4 is given.

4.2 Performed activities

In order to develop the content of deliverable 1.4 the following sub-tasks are performed:

Sub-task 1.4.1

In the first sub-task basic conditions and success factors for VT-application are identified. This is done by analysing the different case (IWT application of the Antwerp case, the North Sea Short Sea shipping case, and the inland Danube case) and from these cases, the most important success factors can be determined. In this sub task the main insights obtained from the detailed cases in WP2 are researched.

Sub-task 1.4.2

In the second sub-task three potential VT-application cases are determined. These application areas should be linked to the European TEN-T corridors and they should have applications to either short sea, sea-river or IWT.

Sub-task 1.4.3

The applicability of the VT will be assessed for the three defined application areas. Also, the shortcomings with respect to the basic conditions and success factors will be identified. These potential shortcomings are also identified from the same cases of sub task mentioned in 1.4.1.

Sub-task 1.4.4

For the identified shortcomings possible solutions are developed. These solutions can be infrastructural adaptations, organisational measures, regulatory measures, vessel adaptation, etc.

Sub-task 1.4.5

Based on the previous sub-tasks three different decision tree diagram are developed. These decision trees are determined for a IWT VT, a short sea VT and a urban area VT. These decision trees are going to be generic so that they can be used in both the VT handbook and in the VT marker uptake plan.

Sub-task 1.4.6

In this sub-task, the project deliverable will be developed.

4.3 Deviations from the plan

There are no deviations from the project plan.

5 RESULTS

5.1 Introduction

In this chapter, the main results are given from the various performed activities in the six sub-tasks as described in section 3 and 4.2. The sub-tasks are structured according to the explained objectives of this deliverable.

5.2 Identifying basic conditions and success factors for VT-application

In the first sub-task, basic conditions and success factors for VT-application are identified. This is done by analysing the different case (IWT application of the Antwerp case, the North Sea Short Sea shipping case, and the inland Danube case[2]) and from these cases, the most important success factors can be determined.

5.2.1 Type of VT OWNER

From this analyses, it was concluded that a VT which is organised by a single shipping company (defined as BM2 in WP2) will lead to higher net benefits for the VO and cargo owner (CO), rather than using a platform business (BM4 in WP2). However, the business model in which a neutral platform is used as a VT OWNER also leads to positive net benefits. From this, it can be concluded that if in a certain potential use area there are a lot of different ship owners (fragmented supply) then the platform BM is the best to use. If there are some large VO (concentrated supply) then BM2 is best to use.

5.2.2 Cargo flows

From the performed analysis in D.2.4 the following can be concluded with respect to the cargo flows:

- If large vessels are used in the VT then the departure frequency must be at least twice a day if the transport distance is less than 150 km between two ports in the network. This means that large cargo volumes[3] are required. For larger sailing distances, this departure frequency can be lower and therefore the required cargo flow can also be lower.
- If smaller vessels are used, then these can be linked to the larger vessels. This also means that the departure frequency must be the same as for the large vessels.
- In order to get enough cargo to be transported with the VT, it is possible to mix different cargo types and therefore also different vessel types. Thus having a good mix of different cargo (and vessel)types can benefit the implementation of the VT.

[2] As the Danube case is still under development (due data 28/2/2021) the prelimanry results of the Danube case are used.
[3] For this case the total required volume is 150.000 TEU and 760.000 tonnes of dry and liquid bulk per year.

5.2.3 Crew cost and availability

- The main benefit of the VT concept is the reduction in the crew at the FVs. This means that the higher the crew cost, the higher the benefits for the VO can become. In regions with low crew wages, fewer benefits can be obtained.
- Another benefit of the VT is that it can solve the problem of having fewer crew members available in a certain region. Thus, if there is a lack of crew members then there is also a need for a VT.
- Finally, with the VT, the productivity of an inland vessel can be increased if only one crew is used instead of two when a vessel is sailing full continues system. This means that inland vessels can sail more (and longer) with only one crew. . This option is not possible for short sea vessels.

5.2.4 Obstacle on the waterway

If locks need to be passed, in which the VT need to be decomposed, on the network then this will deteriorate the net benefits of the VT. Thus to higher the number of obstacles, such as bridges and locks, that need to be passed in which the VT need to be decomposed, the less attractive it is to implement the VT.

5.2.5 VT in urban areas

The success factors identified for the Antwerp case also apply to urban areas. There are however other success factors that are specific to urban areas. A research project has been undertaken at the TU Delft to identify these success factors when penetrating into urban areas and having to interact with the bridges there. The following three factors have been identified as important factors based on a case study located in the province Noord Holland (from de Kaag to Amsterdam).

5.2.5.1 Maximum bridge opening times

Clustering vessels into fewer bridge openings, as it is done with the VT, is one of the aims of the bridge management systems used in on many bridges in Amsterdam and all over Noord Holland (Schelling & Boeren, 2018). The average opening time of bridges including passage, opening, and closing of the bridge is four minutes. If more vessels were to pass clustered into the same opening, this time needs to be extended. It should be considered that these bridge openings should not cause traffic jams in the entire city. Hence, the length of the maximum bridge opening time depends on the distance to the next intersection, the traffic intensity, and the average speed of the traffic at the bridge location.

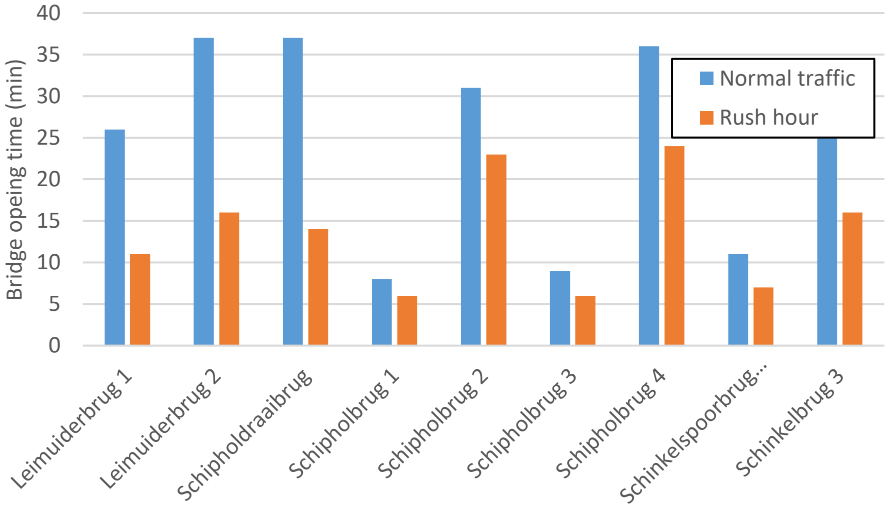

Figure 1: Maximum Bridge Opening Time per Bridge

The case study from which sample maximum bride opening times are calculated involves the city centre of Amsterdam and can hence be considered as the worst-case scenario. The case study bases the assessment on the Nationale Databank Wegverkeersgegevens (CCNR, 2017) traffic information.

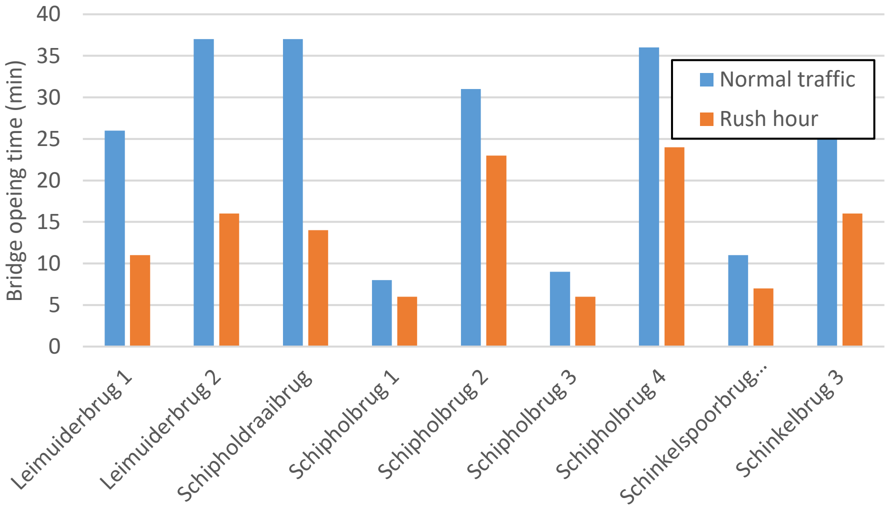

Figure 1 illustrates the expected maximum bridge opening times in both rush hour and regular traffic. The daytime traffic opening times vary between 37 minutes and as little as 8 minutes. Eight minutes restricts the number of FVs to three vessels dependent on the safety distance kept between the vessels. This does not meet the economically viable FV requirements of four FVs for a smaller Vessel class II that would be able to reach the urban areas. The traffic density on some bridges in Amsterdam is simply too high to allow VTs to pass. A bridge opening time of more than 10 minutes would be required to accommodate a sufficient number of class II vessels for economic viability to be achieved.

5.2.5.2 Scheduling

Fout! Verwijzingsbron niet gevonden. emphasises that the increase in traffic density during rush hour reduces the maximum bride opening times to as low as six minutes. This would just allow one FV vessel to pass together with the lead vessel at fairly close proximity (less than 1,5 ships lengths). **Fout! Verwijzingsbron niet gevonden.** does make it clear that some bridges can open for longer than 10 minutes even during rush hour, hence the viability of urban area penetration is dependent on the specific application area. It should additionally be kept in mind that some municipalities do not allow bridge openings during rush hours.

If rush hour passage cannot be accommodated, the VT operators and users need to be willing to adjust their scheduling outside such that bridge passage does not interfere with times of high road traffic densities.

5.2.5.3 Bridge distances

The final success factor that limits urban area access is the distance between bridges. Local regulations do not permit more than two bridges to be opened simultaneously. Doing so may prevent emergency services to reach their destination in a timely manner.

Figure 2 is a visual representation of a generic key that provides bridge distance estimates for differently sized vessels given different number of FVs in a VT (see Annex B). These are based on a 150 m safety distance between vessels. For a VT of class II FVs to operate viably, i.e. at least 4 FVs in a VT, at least 825 m are needed between bridges.

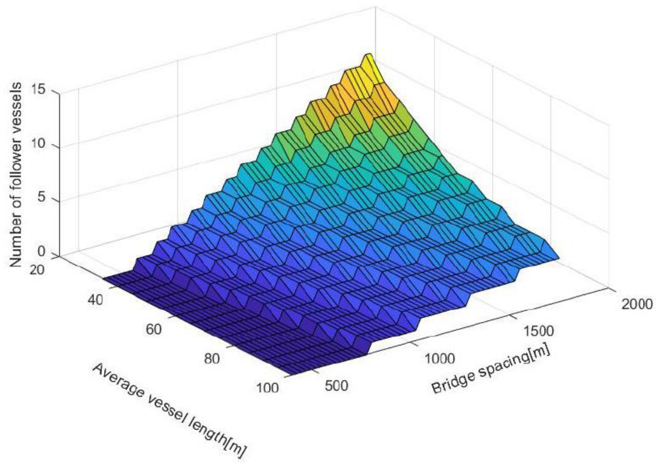

Figure 2: Number of FVs by vessel length and bridge spacing

5.2.6 VT for short sea applications

The main success factors for the short sea application of the VT are the same to those identified in the IWT case, i.e. cargo flows and crew cost and availability. The short sea application is however also hinging on business decisions made by the FV operators. These are related to the waiting times, the limitation in flexibility and the operating at a slower speed.

5.2.6.1 Waiting times

The waiting times created before every departure of a trip accumulate over the duration of a year and reduce the vessels productivity. Any business operations that cannot accommodate these additional waiting times are therefore not recommended to use the VT service.

5.2.6.2 Limited flexibility

The FV operator also has to consider the restriction in flexibility caused by the reduced number of crew on board. Taking crew members off means the vessel can no longer operate continuously on its own. This restricts the FV operating area to that of the operating area VT service plus about 8h of operations before joining and after leaving the VT.

5.2.6.3 Slowing down

The implementation of the VT will create the most benefit if combined with slow steaming operations. It not only allows more vessels to join the same train and thereby possibly reduces the contribution fee of an individual vessel but also creates significantly more savings through the reduction in fuel consumption. If a vessel operator would make an active choice to change its operations to slow steaming the VT could create additional benefits to the operations.

5.3 Three potential VT-application cases

There are three different cases that are researched. These case are:

1. Antwerp case (IWT)
2. Antwerp case (short sea shipping)
3. Danube case (IWT)

The first case can be seen in Figure 3. following route: Turnhout, Antwerp, Rotterdam, Nijmegen, and Duisburg. The Antwerp short sea case, which has an application between Hamburg and Le Havre, can be found in Figure 4, while the Danube case can be found in Figure 5.

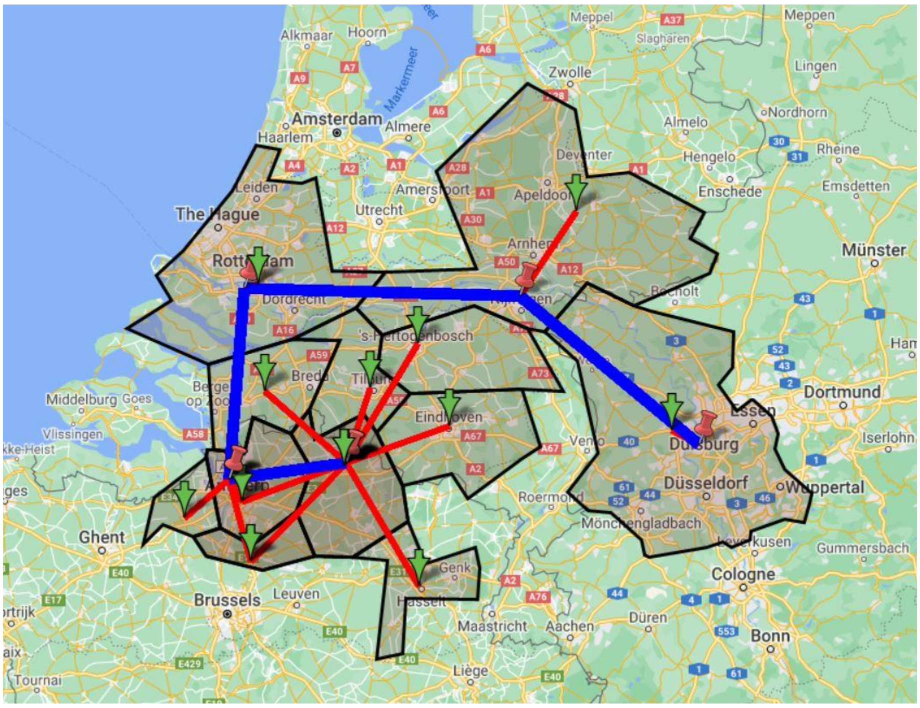

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Figure 3: Antwerp case, IWT

In Figure 3 the network for the Antwerp case VT is shown. In this figure the blue lines represent the VT part between the different port (red pins in the map). The indicated regions in the map are the regions that are linked to the different (inland) ports that are part of the VT. The green arrows is the indication of the location where the cargo has to be shipped to (distribution centres). The red lines are the road distances that need to be covered from the inland ports to the distribution centres. The same legend applies for Figure 5.

In Figure 4 the black dots are the different deepsea ports that are located in the Hamburg – Le Havre range. The red lines are the sailing routes of the VT.

Figure 4: Antwerp case, short sea (Colling & Hekkenberg, 2020)

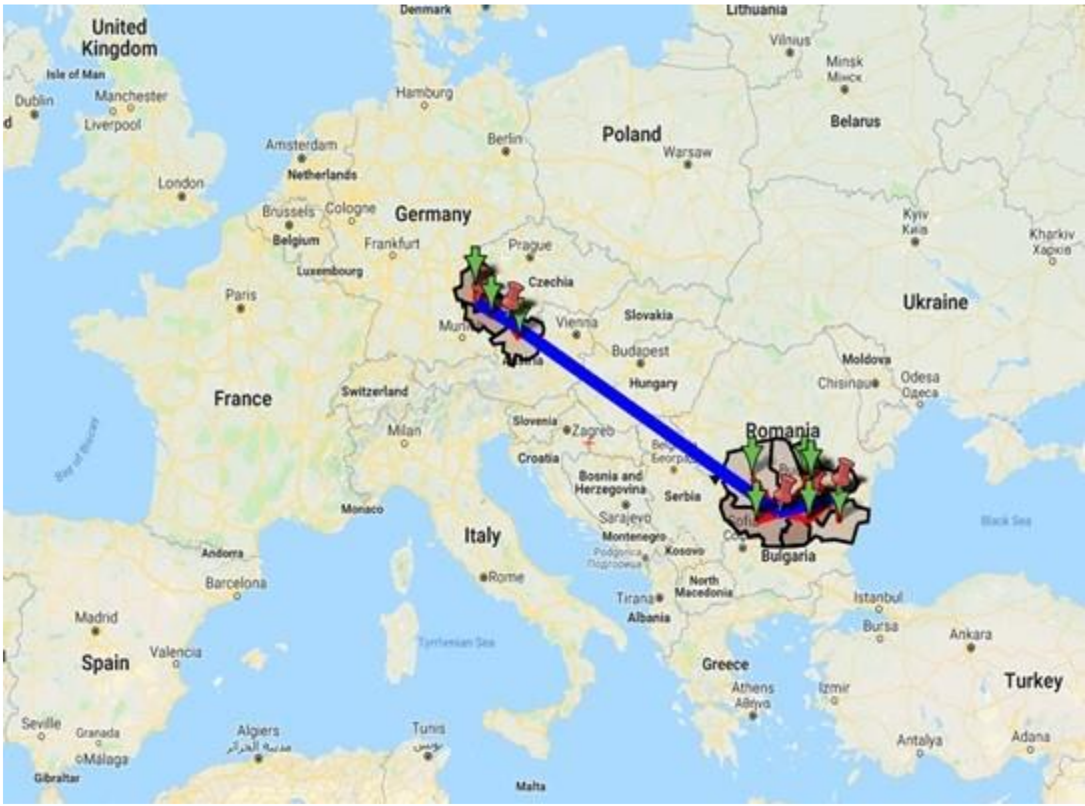


Figure 5: Danube case

5.4 Applicability assessment of the VT

The applicability of the VT will be assessed for the three defined application areas. Also, the shortcomings with respect to the basic conditions and success factors will be identified.

5.4.1 Antwerp case (IWT) (Rhine Alpine corridor)

5.4.1.1 Cargo volume

The first parameter that will be taken into account is the cargo volume. The cargo volume check (CVC) depends on the selected route and VT composition and is considered as a case-specific parameter. The cargo volume is going to be checked which is obtained based on the equation (1). This check is done to validate if the transported cargo volume in the VT is less than the maximum available waterborne cargo volume on a certain transport link.

$$CVC = \frac{VT\ cargo\ (the\ \text{actual amount of cargo transported by VT})}{WMV\ (\text{waterborne market volume})} \quad \text{Equation 1}$$

To establish a VT, CVC should be =< 1 which means the total waterborne volume available on a link should be larger or equal to the amount of cargo that can be transported by VT. For the selected route which is made out of five main segments of Turnhout, Antwerp, Rotterdam, Nijmegen, and Duisburg, the CVC is obtained based on the ratio of the amount of cargo of all the segments that can be transported by VT to the available total cargo volume of all segments.

The total available cargo volume on each link (Waterborne market volume) can be obtained by the NOVIMAR Model for each specific route and segment. However, to calculate the VT transported cargo in each link, the following equation has been applied:

*VT Cargo volume transported per Year = VT Capacity per Trip * Total Trips per Year*

In which: VT Capacity for containers is TEU and for dry bulk cargo and liquid cargo is Ton.

Since there are 2 trips per day (departure interval is considered every 12 hours), and 250 operation days per year, thus, total departures or trips per year is obtained by the product of these two terms[4].

[4] As FV can't sail without a LV, the LV departure frequency is determining the overall departure frequency on the whole VT network.

Table 2 depicts the cargo volume transported by VT per trip for all the types of cargo (container, liquid bulk, and dry bulk) for different segments of the selected route. These values are calculated based on input data of the NOVIMAR model.

Table 2: VT cargo capacity per trip for all types of cargo in each segment

Origin of Segment	Destination of Segment	VT Features	Vessel Train Capacity of transporting cargo per Trip		
			VT Capacity per Trip for Container (TEU / Trip)	VT Capacity per Trip for Liquid Bulk (Tonne / Trip)	VT Capacity per Trip for Dry Bulk (Tonne / Trip)
Turnhout	Duisburg	FV - Class 2 - Container	20	0	0
Antwerp	Rotterdam	FV - Class 5 - Container	165	0	0
Antwerp	Duisburg	LV - Class 5 - Container / FV - Class 5 - liquid bulk	165	2,160	0
Rotterdam	Nijmegen	FV - Class 4 - Container	96	0	0
Rotterdam	Duisburg	FV - Class 5 - Containers / FV - Class 5 - bulk cargo	165	0	2,160

Table 3 shows the computation of total trips (departures) per year. In this calculation, the yearly operational days are 250 days. As the VT departure frequency is every 12 hours, thus, two trips per day occur.

Table 3: Total trips per year

Number of Departure per Day	Number of Days In Year (Operational Day)	Total Departures In Year
2	250	500

Table 4 *demonstrates* the final calculations. The values for *Total cargo volume Transported by Vessel Train* (3rd, 4th, 5th columns) are obtained by multiplying the *Vessel Train Capacity of transporting cargo per Trip* (4th, 5th 6th columns of

Table 2) respectively by total departures in a year (3rd column of

Table 3). The values for *Total Available cargo volume in Waterborne Market Volume* (6th, 7th, 8th columns) are obtained directly from the model for each segment.

In the final stage the ratio of VT concerning the total Waterborne Market Volume (Eq. 1), is calculated based on the following relationship:

$$\%\ \text{ratio of VT (Cargo Volume Check)} = \frac{Total\ cargo\ volume\ Transported\ by\ Vessel\ Train}{Total\ Available\ cargo\ volume\ in\ Waterborne\ Market\ Volume}$$

Finally, for each segment, the total % ratio of VT is obtained by summing up all % ratio of VT for each type of cargo (container, liquid bulk, and dry bulk).

Table 4: Cargo volume check or % ratio of VT concerning total cargo

Segment	Total cargo volume Transported by Vessel Train			Total Available cargo volume in Waterborne Transport Market			% ratio of VT - Cargo Volume Check			Total % ratio of VT	Total % ratio of VT
	VT Cap. (TEU/ Year)	VT Cap. Liquid (Ton/ Year)	VT Cap. Dry Bulk (Ton/ Year)	Total Container (TEU/Year)	Total Liquid Bulk (Ton/Year)	Total Dry Cargo (Ton/Year)	(%)	(%)	(%)	Tonne	TEU
Turnhout - Duisburg	4,640	0	0	50,123	1,159,158	505,113	9%	0	0		
Antwerp - Rotterdam	46,400	0	0	681,823	81,915	559,433	7%	0%	0%		
Antwerp – Duisburg	46,400	769,544	0	50,490	1,075,387	510,510	92%	72%	0%	**8%**	**28%**
Rotterdam - Nijmegen	11,600	0	0	54,683	1,621,873	242,578	21%	0%	0%		
Rotterdam - Duisburg	46,400	0	769,544	378,150	1,506,973	22,159,067	12%	0%	3%		

The average value of 8% for bulk cargo and 28% of the container market means that to apply the VT composition in the Turnhout, Antwerp, Rotterdam, Nijmegen, and Duisburg route, at least these amounts of the exiting waterborne market is required on this route should be transported by VT.

5.4.1.2 Business Model Choice

Based on the evaluation of four available business models (BMs), it is revealed that there are two BMs namely BM3 and BM4 which are more applicable in the IWT sector. The situation of the IWT market plays an important role to choose the best BM between BM3 and BM4. If the IWT market is made out of small and medium enterprises which are called the *fragmented market*, the BM4 is the best one to apply. However, if the IWT market is a *concentrated market* that includes many large companies, thus, the BM3 can be used as the best option.

To compensate for the extra digital platform of BM4, it is suggested to use either cargo consolidating capability, or new cargo handling system, or the RoRo cross transfer platform. However, by using BM3, Vessel Owners can have the highest possible net business-economic benefits, if none of the new VT capabilities is used (Meersman et al, 2020).

5.4.1.3 Departure Time

The VT evaluation displays positive and effective results if the Lead Vessel is either Class 5 or Class 6. Consequently, the departure time should be less than 24 hours. In our calculation, departure time is considered every 12 hours.

5.4.1.4 Number of Crew Members on Board on each FV

The biggest benefit of the VT application is the reduction of crew members and consequently the decrease in crew costs. Therefore, the Follower Vessel should be manned by only one crew member[5] to have the benefits of using VT. In the case of two crew members, then the MMMS (MIXMOVE Match Solution) in combination with the WP4 developments is necessary, otherwise, the business economic evaluation of the VT becomes negative.

5.4.1.5 Business Economic Evaluation of VT

In the business-economic calculation, the VT cost savings are calculated from three different actors' perspectives namely Vessel Owner, Vessel Train Organizer, and Cargo Owner. Table 5 plots the method of calculations.

Table 5: Private cost calculation for three actors involved in VT

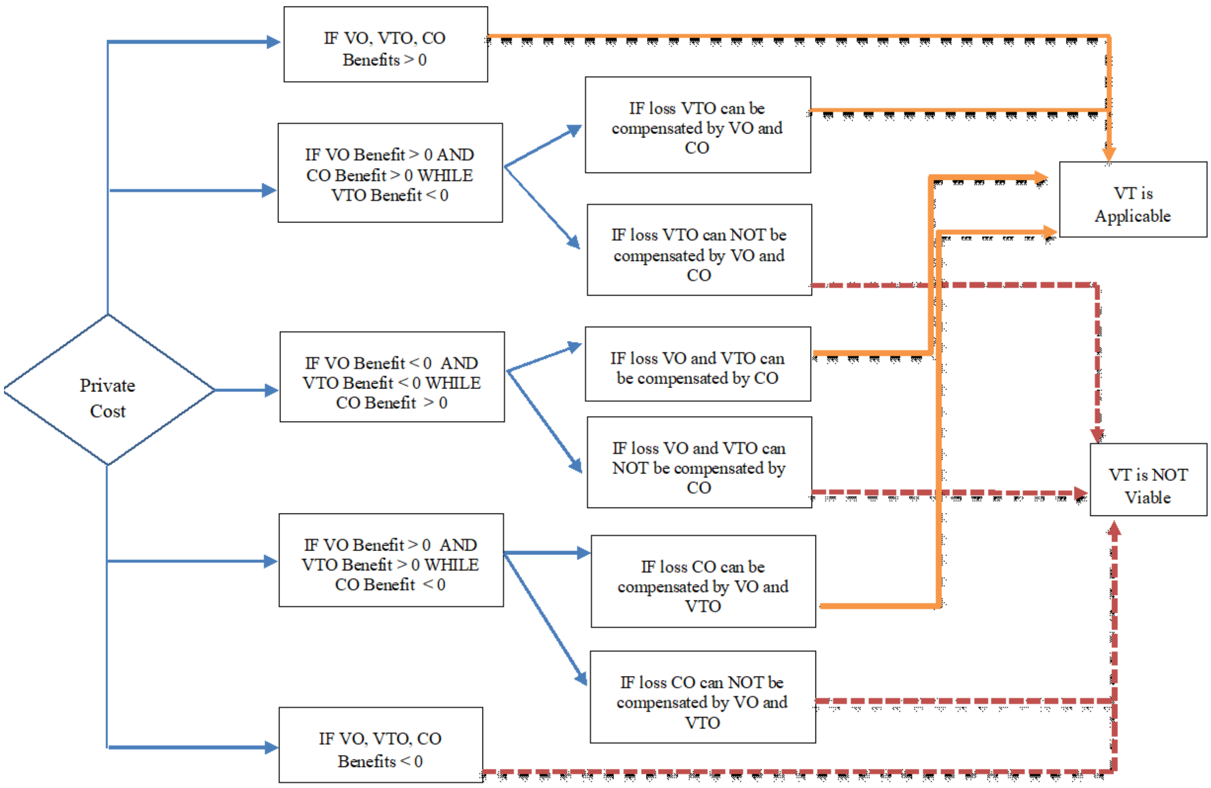
VT cost savings Perspective	Relevant Equation	Equation	Explanation
Vessel Owner Benefits	Based on the Generalised Cost formula	A = Costs of Vessel Owner when using VT – Costs of Vessel Owner of the current situation (No VT is used).	IF A < 0 => Costs of the current situation without VT is higher than of costs of VT using => Therefore, from a Business-Economic perspective, it is viable for VO to use VT.
Cargo Owner Benefits	Based on the Total Logistics Cost formula	B = TLC of VT situation (VT is used) – TLC of the current situation (No VT).	IF B < 0 => From Business-Economic Perspective it is viable for Cargo Owner to participate in VT => An incentive for Cargo Owner for Modal Shift.
Vessel Train Organizer (VT OWNER) Benefits	Considered as the costs for Vessel Owner	VT OWNER Benefit is calculated proportionately to the benefits of VO and based	/

[5] The one crew member depends on the exploitation scheme. If the vessel is sailing 12h a day sailing the one crew member is needed. For 24/24h operation 2 crew members are needed.

VT cost savings Perspective	Relevant Equation	Equation	Explanation
		on a profit margin defined at 20%.	

Based on the computations, there are five main possible outcomes which can define the positive or negative viability of VT from the business-economic evaluation. These five different combinations are drawn in Figure 6.

Figure 6: Business Economic Evaluation of VT



An important boundary condition is that the actors with positive benefits which intend to distribute their benefit to the other actor(s) to compensate for their loss benefits, must still have a positive benefit after this benefit distribution. Otherwise, the business-economic evaluation is negative.

5.4.1.6 Welfare Assessment

Further, welfare assessment needs to be evaluated. If the external cost of VT is less than the external cost of the current situation (when No VT is used), therefore, VT composition is applicable.

In the case of positive business-economic evaluation, it is concluded that welfare assessment can be considered positive as well. However, in the case of negative business-economic evaluation, the external cost savings of the VT composition and current situation (No VT) should be compared. The positive welfare assessment (in favour of VT service) might compensate for the loss of business-economic evaluation which might provide an incentive for the establishment of VT service.

5.4.2 Antwerp case (short sea shipping) (North Sea-Baltic corridor)

5.4.2.1 The required number of vessels

Based on a liner service operating between Le Havre and Hamburg, it is shown that the required number of vessels to establish a viable Short Sea Shipping VT service is 48 vessels which make up less than 1% of the European short sea vessel fleet (Deliverable 2.4).

5.4.2.2 Flexibility of Vessels

Further, the VT is most beneficial for VT users with fast vessels. However, operators of fast vessels need to be flexible to adapt to slower VT operating speeds (3-8kn slower). Smaller vessels that use the VT, do not need to be as flexible, as their vessels operate in their intended environment. Nevertheless, the benefits for slower vessels are significantly smaller, as no fuel savings are achieved on top of the crew savings (Deliverable 2.4).

5.4.2.3 Route Lengths Restrictions

The next parameter which needs to be checked is the length restriction of the route. Based on that, if no monitoring crew is needed, all assessed vessel types have viable conditions for a distance of 500 nm. Further, the route lengths restrictions are larger for the slower vessels and also it is most beneficial to use the VT services for longer routes because waiting times have a smaller impact on productivity (Deliverable 2.4).

5.4.2.4 Number of Crew Members

Short Sea Shipping sets a fixed crew reduction target of three crew members based on the results of Kooij and Hekkenberg (2019), which is the expected crew reduction caused by the implementation of the VT. The authors conclude the crew to shrink by the second officer and two deckhands (Deliverable 2.4).

5.4.2.5 Adaptation of Slow-Steaming Principle

Next to the fact that the main benefit of the VT application is obtained by reduction of crew numbers and crew cost, a much larger benefit can be generated by the adaptation of the slow-steaming principle in VT service for the Short Sea Shipping sector (Deliverable 2.4).

5.4.3 Danube case (Rhine- Danube corridor)

As Deliverable 2.5 is still underdeveloped, a complete assessment of the Danube case is not yet possible. However, in this section, the preliminary results of the Danube case are given.

5.4.3.1 Cargo volume

After having collected the cargo volume data for the Danube it can be concluded that the cargo volumes are much smaller than for the Rhine region. However, the sailing distances are larger. This means that less cargo is needed to set up the VT system, compared to the Rhine case.

5.4.3.2 Business Model Choice

Based on the evaluation of four available business models (BMs), it is revealed that there are two BMs namely BM3 and BM4 which are more applicable in the IWT sector. The situation of the IWT market plays an important role to choose the best BM between BM3 and BM4. If the IWT market is made out of small and medium enterprises which are called the *fragmented market*, the BM4 is the best one to apply. However, if the IWT market is a *concentrated market* that includes many large companies, thus, the BM3 can be used as the best option. Given the fact that in the Danube case a more concentrated market is observed than in the Rhine case, BM3 will be more favourable (Figure 7).

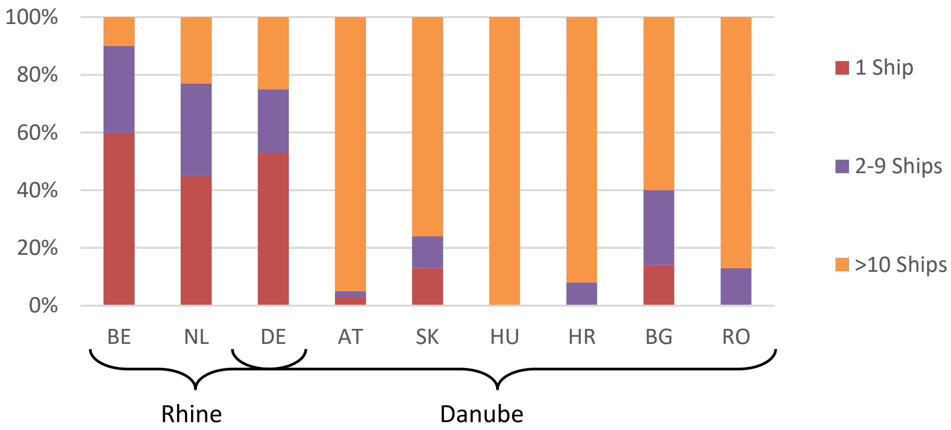


Figure 7: Inland Ship Owners Expressed by the Number of Ships Owned

Source: (A. P. Colling et al., 2021)

5.4.3.3 Departure Time

The VT evaluation displays positive and effective results if the Lead Vessel is either Class 5 or Class 6. Given the longer routes, the smaller fleet size and cargo volume on the Danube, the departure interval needs to be increased. Hence a departure interval of once per day (every 24 hours) is deemed appropriate for the Danube case to meet realistic participants requirements

5.4.3.4 Number of Crew Members on Board on each FV

The potential cost savings by reducing crew members in the Danube region is less than on the Rhine case. This is mainly due to the fact that the wages of crew members in the Danube region are much less than in the Rhine region. In Table 6 can this difference be observed. In this table, the Serbian wages for inland crews are compared to that of the Rhine fleet. The wage differences differ on average 77% between the two regions. The total crew cost savings achieved through the VT implementations are therefore much lower in the Danube region than in the Rhine region.

Table 6: Annual wage of inland crew per role

Role	Boat master >86m	Boat master 70-85m	Boat master <70m	Helmsman	Boatman	Apprentice
Dutch	€ 48.800	€ 47.800	€ 47.000	€ 39.900	€ 39.500	€ 34.900
Serbian	€ 17.600	€ 16.200	€ 14.800	€ 9.500	€ 8.800	€ 7.500

Source: (A. P. Colling et al., 2021)

5.4.3.5 Business Economic Evaluation of the VT

The full business economic evaluation of the VT for the Danube case is still under development. In the first stage of the analysis, the application of the VT is checked from a cargo owner perspective. The preliminary results that are found so for are presented below:

- The best VT application[6] is a VT that will sail between the following regions: ’Regensburg, Passau, Somovit, Ruse, Silistra’’ (see also figure 5). For this VT, the business economic evaluation for the CO is positive in all considered scenarios (different BMs, the application of cargo consolidation and the Novimar handling equipment). This VT is also one with a very long sailing time of the FV in the VT, which makes that a lot of benefits are obtained (reduction crew cost).
- The segments that are included in this VT have net benefits for cargo owners of the following cargo types:
  - liquid bulk cargo
  - containers
  - dry bulk cargo.
- The positive effect of the new cargo consolidating system capability has little benefits for the Danube as
- The capability of new cargo systems such as the Novimar cargo handling vehicle and the cross-transfer platform has a positive impact on the business economic viability of the VT from the perspective of the CO for the Danube case.
- If there are two crew members on board, when applying the BM3, VT capabilities need to be also used in order to boost the business-economic viability of the VT concept.

For the Danube case two additional elements are found:

1. The VT business model in which all vessels are owned by one vessel owner is the best BM to use. This also fits better with the market structure in the Danube region (more larger shipping companies).
2. A large part of the cargo being shipped on the Danube is done in push convoy (85% of all IWT volumes). These convoys are excluded from VT so therefore an additional analysis is made. In this analysis, the share of cargo being transported with push convoys is lowered to see how

[6] Which has the largest Cargo Owner benefits

the VT could compete with these convoys. From the CO analysis was concluded that in all situations (with or without push convoys) there are benefits for the cargo owner.

5.4.3.6 Welfare Assessment

Also with respect to the welfare assessment, no results are possible. However, if the external cost of VT is less than the external cost of the current situation (when No VT is used), therefore, VT composition is applicable. Also for the Danube case, in the case of negative business-economic evaluation, the external cost savings of the VT composition and current situation (No VT) should be compared. The positive welfare assessment (in favour of VT service) might compensate for the loss of business-economic evaluation which might provide an incentive for the establishment of VT service.

5.5 Possible solutions to overcome identified shortcomings

Based on the performed analysis only a few shortcomings are identified.

The main shortcoming that can be identified is the regulatory change needed to allow sailing with fewer crew members which makes that less crew available on the bridge, which makes that the reaction times in case of emergencies are different. Next to that an autonomous system now needs to make decisions regarding the track of the FVs. This can be solved by the regulatory bodies if we can show that the VT system is:

- Safe.
- It makes sense business-wise.

Another shortcoming is there is no insurance policy to make the VT for the Rhine case (platform business model) possible. This means that the insurance cost for both the FV owner, as well as the LV owner will go up. These extra costs could, potentially, be compenetrated by a subsidy if the criteria mentioned in sections 5.4.2.5 and 5.4.3.5 are met.

The last main shortcomings are obstacles on the FT route. As there are many locks that need to be passed in which it is not possible to cluster, the main benefit of using the VT can disappear. Therefore if the lock passages are clustered within a short stretch of the river, the crew can plan such that they take over navigation for a given time span. An additional shortcoming is the added waiting times created at smaller locks, which do not allow the entire vessel train to pass in a single cycle. This means larger looks could be considered as an infrastructural adjustment that can improve the shortcoming.

Other infrastructural adaptations could be made with regards to the gathering or cluster arrival areas at the final destination port, which needs to allow for vessels to wait for the departure of the train without being in the way of the operating vessel.

The fragmented business structure along the Rhine could also be viewed as a shortcoming as it required additional funds to create a platform that coordinates all individual parties. If these parties were to join alliances or restructure themselves as part of a larger organization, smoother cooperation and data sharing can help optimize VT networks and minimize waiting times.

Another shortcoming of the current locations is unpredictable port departures, which emphasized the need for waiting times before the departure of the VT transport system. However, if these departure intervals become more predictable waiting times may also be minimized.

5.6 Decision tree development

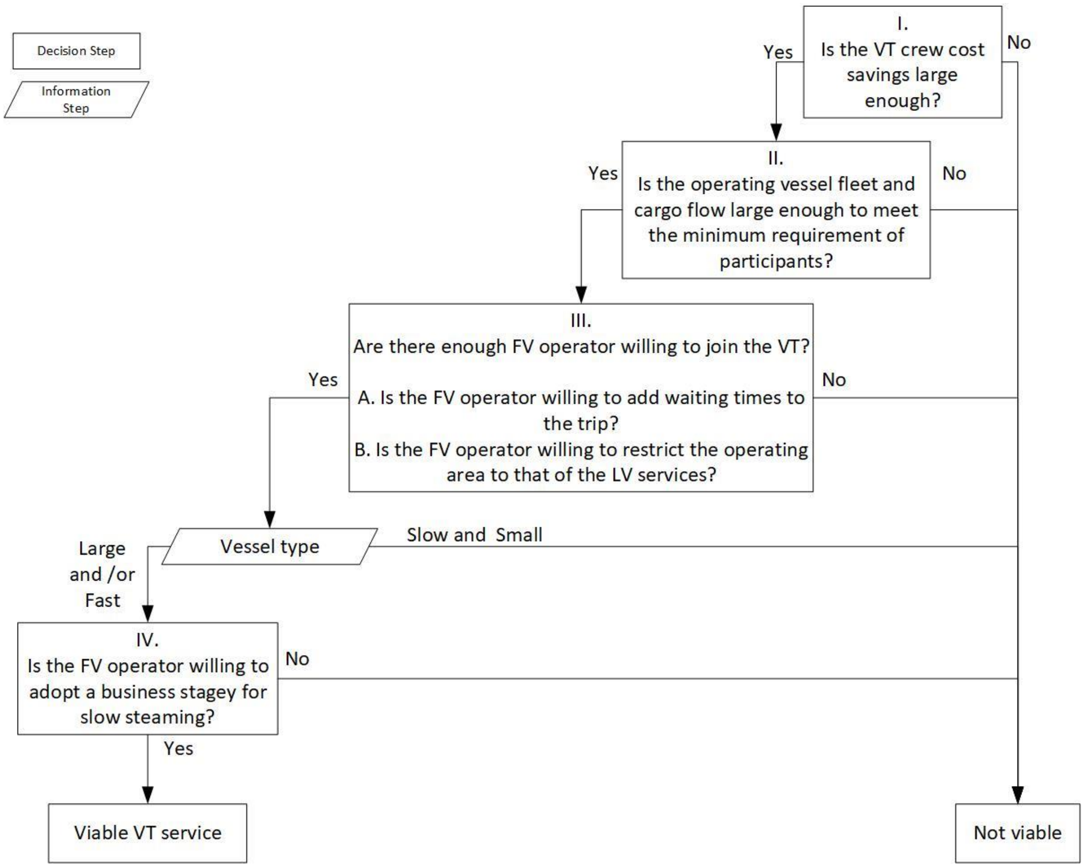
Based on the previous sub-tasks, decision tree diagrams have been developed that provide insights on the VT-application in different geographical areas. In this analysis, a distinction is made between short sea (SS), inland (IWT) and urban area vessel trains.

5.6.1 Decision Tree for the SS sector

In

Figure 8 the decision tree for the SS sector is given. Below the figures, each decision step is briefly described, and reference values are provided to guide the decision-making process.

Figure 8: Decision Tree for the SS sector



Decision step 1: crew cost savings

The case studies have shown that a fully established VT concept create costs €25.000 per LV, for which the VT organiser has to be compensated for or which have to be outweighed by the benefits of a company. At an early stage of implementation, where the technology may still need monitoring, this cost rises to €180.000 per LV. However, for those cases, a VT length of up to five FVs can be expected, which means a cost of €36.000 per year per FV is plausible (A. P. Colling & Hekkenberg, 2020).

In the short sea sector, it is expected that the crew size can be reduced by a 2nd officer and two deck boys. With a vessel operating under a western European flag with a high-income crew, this cost savings sums up to about € 155.000 per FV. A vessel that sails under a different flag with the crew from low-income countries, such as for instance Algeria, can have 90% smaller savings through the crew reduction. In those cases, the savings need to be at least as much as the annual costs divided by the number of FVs, which can be expected around €36.000 per year per FV.

Decision step II: Fleet size and cargo flow

The fleet size can be one indicator to determine the number of vessels operating in the area. However, knowing the fleet size alone is not sufficient as the geographical distribution of the fleet also needs to be known. An indicator to determine the traffic density is to look at cargo flows between specific locations. These two indicators need to be converted to the number of VT participants required in the transport system. The number of participants can be calculated using $2 * \frac{return\ trip\ time}{departure\ interval}$ if the VT service is fully matured. The case study of a VT service between Hamburg and Le Havre showed that with a departure interval of every 6h about 48 participants are needed, which are less than 1% of the European short sea fleet.

Decision step III.A: Additional waiting times

The time the FVs spends waiting before the departure of the VT, reduces the overall productivity of the FVs. The more trips are spent in the VT the more waiting times are created and hence the reduced productivity of the vessel needs to be compensated by the VT benefits. So the most benefit is gained by using the VT for long trips spending a long time in the train and simultaneously reducing the number of VT used which minimises the additional waiting times.

This question emphases operational changes the FV operators have to consider when they join the VT. In the case studies, it was assumed that the liner service departs every 8 hours, which means an average waiting time of 4h has to be expected for every VT trip. This is an estimation based on a trip length of about 900 km. Shorter trips of 550 km can expect an average waiting time of 3h.

Decision step III B: Restricted access flexibility

In addition to these waiting times, the FV operator also has to be willing to restrict its operating area to that of the LV services plus 8h of sailing under its own navigational control, before and after the joining the VT. Once the crew members are taken off-board, there are no longer sufficient crew members to safely operate the vessel continuously under its own navigational control. FV can then only sail for a limited time with their reduced crew.

This restriction in flexibility is particularly an issue in a waterway network with a lot of branches leading into different directions that are too far apart to be reached in an 8h sailing shift. For a waterway network that operates mainly on a single backbone, this is less of a problem.

Information step: Differentiate between vessel types

The information step distinguishes between different vessel types: the large and\or fast vessels and small & slower vessels. The short sea case study has shown that large vessels (~≤9000t GT), but also fast vessels (~≥30 km/h), are able to obtain benefits in combination with a slow steaming business strategy. Vessels that are both slow and small, do not benefit from the VT as they are impacted by the reduction in productivity due to the waiting times, and cannot achieve slow steaming benefits.

Decision step IV: Slow steaming

As mentioned in the information step, the willingness for FV to adapt their operating speed to the other participants in the VT is vital for the viability of the concept. The additional fuel cost savings provide the largest finical benefit to which the crew cost saving in the VT can be added. However, reducing speed to save crew costs and obtain the additional benefit from lower speed is sensible only when it fits the business case of the VT user

5.6.2 Decision Tree for the IWT

In

Decision step I: Fleet size and cargo flow

The VT operating conditions (i.e. the operating speed, the departure intervals, and the journey length) have an influence on the minimum number of participant. The sample Rhine case study over a distance of 325 km and a departure interval of 6h requires 20 participants as part of the transport system. These 20 participants make up less than 1 % of the self-propelled vessel fleet on the Rhine (A. Colling et al., 2021). A case study on the Danube over a distance of 1400 km, with a single company or a small alliance of companies operating the VT, up to 53 participants are required. These 53 participants make up about 11 % of the self-propelled vessel fleet on the Danube (A. P. Colling et al., 2021).

Decision step II: Business size of companies

The business structures may differ between application areas. The Danube case study showed that the operations of large companies would better accommodate the single company business model. Whereas on the Rhine, the market is mainly composed of small single vessel business. Hence, there the subscription-based model would be more appropriate.

Decision Step III: Crew cost savings

In a lower-income country, where the crew cost savings are expected to be low (about €80.000), it is important that the FVs stay sailing in the train for a certain part of the journey, in order to ensure that sufficient savings are generated during that time to compensate for the cost caused by the added waiting times. The Danube case study has shown that a distance of at least 230 km needs to be sailed as part of the VT, if combined benefits of several vessel types are considered. If the typical trade pattern of a ship forces it to operate outside the VT for a significant part of the time, benefits will be strongly reduced.

Figure 9 the decision tree for the IWT sector is given. Below the figures, each decision step is briefly described, and reference values are provided to guide the decision-making process.

Decision step I: Fleet size and cargo flow

The VT operating conditions (i.e. the operating speed, the departure intervals, and the journey length) have an influence on the minimum number of participant. The sample Rhine case study over a distance of 325 km and a departure interval of 6h requires 20 participants as part of the transport system. These 20 participants make up less than 1 % of the self-propelled vessel fleet on the Rhine (A. Colling et al., 2021). A case study on the Danube over a distance of 1400 km, with a single company or a small alliance of companies operating the VT, up to 53 participants are required. These 53 participants make up about 11 % of the self-propelled vessel fleet on the Danube (A. P. Colling et al., 2021).

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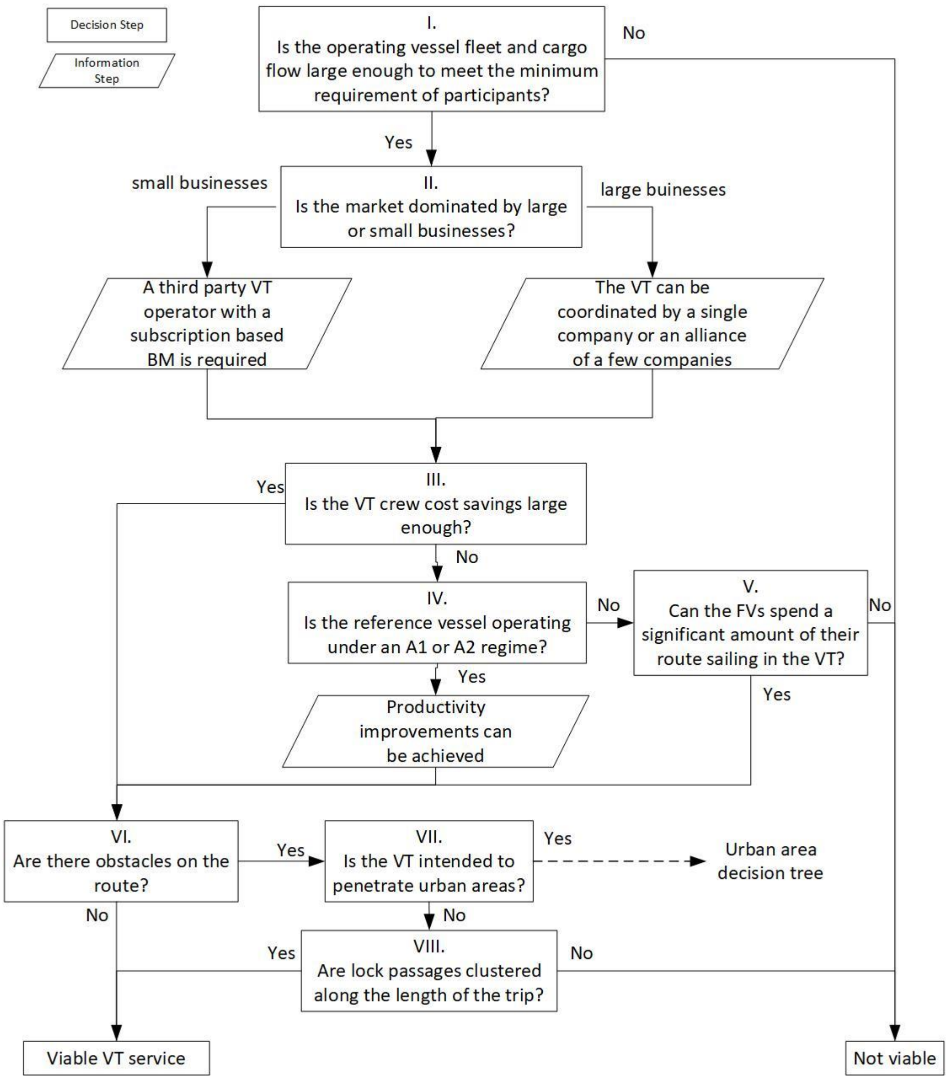
Figure 9: Decision Tree for the IWT sector



Decision Step IV: Reference vessel operating regime

The VT costs that need to be compensated for are equal to the values presented for the short sea decision tree. i.e. €25.000 per LV in a fully matured VT stage and €36.000 per year per FV in case monitoring crew are needed on the LVs. It should, however, be noted that the subscription-based business model is likely to also require additional cost for a platform, operation with which the VT is coordinated. These can make up an additional €350.000 annually that need to be distributed over the FVs. In the earlier described Rhine case with the 20 participants from which 10 are FVs, this would mean that each participant needs to achieve close to €60.000, for a fully matures VT stage, (€71.000 if monitoring crew is needed) of cost benefits from the VT including the standard annual VT technology cost for the LVs. Such an additional cost does not arise for the single company business model.

It is expected that changing the crew size from the minimum requirements of the B regime (continuous operations) to that of an A1 regime (14h of operations per day) can save as many as four crew members. The ultimate crew cost savings are dependent on the crew wages. In a high-income country such as the Netherlands crew saving of up to €390.000 can be achieved. In a lower-income country such as Serbia, along the Danube, these savings can be expected to be about €80.000 per ship per year.

Decision step V: Minimum distance spent in VT
It may occur that the current vessel already operates with a crew of an A1 regime. This is mainly expected in areas where small businesses are operating, which means that no crew cost savings are achieved. Instead, the productivity of the vessel can be dramatically improved as it can sail through the daily resting periods. The Rhine case study has shown improvements of up to 60% if the FVs spend the entire length of their journey part of the VT.

Decision step VI: Obstacles
Obstacles can exist in the form of lock passage, bridge height and opening or water depth bottlenecks, that will require vessels to perform special manoeuvres. Since it is assumed that the system cannot automatically pass locks, the crew needs to be called onto the bridge to navigate through special manoeuvres. This will disturb their resting period, which may lead to regulatory problems that prevent the use of a small crew.

Decision step VII: Penetrating urban areas
If VTs are to penetrate urban areas, some further decisions need to be taken into consideration. These are further elaborated upon in the IWT urban area decision tree.

Decision step VIII: Clustered lock passage
Lock passage is difficult for VT operators. The clustered arrival of many vessels can create additional waiting times since not all vessels in the VT will be able to pass the VT in a single cycle. However, these additional waiting times are of fairly minor consequence compared to the difficulty badly spaced lock passages can bring to the VT users. If the lock passages are clustered within a short stretch of the river, the crew can plan such that they take over navigation for a given time span. Yet, if the lock passages are spaced such that every few hours the crew has to take back control and hence cannot rest appropriately, the benefit of the VT operations are no longer translated effectively.

5.6.3 Decision Tree for IWT in Urban Areas

In

Figure 10

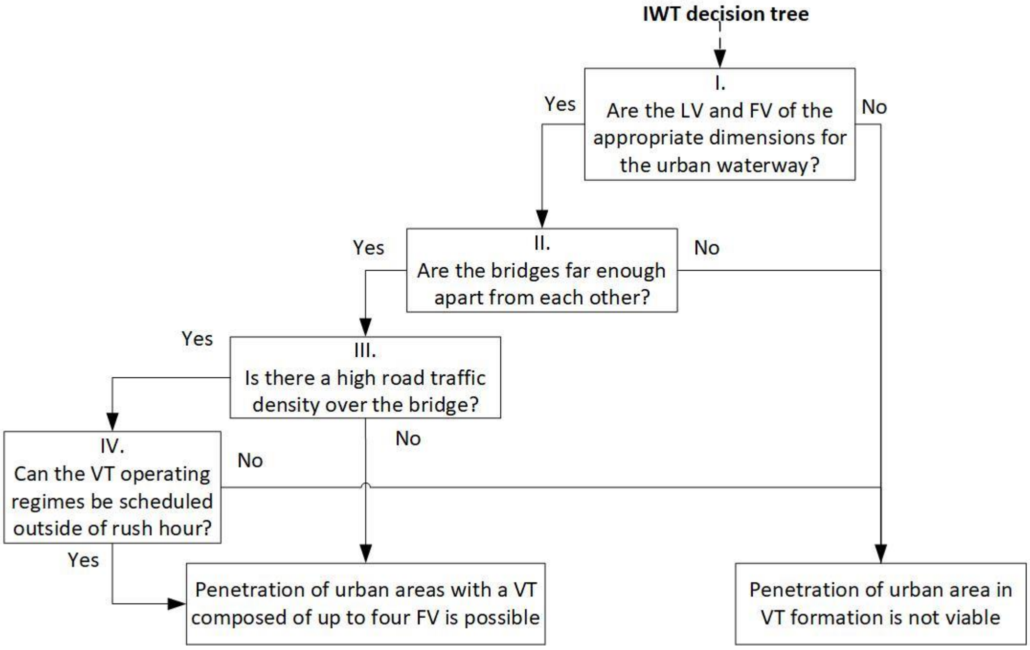
Decision step I: Fleet size and cargo flow
The VT operating conditions (i.e. the operating speed, the departure intervals, and the journey length) have an influence on the minimum number of participant. The sample Rhine case study over a distance of 325 km and a departure interval of 6h requires 20 participants as part of the transport system. These 20 participants make up less than 1 % of the self-propelled vessel fleet on the Rhine (A. Colling et al., 2021). A case study on the Danube over a distance of 1400 km, with a single company or a small alliance of companies operating the VT, up to 53 participants are required. These 53 participants make up about 11 % of the self-propelled vessel fleet on the Danube (A. P. Colling et al., 2021).

Decision step II: Business size of companies
The business structures may differ between application areas. The Danube case study showed that the operations of large companies would better accommodate the single company business model. Whereas on the Rhine, the market is mainly composed of small single vessel business. Hence, there the subscription-based model would be more appropriate.

Decision Step III: Crew cost savings
In a lower-income country, where the crew cost savings are expected to be low (about €80.000), it is important that the FVs stay sailing in the train for a certain part of the journey, in order to ensure that sufficient savings are generated during that time to compensate for the cost caused by the added waiting times. The Danube case study has shown that a distance of at least 230 km needs to be sailed as part of the VT, if combined benefits of several vessel types are considered. If the typical trade pattern of a ship forces it to operate outside the VT for a significant part of the time, benefits will be strongly reduced.

Figure 9 the decision tree for the IWT sector is given. Below the figures, each decision step is briefly described, and reference values are provided to guide the decision-making process.

Figure 10: Decision Tree for IWT in Urban Areas



Decision step I: Vessel dimensions

Most waterways penetrating urban areas will not allow the accessibility of larger vessel classes. This means both the LVs and the FVs have to be of the appropriate size to access these waterways; these are mostly of CEMT class III and under. Such small vessels are usually not competitive on larger waterways where traffic density is higher.

Decision step II: Bridge spacing

A case study performed for the VT penetration into to Amsterdam has shown that a distance of at least 825 m is required between bridges for VTs of up to four FVs, to be able to pass without requiring for more than two bridges to open simultaneously. Four FVs is the minimum viable VT length for class II vessels.

Decision step III: Read traffic density

The road traffic density combined with the arrangement of the road to the next road crossing determines the maximum amount of time a bridge can stay open. For a VT with four FVs, this is expected to be at least ten minutes. The Amsterdam case study has shown that such an opening time cannot be created for all bridges in the area, which means a VT would not be able to provide its service throughout the route without causing traffic jams that would reach further than the roads with direct connected to the bridges.

Decision step IV: Adapting operating schedules

As the traffic flow outside of rush hour is significantly reduced, the bridge opening times are also lengthened during those times. Moving the VT operations outside of rush hours can therefore be a solution to achieve longer bridge opening times. The case study of the Amsterdam area has shown that even in standard traffic conditions, feasible conditions cannot be met unless the VT participants can sail very close (closer than one ship length) to each other, on the crucial stretched of the urban passage.

One can consider Amsterdam as a worst-case scenario for urban penetration, which means that it may well be applicable in other urban areas, that have less road traffic density and more spacing between bridges. Additionally, just because a VT cannot penetrate into urban areas in VT formation does not mean that it cannot influence urban penetration. If smaller vessels can benefit from using the VT for a large part of its way and decuple itself from the train before it reaches urban areas, then the use of smaller vessels will become more competitive.

6 ANALYSIS OF RESULTS

6.1 Summary of results

This deliverable has developed the decision trees which can be used to investigate potential other use areas of the VT concept. In order to do this the definition of the basic conditions and key success factors for VT's are determined. Next to that 3 different potential areas for VT-operations in Europe are studied. These three cases are:

1. IWT application on the Rhine–Alpine corridor
2. A short sea shipping case on the North Sea-Baltic corridor
3. An IWT case on the Rhine-Danube corridor.

These three cases are used to test the viability for VT-operations in potential areas and identification of problems. And for the identified problems, recommendations of possible measures are determined.

Based on the gained insights three different decision trees are developed:

1. One for the short sea application
2. One for the IWT application
3. One for the IWT application in urban areas.

6.2 Analysis of results

In this deliverable, three main decision trees are developed. These decision trees are based on a detailed analysis of different VT cases. With respect to the short sea shipping application the following four main attributes are taken into account:

- The potential cost savings for the vessel owner by applying the VT concept
- The available fleet and cargo flows that could be used to make a VT
- The type of vessel (slow or fast sailing vessels)
- The option of the vessel owner to change its business model (adopt slow steaming principles as they become part of the VT).

From the analysis of the IWT application the main elements that need to be taken into account in the decision trees are:

- Available fleet and cargo flow in the studied region
- The type of freight market (concentrated with larger shipping companies, or fragmented with a lot of small and medium-sized shipping companies)
- The potential cost savings due to crew reduction
- The sailed distance of FV in the VT (1,5 ship lengths)
- Possible obstacles which the VT needs to pass (locks, bridges, etc.).

Finally, for the urban case application we come to the following main elements:

- Vessel dimensions (can the vessel fit on the urban IWT network)
- Bridges and the amount of traffic making use of these bridges
- The possibility to schedule a VT operation outside rush hours.

With these decision trees, it is possible to assess if a VT can be set-up in a specific region. If it turns out that the VT gets a positive evaluation, then the transport model, developed in WP2, can be used to make a more in-depth analysis.

6.3 Corrective measures

There are no corrective measures in this deliverable.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The main result of this deliverable are the three decision trees (short sea shipping, IWT and IWT in an urban context) which are developed. These decision trees are based on detailed analysis of different VT cases (IWT cases on the Rhine and Danube and a short sea case on the north sea).

From this analysis the following main obstacles are identified. These are:

- A reduced crew can lead to more challenging lock and bridges passages.
- There is currently no insurance policy to insure the VT for the Rhine case (platform business model). This means that the insurance cost for both the FV owner, as well as the LV owner could be become very high.
- Another main shortcoming for the implementation of the VT are obstacles on the FT route. As there are many locks that need to be passed in which it is not possible to cluster, the main benefit of using the VT can disappear.
- The fragmented business structure along the Rhine could also be viewed as a shortcoming as it required additional funds to create a platform that coordinates all individual parties.

With the developed decision trees, it becomes possible to assess if a VT can be set-up in a specific region. If it turns out that the VT gets a positive evaluation, then the transport model, developed in WP2, can be used to make a more in-depth analysis.

7.2 Recommendations

- With respect to this deliverable, the following recommendations related to the short comings of the VT concept can be formulated: With respect to sailing with fewer crew members An autonomous system is needed to make decisions regarding the track of the FVs. This can be solved by the regulatory bodies if it can be proved that the VT system is:
    - Safe.
    - It makes sense business-wise.
- With respect to the increase in insurance cost for the Rhine case. These extra costs could, potentially, be compenetrated by a subsidy if the criteria mentioned in sections 5.4.2.5 and 5.4.3.5 are met (if there is a net welfare benefit).
- In order to overcome the many obstacles on the VT route could potentially be overcome if the lock passages are clustered within a short stretch of the river, the crew can plan such that they take over navigation for a given time span. An additional shortcoming is the added waiting times created at smaller locks, which do not allow the entire vessel train to pass in a single cycle. This means larger looks could be considered as an infrastructural adjustment that can improve the shortcoming. Other infrastructural adaptations could be made with regards to the

gathering or cluster arrival areas at the final destination port, which needs to allow for vessels to wait for the departure of the train without being in the way of the operating vessel.

- The fragmented business structure on the Rhine corridor could be overcome if these parties were to join alliances or restructure themselves as part of a larger organization, smoother cooperation and data sharing can help optimize VT networks, VT business models and minimize waiting times.

8 REFERENCES

Colling A., Hekkenberg R. (2020). Waterborne platooning in the short sea shipping sector. in:Transportation Research Part C: Emerging Technologies, Volume 120, 2020, 102778, ISSN 0968-090X, https://doi.org/10.1016/j.trc.2020.102778.

CCNR. (2017). *Waterway Profile of the Rhine*. http://www.ccr-zkr.org/files/documents/infovoienavigable/Wasserstrassenprofil_en.pdf

Colling, A. P., Hekkenberg, R. G., van Hassel, E., Vidić, M., & Bačkalov, I. (2021). A Comparison of the Application Potential of Waterborne Platooning for the Danube and the Rhine Corridors. *The Journal of Transport Geography (under Review)*.

Colling, A., Van Hassel, E., & Hekkenberg, R. (2021). Waterborne Platoon on the Lower Rhine. *Maritime Policy and Management (under Review)*.

Meersman H., Moschouli E., NanwayBoukani L., Sys C., van Hassel E., Vanelslander T., Van de Voorde E. (2020). Evaluating the performance of the vessel train concept in European transport research review - ISSN 1867-0717 - 12:1(2020), 23

Schelling, I., & Boeren, P. (2018). *Evaluatie blauwe golf vervolg*. https://www.watersportverbond.nl/media/5p0fdc2n/evaluatie-blauwe-golf-vervolg_eindrapportage_definitief.pdf

9 ANNEXES

9.1 Annex A: Public summary

This deliverable has developed the decision trees which can be used to investigate potential other use areas of the VT concept. In order to do this the definition of the basic conditions and key success factors for VT's are determined. Next to that 3 different potential areas for VT-operations in Europe are studied. These three cases are:

1. IWT application on the Rhine – Alpine corridor
2. A short sea shipping case on the North Sea-Baltic corridor
3. An IWT case on the Rhine Danube corridor.

These three cases are used to test the viability for VT-operations in potential areas and identification of problems. And for the identified problems, recommendations of possible measures are determined.

Based on the gained insights three different decision trees are developed. With respect to the short sea shipping application the following four main attributes are taken into account:

- The potential cost savings for the vessel owner by applying the VT concept. The available fleet and cargo flows that could be used to make a VT. The type of vessel (slow or fast sailing vessels). The option of the vessel owner to change its business model (adopt slow steaming principles as they become part of the VT).

From the analysis of the IWT application the main elements that need to be taken into account in the decision trees are:

- Available fleet and cargo flow in the studied region. The type of freight market (concentrated with larger shipping companies or fragmented with a lot of small and medium-sized shipping companies). The potential cost savings due to crew reduction. The sailed distance of FV in the VT. Possible obstacles which the VT needs to pass (locks, bridges, etc.).

Finally, for the urban case application we come to the following main elements:

- Vessel dimensions (can the vessel fit on the urban IWT network). Bridges and the amount of traffic making use of these bridges. The possibility to schedule a VT operation outside rush hours.

With these decision trees, it is possible to assess if a VT can be set-up in a specific region. If it turns out that the VT gets a positive evaluation, then the transport model, developed in WP2, can be used to make a more in-depth analysis.

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9.2 Annex B: VT length guidance for different vessel lengths and bridge distances

The table below provides the data for the surface plot provided in

Figure 2. The values from 0 to 14 are the number of Vessels in the VT including the LV.

Table 7: Number of FVs by vessel length and bridge spacing assuming 1,5 ship length safety distance

	Average vessel length [m]													
Minimum bridge spacing [m]	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	0	0	0	0	0
150	0	0	0	0	0	0	0	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0	0	0	0	0	0	0	0
225	1	0	0	0	0	0	0	0	0	0	0	0	0	0
250	1	1	0	0	0	0	0	0	0	0	0	0	0	0
375	1	1	1	1	0	0	0	0	0	0	0	0	0	0
300	1	1	1	1	1	0	0	0	0	0	0	0	0	0
325	2	1	1	1	1	1	0	0	0	0	0	0	0	0
350	2	2	1	1	1	1	1	1	0	0	0	0	0	0
375	2	2	2	1	1	1	1	1	1	0	0	0	0	0
400	3	2	2	2	1	1	1	1	1	1	1	0	0	0
425	3	2	2	2	1	1	1	1	1	1	1	1	0	0
450	3	3	2	2	2	1	1	1	1	1	1	1	1	1
475	3	3	2	2	2	2	1	1	1	1	1	1	1	1
500	4	3	3	2	2	2	2	1	1	1	1	1	1	1
525	4	3	3	3	2	2	2	2	1	1	1	1	1	1
550	4	4	3	3	2	2	2	2	2	1	1	1	1	1
575	5	4	3	3	3	2	2	2	2	1	1	1	1	1
600	5	4	4	3	3	2	2	2	2	2	1	1	1	1
625	5	4	4	3	3	3	2	2	2	2	2	1	1	1
650	5	5	4	4	3	3	2	2	2	2	2	2	1	1
675	6	5	4	4	3	3	3	2	2	2	2	2	2	1
700	6	5	4	4	3	3	3	3	2	2	2	2	2	2
725	6	5	5	4	4	3	3	3	2	2	2	2	2	2
750	7	6	5	4	4	3	3	3	3	2	2	2	2	2
775	7	6	5	5	4	4	3	3	3	2	2	2	2	2
800	7	6	5	5	4	4	3	3	3	3	2	2	2	2
825	7	6	6	5	4	4	4	3	3	3	3	2	2	2
850	8	7	6	5	5	4	4	3	3	3	3	2	2	2
875	8	7	6	5	5	4	4	4	3	3	3	3	2	2
900	8	7	6	6	5	4	4	4	3	3	3	3	2	2
925	9	7	6	6	5	5	4	4	4	3	3	3	3	2
950	9	8	7	6	5	5	4	4	4	3	3	3	3	3
975	9	8	7	6	5	5	4	4	4	3	3	3	3	3
1000	9	8	7	6	6	5	5	4	4	4	3	3	3	3
1025	10	8	7	7	6	5	5	4	4	4	3	3	3	3
1050	10	9	8	7	6	5	5	5	4	4	4	3	3	3
1075	10	9	8	7	6	6	5	5	4	4	4	3	3	3
1100	11	9	8	7	6	6	5	5	4	4	4	4	3	3
1125	11	9	8	7	7	6	5	5	5	4	4	4	3	3
1150	11	10	8	8	7	6	6	5	5	4	4	4	4	3
1175	11	10	9	8	7	6	6	5	5	4	4	4	4	3
1200	12	10	9	8	7	6	6	5	5	5	4	4	4	4
1225	12	10	9	8	7	7	6	6	5	5	4	4	4	4
1250	12	11	9	8	7	7	6	6	5	5	5	4	4	4
1275	13	11	10	9	8	7	6	6	5	5	5	4	4	4
1300	13	11	10	9	8	7	6	6	6	5	5	4	4	4
1325	13	11	10	9	8	7	7	6	6	5	5	5	4	4
1350	13	12	10	9	8	7	7	6	6	5	5	5	4	4
1375	14	12	10	9	8	8	7	6	6	5	5	5	4	4
1400	14	12	11	10	9	8	7	7	6	6	5	5	5	4