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Deliverable T1.2 –

The Overarching Decision Analysis Model (ODAM) Framework Development

Deliverable data

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CONTENTS

List of symbols and abbreviations

VT	Vessel Train
IWT	Inland Waterway Transport
SSS	Short Sea Shipping
TLC	Total Logistics Cost
(S)CBA	(Social) Cost Benefit Analysis
LV	Lead Vessel
FV	Follower Vessel
ODAM	Overarching Decision Analysis Model
ToR	Terms of Reference
WP	Work Package
PI	Performance Indicator
ENPV / FNPV	Economic Net Present Value / Financial Net Present Value
ERR	Economic Rate of Return (ERR)

1 EXECUTIVE SUMMARY

This summary provides concise overview of the results obtained from the work done for this deliverable.

1.1 Problem definition

An Overarching Decision Analysis Model (ODAM) is to be developed that allows a viability assessment of the Vessel Train (VT) concept.

1.2 Technical approach and work plan

The tasks within the development of the ODAM are:

- T1.2.1: Prepare Terms of Reference (ToR) for the ODAM assessment framework
- T1.2.2: Develop the ODAM framework
- T.1.2.3: Develop a method of aggregation, normalisation and weighting of WPs' PIs into indices that will be used in the ODAM model
- T1.2.4: ODAM–method test and validation for VT-variant assessment
- T1.2.5: Prepare the task deliverable

1.3 Results

The ODAM needs to provide quantitative results for the individual actors[1] in the VT to help assessing:

- If the VT provides benefits to the various affected stakeholders in the transport system
- If the VT provides benefits to the society

The ODAM structure is split into ten different modules. Modules 1&2 concern the direct (capital, voyage and operational) costs for and external costs from the vessel operator, modules 3&4 do the same for the VT operator and modules 6&7 for the actors that are in charge of cargo handling and the end delivery. Module 5 adapts the cost information into the VT formation and module 8 includes the transport logistics costs, whilst modules 9&10 are assessment steps to benchmark different modes of transport and adapt the viability of the specific business case that is investigated.

A large number of cost elements have been gathered, which are all in some way related to the cost model of the VT.

A four stage aggregation method has been developed that assesses cost elements based on the following three elements, to determine if and at what stage each cost element should be imbedded into the model.

- Impact
- Data availability
- Calculation complexity

The results of the verification of the ODAM elements show that the ODAM procedure and calculations are in line with already published transport models and analyses. This validates the results that will be obtained from testing different scenarios.

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[1] In the present report, the term 'actors' has the meaning with the term 'stakeholders', which is alternatively used throughout the paper to avoid repetition.

1.4 Conclusions and recommendations

From the generic overview, one can see that 20 % of the cost elements can be neglected from the original list. About 40 % of the elements will be integrated at an early stage of the model development and the rest is case dependent, when more information about the concept is known.

The recommendations concerning further research for the VT concept focus on the crew role that is reduced from the follower vessels (FVs) as well as on the identification of the crew requirements for the monitoring tasks on the lead vessels (LVs). On top of that, it is also recommended to research the effects of waiting times caused by insufficient number of FVs.

2 INTRODUCTION

The introduction describes the specific sub-tasks of WP1 that are discussed and elaborated upon in this deliverable. It explains how these tasks interlink and lists specific actions required to be taken as part of each of these tasks.

2.1 Tasks and Purpose

The original proposal document states these deliverable's objectives to be:

"The viability of a VT cannot be assessed by simply adding the results of individual WPs, as these results interact, especially in relation to the VT economic viability. The costs and benefits from WPs 2-6 together determine the costs of a VT-variant […]. For safety and environmental performance, similar interrelations exist. Task T1.2 will thus develop an overarching assessment framework, in which individual results are merged and assessed as part of the greater whole."

The sub-tasks, which have been identified within the proposal, need to be addressed throughout this deliverable. These are identified to be the following:

- T1.2.1: Prepare Terms of Reference (ToR) for the ODAM assessment framework
- T1.2.2: Develop the ODAM framework
- T.1.2.3: Develop a method of aggregation, normalisation and weighting of WPs' PIs (cost elements) into indices that will be used in the ODAM model
- T1.2.4: ODAM–method test and validation for VT-variant assessment
- T1.2.5: Prepare the task deliverable

2.2 Analysis

The first stage of the ODAM development, which is imbedded in T1.2.1, is the identification of the type of answers that the ODAM is to provide, together with a clear description on how these answers should look. T1.2.2 bases its model structure, in which it becomes clear how different actors interact on exactly these ToR. Also, part of the framework setting of the ODAM is the identification of all the possible cost elements that may be affecting any actor within the VT concept. The third sub-task aims to prioritize the different cost elements and by doing to achieve aggregation and normalization of the results that are expected from each element. Based on this prioritization, certain PIs may be examined in the early stages of the ODAM development, whilst others may be 'pushed back' for the later stages or may be completely disregarded from any further assessment. The final sub–task is used to verify the aggregated set of cost elements.

2.3 Approach

The approach taken for each of the sub-tasks is split into specific actions, which are elaborated below.

T1.2.1: Prepare Terms of Reference (ToR) for the ODAM assessment framework

- Determine circumstances under which the VT concept can be viable
- Determine the stakeholders that are affected by the implementation of the VT

T1.2.2: Develop the ODAM framework

- Design an ODAM structure in which the ToR are met
- Ensure that the assessment and variation in scenarios can be accommodated in the structure

- Research possible cost elements that may be impacting the VT concept
- Cluster the cost elements into structured cost categories that allow a better overview for the assessment and variations

T.1.2.3: Develop a method of aggregation, normalisation and weighting of WPs' PIs into indices that will be used in the ODAM model

- Develop a method of aggregation and normalisation
- Apply the developed method by extended research of the cost elements
- Provide the remaining cost elements for implementation to the transport model

T1.2.4: ODAM–method test and validation for VT-variant assessment

- Compare the aggregated results of the PIs with existing projects in maritime cost modelling

A point that becomes apparent throughout this deliverable is the closeness of the WP1 with the WP2 research (on Transport System). Part of the description of WP1, on how the assessment is structured, describes the PIs and provides the cost elements that are part of the overall social cost benefit analysis (SCBA). Many of these elements are explained and calculated within WP2. The WP roles can thus be described in the following manner: WP1 describes the approach, whilst WP2 provides the calculations of the VT cost model.

3 PLAN

3.1 Objectives

The objective of the plan is to accomplish all activities set by the individual sub-tasks and thereby develop the ODAM in such a way that it meets all requirements.

3.2 Planned activities

The specific actions needed to be accomplished for each sub-task to be a success have been presented in the approach (section 2.3). These activities are the planned activities with the added activity of having to write the deliverable report. All these activities are presented in the Gantt chart of the timeline (Figure 1).

3.3 Resources and involved partners

The main part of the work for the development of the ODAM is done by UANTW and TUD. MARLO provides also some input with regards to the cargo side of the operations, i.e. the sorting and storage cost estimations.

The work split between UANTW and TUD is mainly based on the following:

- TUD focuses on the economic private costs that are related directly to the vessels and are created due to the operations of the vessel, but not on authority or service pricing related costs.
- UANTW focuses on the social external costs within the VT transport system as well as on any societal cost that these external costs may cause.

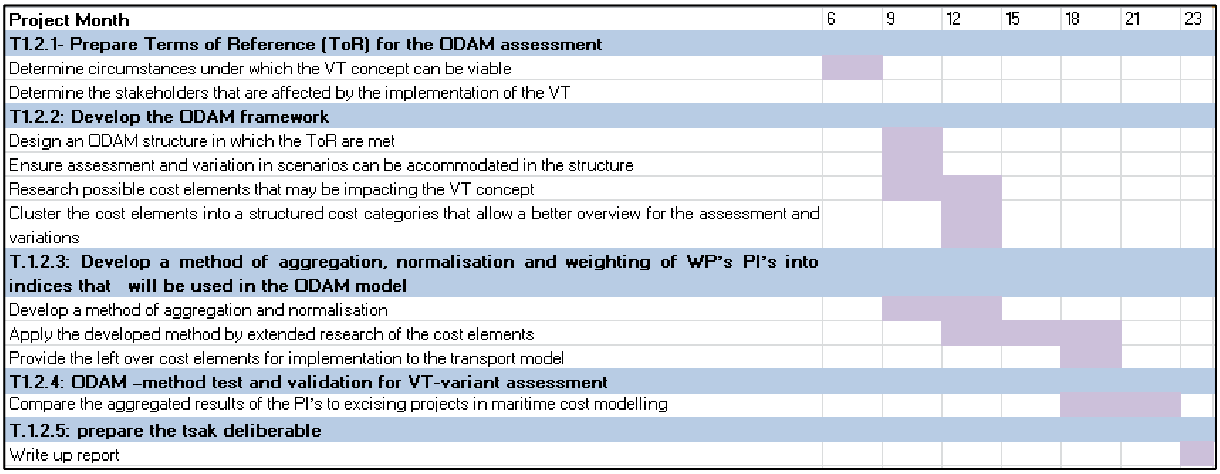
An overview of the work split, with regards to specific cost elements, which will be later discussed in more detail, can be found in Table 1.

	Cost elements of Actors		Responsible partner
Fixed Cost	Capital Cost	Technologies installed on board	TUD
		Capital cost of refit or new built vessels	TUD
		Interest	UANTW
	Operational Cost	Insurance	UANTW
		Crew cost	TUD
		Black and grey water	TUD
		Waste management systems on board/port	TUD
		Repair and maintenance cost	TUD
		Sorting cost	MARLO
		Storage cost	MARLO
		Overhead cost	UANTW
Variable Cost	Voyage Cost	Fuel consumption	TUD
		VT dues	UANTW
		Port dues	UANTW
		Bridge, lock passage cost and canal fees	UANTW
	External Cost – Congestion	Congestion created for the end delivery of goods	UANTW
		Speed/flow relations on the water	UANTW
		Waiting time at locks and ports	UANTW
	External Cost – Infrastructure	Decay to waterways caused by changes in displacement	UANTW
		Marginal external infrastructure costs	
	External Cost – Environmental	Water pollution	TUD/UANTW
		Emission of SOx, NOx, CO2, VOC, GHG and PM	TUD/UANTW
		Sound pollution	TUD/UANTW
		Light pollution	UANTW
		Impact on natural habitat	UANTW
		Accidents	TUD/UANTW

Table 1: Involvement of partners

3.4 Timeline

The timeline for the completion of this deliverable is between months 6 and 23 of the NOVIMAR project. The individual tasks have been planned into a Gantt chart (see Figure 1) that provides a more detailed overview of the planned time spent on each of the tasks.



Project Month	6	9	12	15	18	21	23
T1.2.1- Prepare Terms of Reference (ToR) for the ODAM assessment							
Determine circumstances under which the VT concept can be viable	▨						
Determine the stakeholders that are affected by the implementation of the VT							
T1.2.2: Develop the ODAM framework							
Design an ODAM structure in which the ToR are met		▨					
Ensure assessment and variation in scenarios can be accommodated in the structure		▨					
Research possible cost elements that may be impacting the VT concept		▨	▨				
Cluster the cost elements into a structured cost categories that allow a better overview for the assessment and variations			▨				
T.1.2.3: Develop a method of aggregation, normalisation and weighting of WP's PI's into indices that will be used in the ODAM model							
Develop a method of aggregation and normalisation		▨	▨				
Apply the developed method by extended research of the cost elements			▨	▨	▨		
Provide the left over cost elements for implementation to the transport model					▨		
T1.2.4: ODAM –method test and validation for VT-variant assessment							
Compare the aggregated results of the PI's to excising projects in maritime cost modelling					▨	▨	
T.1.2.5: prepare the tsak deliberable							
Write up report							▨

Figure 1: Gantt Chart of Timeline

4 PLAN EXECUTION

4.1 Introduction

This section summarizes the fact that the plan was executed as expected.

4.2 Performed activities

All planned activities were performed as expected, hence see the approach section of the introduction for the list of the performed activities.

Envisaged activities:

- Sub-task T1.2.1: Prepare Terms of Reference (ToR) for the ODAM assessment framework
- Sub-task T1.2.2: Develop the ODAM framework
- Sub-taskT1.2.3: Develop a method for aggregation, normalisation and weighting of WPs' PIs into indices that will be used in the ODAM model
- Sub-task T1.2.4: ODAM–method test and validation for VT-variant assessment
- Sub-task T1.2.5: Prepare the task deliverable

Role of the partners:

- UANTW (leader) with TUD develop and test the ODAM method and prepare the task deliverable

Input/output relations:

- Task T1.2 receives input from task T1.1

Task T1.2 provides output to tasks T1.3, T1.5, T1.6.

4.3 Deviations from the plan

No major deviations from the plan were encountered.

5 RESULTS

5.1 Introduction

This chapter provides the results of each individual sub-task of the deliverable. The purpose of the ODAM and the affected actors are identified. Furthermore, a step by step description of the ODAM structure and the interrelation between the different actors within the structure is provided, as well as an extensive list of all possible factors that are in any way related to the costs created within the VT transport system. The third section explicates the approach taken in the aggregation of the list of the cost elements and provides a detailed description about which of these elements are integrated into the model at an earlier or later stage and which will be completely disregarded for the assessment. The final section simply serves to reassure that the final set of cost elements is indeed comparable to existing cost models that have been verified and validated.

5.2 Terms of Reference of the ODAM (sub-task 1.2.1)

There are four main ToR that apply to the VT concept and thus by default also to the ODAM. The first two ToR relate to the cost, while the last two relate to the operational aspects of the VT.

1) Does it provide private benefits to the various affected stakeholders in the transport system? A solution will only work if all stakeholders with decision power benefit. If this is not the case, a solution will have to be found to replace a losing actor with a more beneficial stakeholder.
2) Does it provide social benefits? (WP1 addition to the outputs of WP2)
3) How does the navigation of the VT work? (WP3)
4) Is the VT concept safe? (WP5)

Knowing these ToR, it has to be pointed out that 3 and 4 will be taken as given outputs in the form of standalone solutions from WP3 and WP5, and will as such not be elaborated upon in this deliverable.

The assessment of all these four topics helps to determine whether a VT variant is a desirable alternative to conventional inland waterway transport (IWT), Short Sea Shipping (SSS) and Sea-river transportation. Another ToR that is more directly related to the ODAM is the requirement for quantifiable data (see Table 2 & Annex B). The data will make the assessment of the VT concept's viability possible and the determination of the extent of remedial actions to be taken to make the concept viable.

To determine the VT's benefit to society, the societal costs created are examined. For this analysis, it is important to be able to assess costs per stakeholder. To study differences in conventional IWT, the following relevant stakeholders are selected:

A) The IWT/SSS/Sea-river vessel owners
B) VT operators
C) The shipper/cargo owner
D) Others that are not directly affected, like the transport operators that provide pre/end haulage and cargo handling.

The reason why the stakeholder group 'D' is included is not to determine if they benefit from the concept, since for them the situation will be equivalent to current operations. However, they are considered as part of the overall supply chain, since they create costs that are of relevance for the cargo owner. These costs need to be included in order to determine the benefits for the cargo owners, but also in order to provide a fair ground of comparison for the VT, towards other modes of transport. This forms the basis for the benchmarking of the VT concept and its possible business models.

Apart from the societal costs, the economic costs are also examined. Figure 2 demonstrates the current structure of the cost correlation between the different actors. This approach has been proven to be effective in previous studies of IWT competitiveness (Hekkenberg, 2013, ch. 6) and can also be applied to the short sea and the sea-river case.

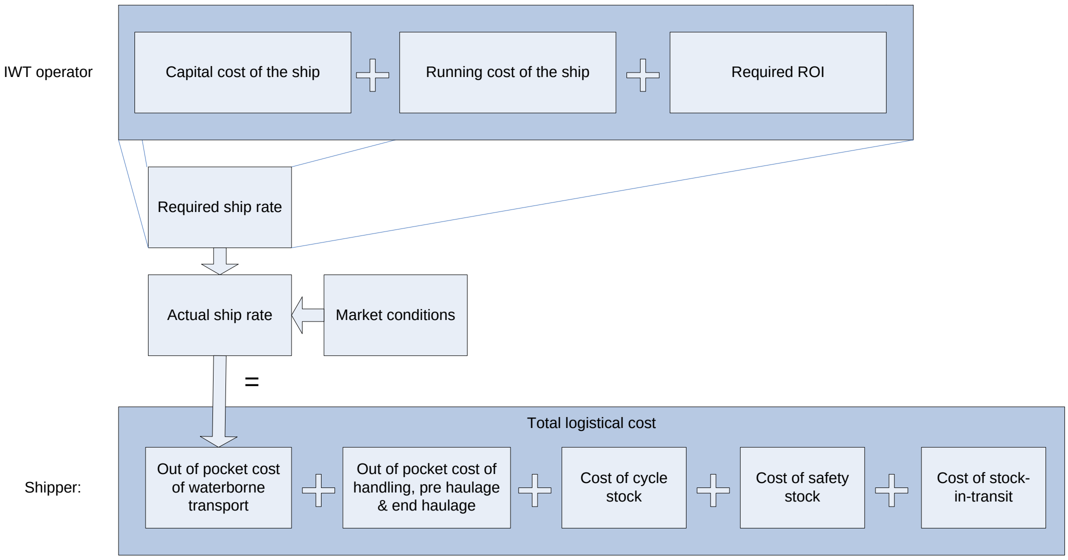


Figure 2: Existing cost model approach from previous study (Hekkenberg 2013)

The element of economic costs of the ODAM is based on this structure with the addition of the relevant stakeholders (see Figure 5). The new actor that is introduced is the VT operator. This actor organizes the transport via the VT and controls the VT. The VT operator incurs cost (e.g. through a shore control station, the VT control system on board and through operating, possibly, a dedicated LV), but does not get income in the same way as the conventional Vessel operators, since a LV does not necessarily carry cargo[2].

The assessment of the benefit of the concept for the shipper/cargo owner is usually done by looking at the total logistics costs (TLC), either with or without internalizing the external costs.

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[2] In D.2.3 the different VT business models are developed. Based on these business models, the role of the VT operator will be known.

5.3 ODAM framework (sub-task 1.2.2)

This section on the ODAM framework will first focus on the way the ODAM is structured and the procedure that it undertakes to calculate the necessary cost elements. Then it will further emphasise how the different WPs contribute with specific research actions and results. At first a description of the procedural steps is given to emphasise the individual requirements the ODAM will have to incorporate within its structure.

To ensure that all ToR can be successfully imbedded within the ODAM, the overall structure has been split into three smaller ones, before coming to overall conclusions. These three assessment blocks are the: 1) identification of the waterborne transport costs, 2) the cargo related costs and 3) the assessment of the business concepts. The following paragraphs explain the steps. The waterborne transport cost are deduced from the technical specification of the vessel, whilst the cargo make up the missing link to the rest of the supply chain for the overall transport system. The final category of the assessment is representative of the final goal that is to be achieved with use of the ODAM and is thus separate of the rest of the cost calculations.

Section 1: Waterborne Transport Costs (private and external)

i) Determine the economic cost of a VT trip for each individual FV (i.e. those vessels that join the train with their cargo and surrender control to the VT operator/LV, and having a reduction in crew). This trip cost is comparable to the cost of a conventional vessel trip, but it also includes the cost created due to the added technologies that are required for the FVs in a VT and also the costs related to the adjustment of the speed, sailing schedule and the associated costs as dictated by the VT (VT fee that is paid by the FVs to the VT organiser/operator).

ii) Calculate the external costs for that trip for each individual FV, so that they can be internalized if desired. It is important to be aware of where the external costs come from and how each actor contributes to them, to be able to potentially internalize these costs appropriately. The internalization of the external costs is an additional assessment option that can be used to estimate future conditions. If the costs are internalized, these will be internalized for all transport modes.

iii) Determine the economic costs for the VT operator (i.e. costs to operate the LV, depreciation of the VT-related equipment etc.). These costs will change with the different business cases that are being considered.

iv) Calculate the external costs for the VT operator. This includes societal costs caused by the LV. The calculation of the external costs per stakeholder/main actor is an important element, so as to be able to understand the true origins of the environmental impact and hence, if needed, to specifically target support mechanisms to make the transport concept efficient.

v) Sum all economic and, if applicable, internalized external costs and determine how the total cost & income shall be divided over all the followers and the VT operator. (Note that you can only do this if you know the costs of each individual actor in the train!)

Section 2: Cargo Related Costs

vi) Add the costs (economic and external) of handling and pre/end haulage that are missing. These costs are the same as the current cost of cargo handling and haulage. This land side cost of the transport system is required to be known for the completeness of the total transport cost.

vii) Calculate the overall external costs for the landside operations.

viii) Insert all the relevant aspects of the VT operation (cost, reliability, transit time etc.) in the relevant parts of the TLC calculation for the shipper; the water based and the landside transport costs together for the total transport cost that are of interest for the cargo owner.

Section 3: Assessment of business concepts

ix) Assess if the VT variants provide benefit to all stakeholders and society and find solutions to occurring problems.

5.3.1 Overall Structure

Based on the above described approach of the ODAM, a structure to identify the main elements which are needed in the assessment has been developed, ensuring every one of the identified tasks are incorporated in the overall structure This structure is built up of ten different modules (see Figure 3). These modules split up the overall structure into clear segments that allow a comparison between the different actors. A visual representation of the interdependence of the stakeholders as well as the identification of different calculation levels is provided in the scheme.

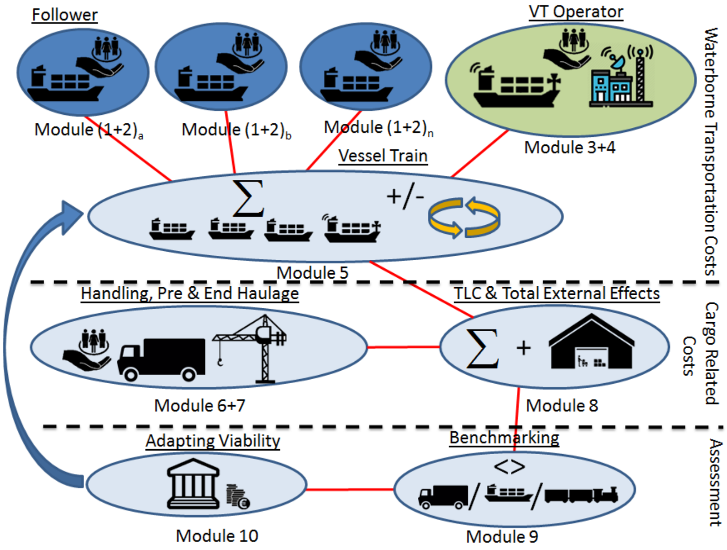
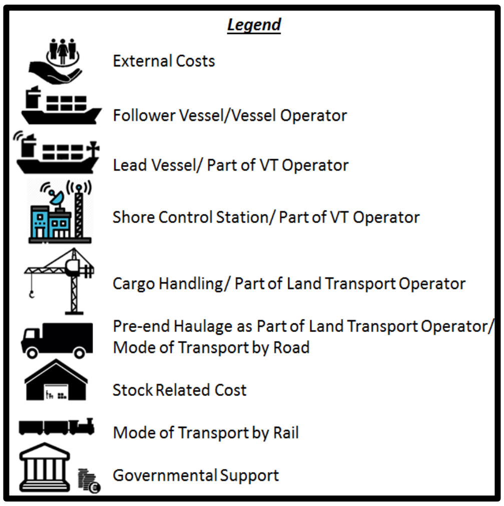


Figure 3: Identification of the main elements to be included in the ODAM

Module 1: Economic Costs of Vessel Operators
(where *a* to *n* represent different Vessel
Operators that can join the VT)
Module 2: External Costs from Vessel Operators
Module 3: Economic Costs of VT Operators
Module 4: External Costs from VT Operators
Module 5: Costs for the Entire Train & Cost Distribution Among Actors
Module 6: Economic Costs of Pre/End Haulage & Handling with Different Modes of Transport
Module 7: External Costs from Pre/End Haulage & Handling
Module 8: Total Logistics Cost of Cargo Owner
Module 9: Relation to Benchmark
Module 10: Adapting Viability



The economic transport costs for the FVs' operators are calculated in module 1. The impact that each operator has on societal welfare is determined in module 2. These external (societal) costs are determined for operations within and outside of the VT, to encompass the full impact of each individual vessel on society. The societal costs are congestion, infrastructural, environmental and accidents related. Individual vessel properties influence both the economic and societal costs, hence modules 1 and 2 are computed for a variety of different vessel operators that compose the VT.
Modules 3 and 4 are the cost assessment equivalent of modules 1 and 2, but with a focus on the VT operator. Thereby, costs such as for shore control station that coordinates the formation of VTs are integrated into the overhead cost of the VT operator. The societal costs of the module 4 incorporate both the costs created by the leading action and the costs added by the tagging of all followers.

Module 5 brings all previous modules together to estimate the total costs of the VT operation. The incorporations of the two different types of actors into the VT concept need to be done with caution, so as not to double count external cost factors that are present within both modules 2 and 4. As an example, a single vessel may add to congestions costs, when the opening of a bridge is needed. This is of course increased, when instead of a single vessel now a VT is passing, since there are more vessels. Yet, the individual vessel still makes the overall VT longer, so the impact that an individual vessel has on a VT is different than the cost impact that it has when it sails on its own. Figure 4 demonstrates in a simplified manner the VT costs calculations.

The next cost elements are of interest to the overall transport system but no longer to the actual VT operation. Even though the vessel operators are directly influenced by the un/loading, it is the land-based transportation stakeholder that is concerned with the costs for the final leg. This is the reason why a separate emphasis is given to the cargo handling and haulage of the goods in module 6. This land-based part of the transportation system of course also brings social cost with it, which is elaborated upon in module 7.

Module 8 sums up the information from the VT and the land-based handling to determine the overall costs for the cargo owner. Additional to the economic transport costs are stock related costs that are dependent on the business strategies (see TLC indicator in D2.1). These stock related costs do not create any additional external costs for the given trip. The societal impact is hence included by summing the internalized societal costs of the other modules.

The third section of the ODAM will actually analyse the data for various business cases that have been created up in module 9. It benchmarks the different business concepts against current cases of waterborne and alternative modes of transport, to determine its economic and societal benefit as a whole. It is implied in this that the societal costs will of course, also be determined for the other modes of transport. Every procedural step that is done to the VT transport system will be equally done to any scenario it is compared to, to allow a fair comparison.

The final module 10 gives the opportunity to adapt business cases, which have been deemed ineffective by their results. These adaptations can be either conceptually made by trying and reworking the circumstances and iterating the entire process back from module 5 onwards or by considering governmental support approaches. In the latter case, the societal impact determined within modules 2, 4 and 7 is compared and brought together to be able to allow cost adjustments. This is the reason why it is important to understand the individual societal cost contributions of each actor to the overall transport concept.

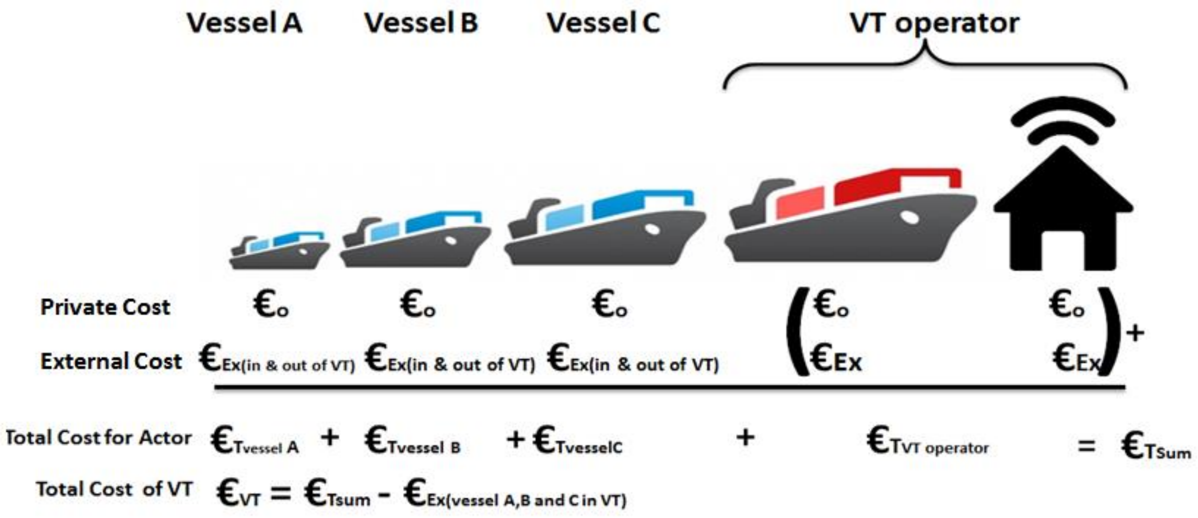


Figure 4: Cost Composition of the VT

The main point of investigating each actor individually, is to calculate the cost difference for the several actors. The difference gives the changes that the VT brings compared to the current situation. If there is a cost reduction, this will be a net private benefit. If external costs are also included, this determines the net societal benefits.

Figure 3 describes the approach and structure of the ODAM, yet it is not explicitly mentioned how the NOVIMAR project is working towards obtaining information that allows this assessment to be made. Figure 5 clarifies how and with what information the different WPs contribute to the ODAM.

The following inputs are taken from the different WPs:

- The private economic benefits of the different actors are calculated in WP2 and can be used as inputs in the ODAM model. The private benefits are determined for the following actors:
  - The IWT/SSS/Sea-river vessel owners
  - VT operators
  - The shipper/cargo owner
- In order to calculate the potential societal benefit of the VT, also the external costs of the VT along with the other transport modes (rail and road) need to be taken into account. These external costs are determined in this deliverable (WP1).
- WP4 will provide input to WP2, with respect to the new vessel types and the cargo loading systems.

For the navigational aspects, WP3 will deliver a system that either works or does not work. This input to the ODAM is therefore a 'yes' or 'no'.

- For the safety aspects of WP5, the same approach is used. Based on the results of WP5, the conclusion can be drawn that either the VT system is safe or it is not. If the VT is not safe, WP5 can advise on what should be done to make the VT safe. If those measures are brought forward, in the ODAM we can accept that that the VT is safe.
- WP1 provides the data concerning the external costs for the social cost benefit analysis (SCBA). This is a part of the ODAM. However, the economic costs calculations need to be also made via the model presented in WP2, so as to be able to obtain data differences dependent on the different variations of the VT. Thus the external costs are pulled out of WP1, in a form of a 'cost per unit per km' value, and feed back in together with the rest of the economic costs that are calculated in WP2.

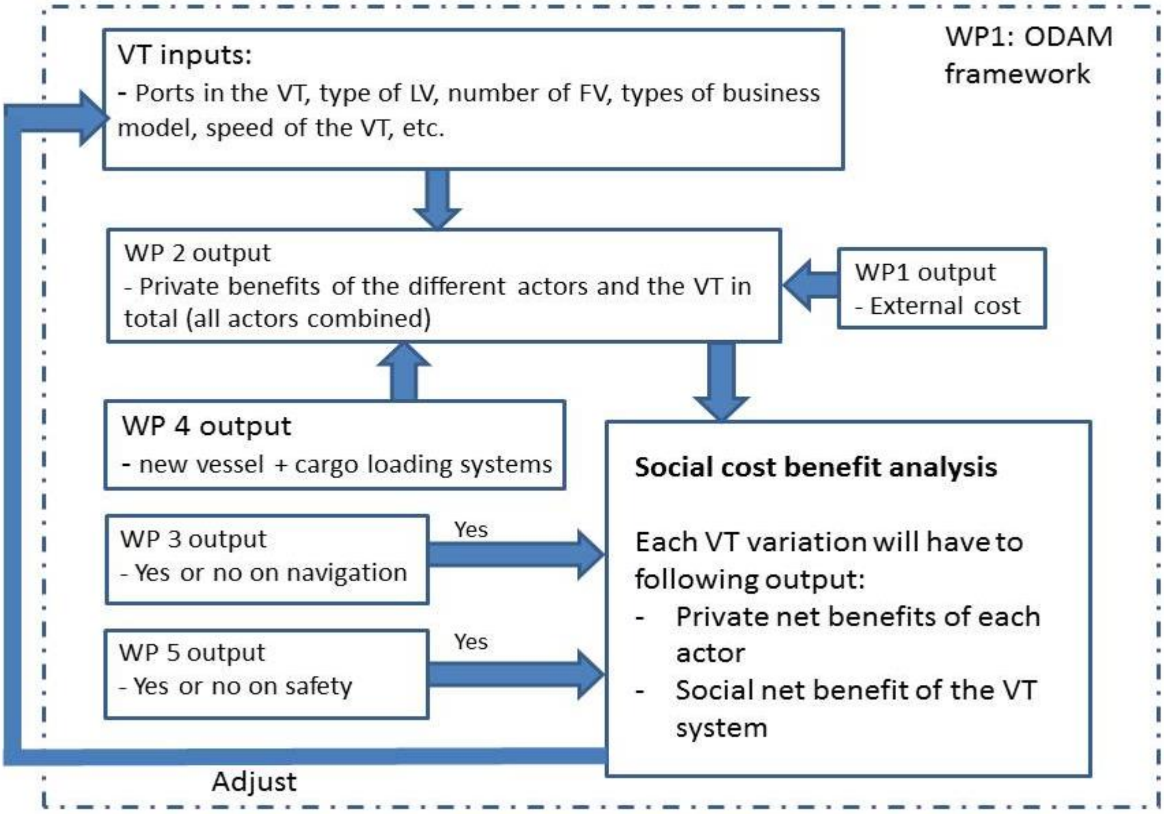


Figure 5: Overall ODAM structure

5.3.2 External Cost Elements

Now that the structure of the ODAM is clear, it is time to get to the cost elements that are filled into this structure to provide quantitative data for the analysis. In order to ensure that all possible cost elements are being considered without risking any areas to be left uncovered by the NOVIMAR research, a long list of such elements has been composed. The basis of this list is existing transport projects in the maritime sector but also in alternative modes of transport. Secondly, to ensure that research and modelling time is used efficiently, a prioritization between the cost elements needs to be set, which allows more detailed assessments of the VT concept, if the need arises. Most of the sources used as inspiration for the cost elements are SCBA sources.

Examples of studies that are specifically looking at the maritime sector are: van Essen et al. 2012; TRT Transortie Territorio Srl, 2007; Jiang, Kronbak, and Christensen n.d.; Kehoe, Connor, and Trant 2010; Kretschmann, Burmeister, and Jahn 2017 and Miola et al. 2009. However, also sources such as Apicella, Fiorello, Malgieri, & Scatamacchia, 2012, European Commission, 2014, Korzhenevych et al., 2014 and Waldhoff, Anthoff, Rose, & Tol, 2014 were either comparing different modes of transport or specifically focusing on road. The road transport sector has more data available on external costs created by accidents, congestion and noise pollution, than the waterborne transportation sector does. The list of the gathered cost elements is presented in Annex B. It also indicates specific references for each of the topics.

5.4 Method of aggregation, normalisation and weighting of PIs (sub- task 1.2.3)

This sub-task deals with the development of the method to incorporate the different outputs of the different WPs.

The long list of cost elements that was obtained as a result of the sub-task 1.2.2 needs to be filtered on application relevance for the VT concept and data availability on the quantification of each cost element.

To be able to determine the relevance of each of these topics, a four-stage evaluation method has been set-up. By the end of the method's application on the cost elements' list, detailed information on the impact, data availability and calculation complexity is known.

- The first stage identifies the possible impact of the cost elements compared to the overall expected cost. If any cost information of the cost element compared to the total cost of transport is known, then this is taken as the main indicator for the classification. If such information is not available, a judgement based on source descriptions is made to determine the either large/low impact. The impact is dependent on the business case application.
- The second stage determines whether there are any, and if so, sufficient data available do the respective calculations. Sufficient data are identified by either a variety of sources that provide values within a similar range and thus form a solid basis of using the value as impute assumptions for the model, or by obtaining all data units needed to allow a calculation of the cost element within the model. The result answers for this stage are thus: yes or no.
- The third stage determines the simplicity of the calculations needed to obtain usable data for the model. A calculation of high simplicity would be a situation in which standardized values can be used for a cost estimation. A calculation of low simplicity or in other words a complex calculation requires interpretation and processing of large amounts of data together with numerous calculation steps. This categorization of "low" simplicity also considers any kind of adjustments needed to normalize all data to a quantitative cost value in Euro.
- The final categorization takes all the scores from the previous stages into consideration. This last categorization is the one that is used as the final prioritization criterion. Here the three options are: 1) The cost element is always included into the assessment, 2) the inclusion of the cost element is dependent on the business case application[3] and may become more relevant at a later stage of the VT development, or 3) the cost element is not included in the assessment.

Figure 6 gives the overview of the type of scores given for each decision stage. The purple diamond describes a special stage of the categorization. There are cost elements that are known to have a large impact on the model, but do not have any data to refer to, since they are directly related to the new concept. In such cases, an assumption is set that is mostly based on experts' opinions. These are included in the early stages of the model. The impacts of such cost elements will be further investigated

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[3] It should be pointed out that the cost elements of the base case (current situation) that is used as a benchmark will be the same cost elements of the VT case application, so as the results to be comparable. The 'new' cost elements that are present in the new situation of the VT application will take a value zero in the base case.

throughout the assessment, to understand the effects a miss-estimation may have on the viability of the overall concept.

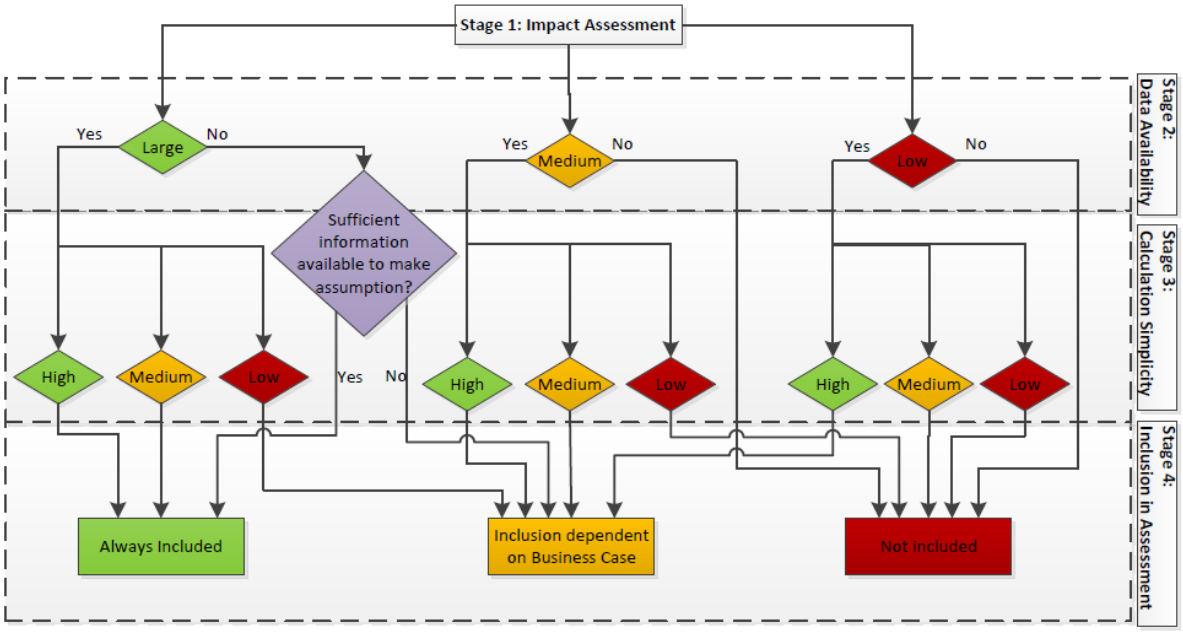

Figure 6: Cost Elements' Prioritization Method

Once the entire list of cost elements has been processed with this method, the result will be an aggregated and normalized list that allows different cost elements to be prioritized within the model development.

A summary of this final cost element list is provided in Table 2. More detailed information about the cost elements, calculations, references and the way they may differ depending on the application of the cost element to different transport system actors, is provided in Annex B. Please note that in Annex B, the cost elements have been sorted into their respective modules based on the ODAM structure. To provide a simplified overview, the summary in Table 2 is structured in the same manner in which the work distribution Table 1, in section 3.3, has been presented.

Category of Cost Breakdown	Cost Element	Comments	Prioritization Always 2 Dependent 1 Not 0
Capital Cost	Depreciation - Ship Cost	Even though the ship costs are highly dependent on the business case chosen for a given scenario, these values can be adjusted based on known costs of construction for respective vessels.	2
	Depreciation-VT Technology Cost	This is a cost element that is so far unknown and will most likely stay so, for the most part of the VT development process. However, educated estimates can be set by experts in the consortium. The VT technology is one of the predominant features of the concept and thus its cost will be based on	2

		assumptions. The value of this technology will change depending on being a FV or a LV.	
	Interest	The interest rate is set at 4.5% (Verberght, 2019).	2
Operational Cost	Insurance	Four interviews have been conducted with insurance companies (Annex C), asking them what is the expected impact of the VT on the insurance costs. The common element among all the four interview' answers is that less insurance premium is expected thanks to the less crew on board and as a result of the less risks for crew claims and increased insurance costs due to the additional (unknown at the present time) IT system-related additional risks (exposure to cyber risks) (René, 2018); (van Geyte, 2018); (Vrints 2018); (Moens, 2018). Initially, costs are expected to increase with 5%-10% and after some years, when technology proves itself to be safer/less claims active, insurance costs might decrease (10% at year 6) (van Geyte, 2018) (see Annex C).	2
	Crew Cost	The crew cost per crew member and number of crew members vary significantly depending on the sector in which the vessel operates and the amount of cargo that is transported. Furthermore, even the nationality of the crew members makes a significant difference to the crew cost for SS vessels. Due to the large amount of uncertainty surrounding this cost element, it is important to perform analysis on a wide range of different circumstances to ensure that the effect of changing crew is fully understood from an early stage into the concept development.	2
	Black and grey water	These may change depending on the amount of crew members on board. The environmental footprint of the concept will improve but the cost reduction for the operators will be very small.	1
	Waste management systems on board/port		1
	Maintenance cost	Repair and maintenance costs make up a noticeable chunk of the vessel's annual costs, which is the reason why they are included in the ODAM from the start. It has to be said however that there is no real trend in the identifications of these costs on a vessel and operation bases, which makes it not possible to accurately predict them.	2
	Sorting cost	These are elements that will affect the effectiveness of the VT but not the viability of the concept itself, since these are independent concepts from the overall VT. Notable time within the NOVIMAR research is dedicated towards the development of	1
	Storage cost		1

		this system, so it may be added into the model at a later stage in a form of a plug-in.	
Voyage Cost	Fuel consumption	This cost element contributes significantly to the overall cost and will change depending on the business case chosen.	2
	VT dues	VT dues are the fees that need to be paid by the vessel owner/operator of the FVs to the vessel operator of the LV. The VT operator can be either a large shipping company creating a VT using its own vessels or a third party service provider. In the former case, the cost of operating the LV will be included in the cost of the LV. In the latter case, the VT operator's costs are to be transferred to the FVs. The VT dues are determined by the marginal cost per FV. For the application in this model (see (van Hassel et al. 2018)), the VT dues are determined by an average cost plus a mark-up (the profit margin in the case the VT operator is not the same as the FV operators). The VT dues are determined using the following equation: $\mathrm{VT}_{\mathrm{DUES}}=\mathrm{AC}_{\mathrm{VT}}.(1+PM)$[4] $\mathrm{AC}_{\mathrm{VT}}$: average VT cost; PM: Profit Margin (van Hassel et al., 2018: D2.2, Annex C).	2
	Port dues	Port dues can be categorised into port dues for ship-related services and for crew-related services. The service level for vessels of different size may differ, depending on the number of crew members and the technology on board. Many of the port services, such as for example the storage of cargo, are not related to the vessel operations as such, but need to be added to the overall system analysis, thus these are only going to be added to case dependent calculations (van Hassel et al., 2018: D2.2, Annex B).	1

	Bridge, lock passage cost and canal fees	Fairway dues (which do not exist in the Netherlands and on the Rhine) for Flanders are also very low. In a case study on the Danube, these may have a larger impact, thus the cost element is included depending on the case.	1
External Cost – Congestion	Congestion created for the end delivery of goods	Inland waterways: 0.4 euro/TEU*km SSS: 0 Sea-River: 0 Urban-areas: 1.8 euro ct per veh.km, 2010	2

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[4] In D.2.3 a more detailed description of the business models will be developed. Based on this information these formulas in the ODAM will be used.

		Road/Rural/Motorways: 0.4 euro ct per vkm, 2010 Rail: 0.2 euro per 1000 vkm, 2011	
	Speed/flow relations on the water	Speed-flow relations are considered the best method to calculate the external costs of congestion. However, no data are available for maritime application. It is taken indirectly into consideration via the external cost values of congestion given above.	0
	Waiting time at locks and port	No data are available.	0
External Cost – Infrastructure	Decay to waterways caused by changes in displacement	No quantitative data are available.	0
External Cost – Environmental	Water pollution	Water pollution is an external factor that is prone for internalization. Environmental pollution research has been performed on the effects of waste water discharge of sea-going vessels. Some sources also suggest possible surcharges applied within the inland sector for the wastewater created by gas oil, in the future. This is the reason why the topic may only be applicable on a case study basis.	1
	Emission of SOx, NOx, CO2, VOC, GHG and PM	The emission of a ship is the most important environmental factor, however not all of the gases are equally relevant, which is the reason why a prioritization has been set among them. **Inland Waterways** Total: 3.02 (€ / 1000 tkm, 2010) **SSS** PM2.5: 17,240 NOx: 3,790 SO2: 6,080 NMVOCs: 1,566 (€ per tonne, 2010) **Sea-river** Total: 2.8 (€ / 1000 tkm, 2010) **Urban areas** PM2.5: 270,178 NOx: 10,640 SO2: 10,241 NMVOCs: 1,566 (€ per tonne, 2010) **Road/Rural/Motorways** PM2.5: 28,108 NOx: 10,640 SO2: 10,241 NMVOCs: 1,566	2

		(€ per tonne, 2010) **Rail** Total: 0.6 € ct/tkm, 2010 **Climate change-GHG emissions mostly CO2** Inland waterways: 3 (€/1000 tkm, 2010) SSS: 1.8 (€/1000 tkm, 2010) Sea-river: - Urban areas: 3.2 (€ct/vkm, 2010) Road/Rural/Motorways: 2.0 (Rural) & 2.5 (Motorways) (€ct/vkm, 2010) Rail: 0.26 (€ct/ tkm, 2010)	
	Sound pollution	Even though this topic may be of importance, especially when considering to deliver more goods into urban areas, it is very difficult to be calculated, since real data are needed and are usually either not recorded or not accessible. This can be shown by the data presented below, which are available only for the road and rail transport modes but not for the waterborne transport modes. **Urban areas** Day 75.5 Night 137.5 **Road/Rural/Motorways** Day 0.6 Night 1.1 **Rail** Day 827.2, Night 1977.6 in urban areas Day 43.85, Night 97.7 in rural areas (€ per 1000 vkm)	0
	Light pollution	Even though this topic may be of importance especially when considering to deliver more goods into urban areas, it is very difficult to be calculated, since real data are needed and are usually either not recorded or not accessible. Thus, we consider this external cost having a zero value.	0
	Impact on natural habitat	No data are available. Thus, we consider this external cost having a zero value.	0
	Accident	Accidents can cause significant external costs, however large accidents are fairly rare in the waterborne modes of transport. So the assessment of such circumstances is kept for a later stage in the model development. The data found are the following: Urban areas: 1.1 (€ ct per/vkm, 2010) Road/Rural/Motorways: 1.2 (€ ct per/vkm, 2010)	1

		Rail: 0.2 (€ per 1000 vkm)	
	Marginal infrastructure external costs	The data available are the following: Inland waterways: 1.92 (€ct/tkm, 2010) Urban areas: 1.5 (€ct (2010) per vkm) Road/Rural/Motorways: 0.6 (€ct (2010) per vkm) Rail: 0.45 (€ per train-km)	1

Table 2: Cost Elements' Summary

Most of the cost elements with prioritization type two have at this stage already been implemented into the transport model. It is only the 'external costs emissions' category that has not yet been imbedded. It is expected that the emissions have an effect on the environmental footprint but will not affect the economic viability of the overall VT concept.

All these elements will be input to the method that will be applied for appraising the VT project, being the SCBA. The latest 'Guide to Cost-Benefit Analysis of Investment Projects' of the European Commission has been used for identifying the main principles for applying the SCBA to the VT concept (Korzhenevych et al., 2014). *"Cost-Benefit Analysis (CBA) is an analytical tool for judging the economic advantages or disadvantages of an investment decision by assessing its costs and benefits in order to assess the welfare change attributable to it".* A quality CBA report should therefore be: self-contained; transparent; verifiable and credible. CBA is measuring all the benefits and costs of the project to the society in monetary terms. Therefore, key performance indicators are used, being the Economic Net Present Value (ENPV) and the Economic Rate of Return (ERR) (see formulas below of the financial net present value and the financial rate of return). *"The Financial net present value on investment is defined as the sum that results when the expected investment and operating costs of the project (discounted) are deducted from the discounted value of the expected revenues"* :

$$\mathrm{FNPV(C)} = \sum_{t=0}^{n} a_t S_t = \frac{S_0}{(1+i)^0} + \frac{S_1}{(1+i)^1} + \ldots + \frac{S_n}{(1+i)^n}$$

Where: $\mathbf{S_t}$ = the balance of cash flow at time t,

$\mathbf{a_t}$ = the financial discount factor chosen for discounting at time t

i = the financial discount rate

"The financial rate of return on investment is defined as the discount rate that produces a zero FNPV, i.e. FRR is given by the solution of the following equation":

$$0 = \sum \frac{St}{(1+FRR)^t}$$

The former is expressed in monetary terms (EUR), while the latter is a pure number. CBA compares a scenario with the project with a baseline scenario without the project. For the scenario without the project: either the business as usual (BAU) approach or do-minimum approach can be used. However, the BAU approach is recommended to be used because when using the do-minimum approach, there is the risk that unrealistic benefits or costs might be caused. Also, if there is uncertainty, the BAU scenario is going to be adopted as rule of thumb. For the scenario with the project, projections of cash flows are made, taking into account all the investment, economic and financial costs and benefits from the project.

The main steps of the CBA are the ones in which the actual calculations of the financial and social benefits and costs take place respectively (European Commission, 2014). In the step of the financial analysis, the investment costs, the operating costs, the revenues and lastly the sources of financing are determined, based on which the measurement of project profitability is possible through the FNPV and FRR, mentioned above. Similarly, for the economic analysis the Economic Net Present Value (ENPV), Economic Rate of Return (ERR) and benefit/cost ratio (B/C ratio) are calculated. If ENPV<0, then the society is better off without the project, while if ENPV>0, then the society is better off with the project. The economic analysis is carried out to appraise the project's contribution to welfare, by monetising the project's impact on three levels: consumers surplus, producers surplus and externalities.

The difference between ENPV and FNPV is that the former includes social and environmental externalities because the analysis is done from the point of view of society, not only of the project owner. *"An externality is any cost or benefit that spills over from the project towards other parties without monetary compensation"*. The ENPV is the most significant SCBA indicator and as a result it must be used as the main economic performance indicator for project appraisal.

NOVIMAR aims at reducing welfare loss. In Figure 7 below (Blauwens et al., 2016), it is shown that the marginal private cost (Mpc) is smaller than the marginal social cost (Msc) because the transport producer offers his/her services at a price equal to Mpc, which is lower than Msc. This happens because the transport producer is not charged for part of the external costs that he/she causes, resulting to a transport quantity M instead of C (thus causing overproduction), which causes a welfare loss to the society (see the shaded triangle). NOVIMAR, taking this into account, measures the external costs, so as to allow the possibility of internalising them and thus increase the price and as a result reduce the demand to the optimum volume C (Blauwens et al., 2016).

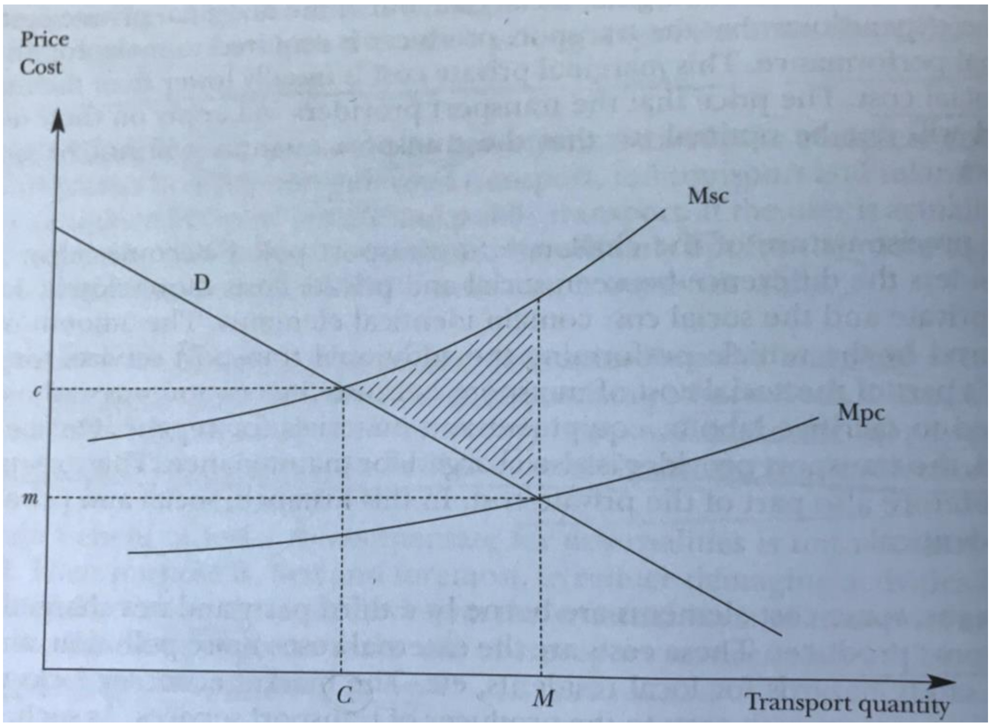

Figure 7: Market equilibrium and social optimum (Blauwens et al., 2016).

5.5 ODAM–method test and validation for VT-variant assessment (sub-task 1.2.4)

At this stage the model has been set up and all relevant factors have been integrated. However, specific case studies have not yet been identified and run through the model, which means method testing or a direct validation of the results is not possible. However, one can validate the set-up of the model and the consistence of the cost elements compared to existing models and estimations of transport systems. As such, the validation done in this sub-task is done on a theoretical level. The aim of this section is to compare the cost elements that the NOVIMAR team selected to include for conducting the SCBA for the VT concept with the cost elements used by other studies. The verification procedure cross-checks the generally identified cost elements from Figure 2 with the topics covered in the sources. The main sources used for this comparison are on the one hand academic models that are used to estimate the private costs (van Hassel(2011) and Beelen (2011)) and on the other hand the other sources on SCBAs that focus on the identification of the societal costs. Four different symbols are used to classify the findings from the sources, so as to create a visual understanding and allow the verification of the ODAM. These symbols are:

-	:	Included in the source but not the ODAM
+	:	Not indicated in the source but included in the ODAM
✓	:	Included in the source and the ODAM
na	:	Not applicable means that it is only of relevance for the VT application, therefore it is not possible to find this in any other sources
X	:	This element is included in neither a source nor the ODAM

Cost Element	Sources used for varification						
	Van Hassel (2011)	Beelen (2011)	Miola (2009)	Blauwens (1986)	Verberght (2019)	Grønsedt (2014)	Lyridis et al. (2005)
Depreciation - ship cost	✓	✓	+	+	✓	✓	+
Depreciation- VT technology cost	na	na	na	na	na	na	na
Interest	✓	✓	+	+	✓	✓	✓
Insurance	✓	✓	+	+	✓	✓	✓
Crew cost	✓	✓	+	+	✓	✓	✓
Maintenance & repair cost	✓	✓	+	✓	✓	✓	✓
Fuel consumption	✓	✓	✓	+	✓	✓	+
VT dues	na	na	na	na	na	na	na
Port dues	+	✓	+	+	✓	✓	+
Emission of SOx, NOx, CO2, VOC, GHG and PM	✓	+	✓	+	✓	+	+
Black and grey water	+	+	✓	+	+	+	+
Waste management systems on board/port	+	+	✓	+	+	+	+
Sorting cost	na	na	na	na	na	na	na
Storage cost	+	+	+	+	+	+	+
Bridge, lock passage cost and canal fees	+	✓	+	+	+	✓	+
Congestion created for the end delivery of goods	+	+	+	+	✓	+	+
Water pollution	+	+	✓	+	+	+	✓
Accident	✓	+	✓	+	✓	+	✓
Marginal infrastructure external costs	✓	+	+	+	✓	+	+
Speed/flow relations on the water	×	×	×	×	×	×	×
Waiting time at locks and port	-	×	×	×	×	×	×
Decay to waterways cause by changes in displacement	×	×	-	×	×	×	×
Sound pollution	×	×	-	×	×	×	×
Light pollution	×	×	-	×	×	×	×
Impact on natural habitat	×	×	-	×	×	×	×

Table 3: Verification of the ODAM's Cost Elements

Below we dig deeper into the symbols of Table 3 per source, in order to show similarities of our cost elements with the cost elements used by other authors and thus validate our list of cost elements.

The two sources that have been chosen for comparative purpose of the private cost with the ODAM, focus in their application on inland vessels. Van Hassel (2011) developed a transport concept and uses his private cost estimation within his model to determine his concepts viability. This application is very similar to what the ODAM aims to do for the VT concept. In van Hassel research even external cost have been considered as part of his transport system analysis. He includes both the marginal infrastructure external costs and as well as the accident cost created. Even though he includes close to all private cost that made it into the final cost element selection of the ODAM; he even includes cost aspects such as crew logistics costs. Such costs have however so far not been deemed relevant for the

VT concept. Port dues are the only private cost element that cannot be directly found in the data of van Hassels research model.

Bellens (2011) research is focused on determining the private cost of the inland navigation users to gain a better insights into their reasoning and decision making. Just like van Hassel, she incorporates the most prominent private transport cost, however over a larger variety of different vessel classes. She does not consider any external costs since they do not directly influence the decisions of companies in the inland navigation sector. Overall a close correlation between the private cost elements chosen in the ODAM and considered by Bellen can be found.

Any sources further sources from here onward used as a mean of comparison mainly focus on the identification of external costs.

Miola et al. (2009) specifically focuses on the identification of external costs in maritime transport. This source provides descriptive information and emphasise on the importance on many of the cost elements that did not make it into the final cut of the ODAM, due to the lack of data. The harmfulness of topics such as the erosion of waterways and impact on natural habitat are discussed in great depth but are not sufficiently quantified is given to make it possible to include these external cost in the actual ODAM.

With respect to the last four columns/sources the following information is worth being mentioned.

It is positive that there is consensus with respect to how to execute a CBA. However, the majority of the CBAs are done for transport infrastructures (Blauwens, 1986); while the VT concept is not a transport infrastructure project. Nevertheless, it is understood why the focus is on appraising mainly transport infrastructure projects, since their cost is very high, sometimes exceeding 75 million euro (major projects) (Korzhenevych et al., 2014). Blauwens (1986) conducted a CBA of transport and port projects in Belgium (road, waterways, metro works, port investments and rail line applications). For the road construction investment projects, the benefits per car are the following:

- Time savings;
- Savings on wear and maintenance of the vehicle;
- Fuel savings;
- Accident savings;
- Improved comfort.

Since the VT project is expected to shift traffic from road to waterborne transport modes, some of the above could be indeed benefits thanks to the VT concept, such as the time savings thanks to the less congested roads, since less cargo is expected to be transported via road and thus leading to savings on wear and maintenance of the vehicle and accident savings. However, the fact that there will be less vehicles does not guarantee that there will be less accidents. Therefore, it can be seen that benefits should also be examined and not only the costs, presented in Table 2 because it is the difference between the costs and the benefits of the VT project that will give us the net present value of the project, which should be positive. In other words, what needs to be pointed out is that although the focus of this deliverable is on the cost elements of the VT concept, both economic and external, the benefits will be also calculated in the SCBA. With respect to the costs, since we refer to a transport infrastructure, they are the following:

- Expropriation
- Construction and
- Maintenance

(same cost elements are indicated for the 'port extension investment' in Belgium of Blauwens, 1986)

ince the CBA in the NOVIMAR project will be conducted for appraising the VT concept, which does not include an infrastructure investment, it is considered useful to also review the CBA conducted for appraising the use of a fully autonomous vessel in the inland navigation sector compared to the use of a conventional vessel (Verberght, 2019). A CBA has been conducted also for a vessel using LNG instead of diesel in the same study. This study is of high interest for the NOVIMAR project because it involves the element of autonomous vessels (although in NOVIMAR fully autonomous vessels are not considered) and also it is an inland navigation project application, which is one of the main sectors on which NOVIMAR focuses on, together with the SSS and the sea-river sector. All the private cost elements used in the CBA of Verberght (2019) are also used in the NOVIMAR CBA, except one cost element, the lubricant consumption, which is only used in the NOVIMAR CBA. Some cost elements that are included in the CBA of Verberght (2019) but not in the NOVIMAR CBA are: shore control center costs, administration and communication costs and technical compliance costs (certificates). Key external costs for the IWT are also included, such as emissions and climate change costs, congestion, accidents and infrastructure external costs. An additional impact that Verberght (2019) examines is the impact on the labour market and based on the facts of aging of the employees working in the inland navigation sector, the difficulties to find people for working in the sector and also keeping in mind the assumption that automation will be incremental, the author came to the conclusion that the development of fully autonomous vessels will not affect negatively the labour market. It might even create jobs for the ICT personnel that is needed for the on shore control centers. What is also interesting in this study is that NPV is measured for different number of crew members on board, so as to see which scenario gives the highest NPV. This is also what will be done for the VT concept.

Lyridis et al. (2005) conducted a CBA for the retrofit of innovative ship automation systems to be implemented in the icebreaker Frej in the context of the EU-funded project ATOMOS IV (Advanced Technology to Optimise Maritime Operational Safety: Intelligent Vessel). Only existing operating vessels are tested in the present paper. Thus, CBA is conducted so as to reply to one main question: in the case of an existing conventional vessel, is it worth it for the vessel owner to invest in retrofitting his/her existing vessel with automated technologies and thus convert it from conventional to automated? This is the reason why, the ship building costs are not included in this CBA, since the retrofit of an existing vessel is examined and not the construction of a new one. This research question seems very relevant to the ones of the VT concept, since also the vessel owner is one of the main actors for the VT concept. Also in the VT concept, there are two possibilities: 1) of using an existing vessel that will be upgraded by installing the technological equipment or 2) building a new vessel. The main motivation behind the retrofit is also in this paper the reduction of crew members, which will lead to reduction of operational costs, as for the VT concept. There is almost a complete overlap of the private cost elements of the VT CBA and the CBA of Lyridis et al. (2005). Ship costs are not taken into consideration because this paper focuses on the retrofit of existing vessels and not on building new ones, as mentioned above. From the external costs, only accidents and water (oil) pollution are taken into consideration. Also, it is interesting to note that Lyridis et al. (2005) use some additional costs in their CBA that are not used in the VT CBA, which in VT terms could be translated into the "crew training cost" for the new technology equipment, the "non-VT equipment costs", which will (among others) ensure compatibility of the VT with the non-VT equipment and the "opportunity cost" for the duration of the retrofit adding the travel time to the shipyard.

A CBA in the maritime shipping sector is also examined, since NOVIMAR also examines the sea-river and SSS sector. Grønsedt (2014) conducts a financial CBA on the feasibility of transporting containerized goods between Rotterdam and Yokohama using the North Sea Route (NSR) as an alternative to the Suez Canal Route (SCR), since transporting goods via the NSR reduces the travel distance up to 35%. Thus, Grønsedt (2014) tests if it is worth it to invest in an ice-strengthened containership that will transport cargo using the NSR. Since the author conducts a financial CBA, external costs are not taken into consideration, however with respect to the financial cost elements, there is almost a complete overlap with the cost elements used in the VT CBA, as shown in the table 3.

From Table 3 it becomes clear that the choice of cost elements in the ODAM is successfully verified and supported by the given sources. The comparison shows that all the included costs, except for the storage cost, are found in existing transport system analyses. The reason why the storage cost is not found is that, even though all transport chains generate these costs, they are extremely difficult to obtain, since they are company-internal costs. They are however, kept in for potential business case applications where presorting operations are integrated into the VT services. Such applications may involve an increase in these storage costs compared to the current state of operations. Such a development is specific to the NOVIMAR research and can thus not directly be found or even compared excising sources.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

We have successfully developed the Overarching Decision Analysis Model (ODAM) that gathers all the results of WPs 2-6 in order to assess the viability of the VT concept. We have selected relevant cost elements, both economic and external, which are two main structural elements of the ODAM (output of the WP2 and WP1 respectively). These cost elements have been verified based on a literature review of other performed CBA studies, thus confirming that we have made a correct selection. It can be concluded that the cost elements do not change with the implementation of the VT concept, it is rather the way these elements are split up over more actors that will cause the changes in the modelling and results.

However, not all the cost elements that we identified in literature are shortlisted. About 20 % of the cost elements are neglected from the list. Nearly one third could become relevant throughout the development to provide a more accurate view of the VT concept and its variances but will not impact the concept's economic viability. Thus, this share of cost elements might be added at a later stage. Therefore, about 40% (10 elements) of the original cost elements left are considered to be vital for the ODAM model implementation, out of which, almost all, have already been implemented in the transport model of WP2.

Although the aforementioned cost elements' model has not been applied yet and only verified theoretically at this stage, we trust that we have built a structure that can be applied in the rest of NOVIMAR to assess the viability of the VT concept.

The tasks set for this deliverable were met and the progress is according to the plan.

6.2 Recommendations

The preliminary results obtained by the WP2 model (D2.2), which is based on the ODAM structure, showed that the waiting times and the crew costs are the two main deal breakers for the concept, if they are miss-estimated. It is therefore highly recommended that the research focus is placed on identifying the monitoring crew requirements on the LV as well as the role of the FV crew members that is being reduced.

7 REFERENCES

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8 ANNEXES

8.1 Annex A: Public summary

In this deliverable, the Overarching Decision Analysis Model (ODAM) is developed that allows a viability assessment of the Vessel Train (VT) concept.

The main objective of the ODAM is to provide quantitative results for all actors involved to assess:

- If the VT provides benefits to the various affected stakeholders in the transport system
- If the VT provides benefits to the society

A large number of cost elements have been gathered, which are all in some way related to the cost model of the VT.

A four-stage aggregation method has been developed that assesses cost elements based on the following three elements to determine if and at what stage each cost element should be imbedded into the model:

- Impact
- Data availability
- Calculation complexity

The results of the verification of the ODAM elements show that the ODAM procedure and calculations are in line with the already published transport models and analyses. This validates the results that will be obtained from testing different scenarios.

Recommendations concerning further research on the VT concept are to focus on the crew role reduced from the follower vessels (FVs) as well as the identification of the crew requirements for the monitoring tasks on the lead vessels (LVs). On top of that it is recommended to research the effects of waiting times caused by insufficient number of FVs.

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Name of responsible person:	Alina Colling / Edwin van Hassel
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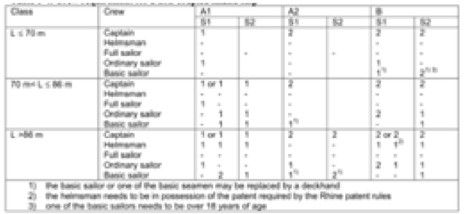
8.2 Annex B: Cost Element List

	Assessment subtopics	Elements per topic	Impact on Concept	Comments on how to turn this into an assessable value	Is the required data available?	Formula to calculate or specific reference data	References	Calculation Simplicity	Included in the assessment topic?	
			Large					High	Always included	2
			Medium		Yes			Medium	Included dependent on Business case	1
			Low		No			Low	Not included	0
	Capital Cost									
Module 1: A Vessel Operator	Capital cost of ship and technologies	Depreciation of the ship	Large	Dependent on the business case scenario, one may wish to assess the effect of the VT on vessels that are newly built or at least not yet fully depreciated. The amount of depreciation is based on the value of the vessel at the point of its re/instatement. This can either be provided in the vessel information or calculated via generic formulas that estimate the construction costs. The depreciation value is a fixed percentage of this worth.	Yes	$C_{dep} = \frac{I_{hull} - R_{hull}}{t_{dep,\,hull}} - \frac{I_{mach} - R_{mach}}{t_{dep,\,mach}}$ C_{dep}: annual depreciation cost (€/year) I_{hull}: building cost hull (€) R_{hull}: remaining value hull (€) I_{mach}: building cost ship minus building cost of hull (€) $t_{dep,\,hull}$: depreciation period (years) $t_{dep,\,mach}$: depreciation time of a ship minus hull In general, the depreciation of a vessel occurs over a period of 20 years, thereby making the yearly depreciation of the construction value 5%. This may change if the vessel is already partially depreciated at the point of its instatement into the VT concept. Thus, it will have to be adjusted based on scenarios set within the model.	Hekkenberg, R. (2013). Inland Ships for Efficient Transport Chains. Technische Universiteit Delft.	High	2	
		Depreciation of the VT technology	Large	Every FV will require some technology on board to make it possible to follow the LV. The cost is expected to be equivalent for the LVs and FVs. It also has to be noted that technology depreciates at a much higher rate than steel and thus the constant depreciation percentage will be higher than for the value of the vessel.	No	This is a new concept, so neither the technology nor its cost are definetely known. These values can only be estimated educated guesses that experts developing the guidance system may suggest. Such a value is set to 40,000€-60,000€ per vessel. The period of depreciation for the technology is set to 5 years, thereby making the yearly depreciation 20%.		High	2	
	Interest		Large	The interest rate is highly dependent on the circumstances under which the vessel is bought. It is dependent on the total investment cost for both the vessel and the technology.	Yes	The interest rate is set at 4.5%.	Verberght (2019)	High	2	

<table>
<tr><td rowspan="4">Module 1: A Vessel Operator</td><th colspan="9">Operational Cost</th></tr>
<tr><td colspan="2">Insurance</td><td>Large</td><td>Four interviews have been conducted with insurance companies asking them what is the expected impact of the VT on the insurance costs. The common element among all the four interviews' answers is that less insurance premium is expected thanks to the less crew on board and as a result the less risks for crew claims and increased insurance costs due to the additional (unknown at the present time) IT system-related additional risks (exposure to cyber risks).
Initially, costs are expected to increase from 5%-10% and after some years when technology proves itself to be safer/less claims active, insurance costs might decrease (10% at year 6) (van Geyte, 2018).</td><td>Yes</td><td>The insurance premium per year is **0.5%-1%** for medium size vessels of a cost of 10 million. The insurance premium/tariff for hull & machinery is almost linear to the cost of the ship (capital cost).
We thus assume a 0.75% of the capital cost as an annual insurance cost.</td><td>(René, 2018)
(van Geyte, 2018) (Vrints, 2018) (Moens, 2018).</td><td>High</td><td>2</td></tr>
<tr><td rowspan="2">Crew Cost</td><td>IWT</td><td>Large</td><td>Increases in crew cost due to added waiting time are included as part of the voyage costs. IWT regulations on manning are a lot more clear and structured. They provide a generic estimation of crew costs that include all the added expenses for the employer. The calculation of the hourly wages is calculated based on the operating time of the vessel and not on the hourly shift of each individual crew member.</td><td>Yes</td><td>
<table>
<tr><th>IWT Vessel Type</th><th>Average Crew Cost per Member €/h</th></tr>
<tr><td>Class V</td><td>9.45</td></tr>
<tr><td>Class IV</td><td>8.84</td></tr>
<tr><td>Class II</td><td>8.29</td></tr>
</table>

<table>
<tr><th>Class</th><th>Crew</th><th colspan="2">A1</th><th colspan="2">A2</th><th colspan="2">B</th></tr>
<tr><th></th><th></th><th>S1</th><th>S2</th><th>S1</th><th>S2</th><th>S1</th><th>S2</th></tr>
<tr><td>L ≤ 70 m</td><td>Captain
Helmsman
Full sailor
Ordinary sailor
Basic sailor</td><td>1
-
-
1
-</td><td>

-

</td><td>2
-
-
-
-</td><td>

-

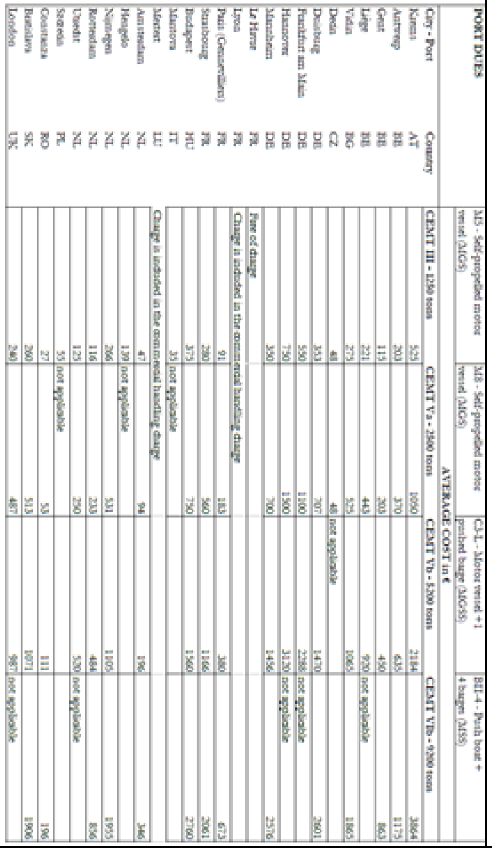
</td><td>2
-
-
1
1$^{1)}$</td><td>2
-
-
-
2$^{1)3)}$</td></tr>
<tr><td>70 m < L ≤ 86 m</td><td>Captain
Helmsman
Full sailor
Ordinary sailor
Basic sailor</td><td>1 or 1
- -
1 -
- 1
- 1</td><td>1
-
-
1
1</td><td>2
-
-
-
1$^{1)}$</td><td></td><td>2
-
-
2
-</td><td>2
-
-
1
1</td></tr>
<tr><td>L >86 m</td><td>Captain
Helmsman
Full sailor
Ordinary sailor
Basic sailor</td><td>1 or 1
1 1
- -
1 -
- 2</td><td>1
1
-
-
1</td><td>2
-
-
1
1$^{1)}$</td><td>2
-
-
-
2$^{1)}$</td><td>2 or 2
1 1$^{2)}$
- -
2 1
- -</td><td>2
1
-
1
1</td></tr>
<tr><td colspan="8">1) the basic sailor or one of the basic seamen may be replaced by a deckhand
2) the helmsman needs to be in possession of the patent required by the Rhine patent rules
3) one of the basic sailors needs to be over 18 years of age</td></tr>
</table>
</td><td>Hekkenberg, R. (2013). Inland Ships for Efficient Transport Chains. Technische Universiteit Delft.

CCNR. (2016). Regulations for rhine navigation personnel (rpn), (July).</td><td>High</td><td>2</td></tr>
<tr><td>SS</td><td>Large</td><td>The regulation for SS crew seems to be less strict than for inland. There are references that provide monthly and annual costs for these vessels but the number of crew is more challenging to identify. Even though there are sources that state 20 crew members, it was found from practical experience on board of SS vessels that this number of crew members is more a suggestion rather than the actual number, which is around 12 crew members. The data used for the crew calculations are inflation adapted and based on crew estimations. The figure of the hourly wages is calculated based on the operating time of the vessel and not on the hourly shift of each individual crew member.</td><td>Yes</td><td>
<table>
<tr><th>Crew Role</th><th>Wage €/h</th></tr>
<tr><td>Master</td><td>17.54</td></tr>
<tr><td>Chief Engineer</td><td>17.11</td></tr>
<tr><td>Chief Officer</td><td>13.32</td></tr>
<tr><td>Second Engineer</td><td>13.32</td></tr>
<tr><td>Second Officer</td><td>8.11</td></tr>
<tr><td>Cook/Bosun</td><td>4.22</td></tr>
</table>
</td><td>Kooij, C. (2019). Towards Unmanned Cargo-Ships : The Effects of Automating Navigational Tasks on Crewing Levels, 104–117.

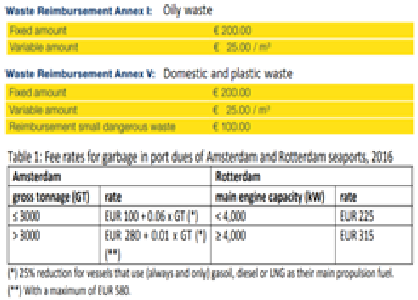
Stopford, M. (2009). Maritime Economics, Chapter 6: Costs, Revenue and Cashflow. In Maritime Economics (3rd edition, pp. 217–267). Abingdon: Routledge.</td><td>High</td><td>2</td></tr>
</table>

Module 1: A Vessel Operator	Overhead	Large	Operating costs are mainly composed of the crew cost but also of the repair and maintenance costs for the vessel, the overhead cost and the insurance. *"From the current state of transport, the overhead costs for IWT vessels are fairly limited, since they are mostly family owned vessels and hence don't have any land side management costs. Even though the situation is different for the SS sector, for now the overhead cost is not included in the model. This also has to do with the fact that it will become significantly more relevant at later stages, when more information about a consolidation and managerial shore centre for the coordination of the VT is known."* Data for the overhead cost are usually only available on an annual basis for vessel operators. Depending on how the VT is set up, the overhead cost of the FV may change somewhat depending on the type of business case applied and how much pre-sorting will be done for the cargo.	No	- Overhead Cost: 5% (ASSUMPTION) (for the LV) - Overhead cost is calculated based on the capital cost of the LV.	(van Hassel et al, 2018, D2.2.)	High	2
	Repair and Maintenance	Large	Only generic estimations of repair and maintenance have been able to be predicted from studies. However, these show that maintenance cost can vary greatly depending on the ship and its age, so it is difficult to predict the exact cost.	Yes	$C_{maintnenance} = C_{main,\,fixed} * L * B * T + C_{main,varible} * \frac{t_{sailing}}{t_{trip}} * t_{operational} * P_{eng}$ $C_{maintenance}$: annual maintenance cost (€/year) $C_{main,fixed}$: fixed maintenance cost (€/m^3/year) using value of 5 $C_{main,varible}$: variable maintenance cost (€/kWh/year) using value of 0.009 L: Ship length (m); B: Ship Beam (m); T: Ship Draught (m); t_{trip}: total time per trip (h); $t_{sailing}$: sailing time per trip (h); [2] t_{trip}: annual # operating hours (h) P_{eng}: Installed power (kW)	Beelen, M. (2011). Structuring and modelling decision making in the inland navigation sector. Universiteit Antwerpen, Faculteit Toegepaste Economische Wetenschappen Hekkenberg, R. (2013). Inland Ships for Efficient Transport Chains. Technische Universiteit Delft.	Medium	2

<table>
<tr><th></th><th colspan="9">Voyage Cost</th></tr>
<tr><td></td><td rowspan="2">Fuel Consumption</td><td>IWT</td><td>Large</td><td>Fuel consumption is calculated per vessel and is dependent on the resistance and hence water depth of the waterway.
The fuel consumption (fc) of an engine is usually given at its design speed, which is around 75% maximum continuous rating (MCR). This is the point at which the specific fuel consumption on the engine is at its lowest.
To be able to calculate the fuel consumption of the vessels, when they are not operating at their ideal speed, a certain number of grams of fuel consumption per kW/h are added to the ideal specific fuel consumption.</td><td>Yes</td><td>**Catapillar 3406E**<table><tr><th>% MCR</th><th>Added fuel compared to 85% MCR (g/kWh)</th></tr><tr><td>21</td><td>18</td></tr><tr><td>26</td><td>16</td></tr><tr><td>32</td><td>13</td></tr><tr><td>39</td><td>9</td></tr><tr><td>46</td><td>5</td></tr><tr><td>55</td><td>8</td></tr><tr><td>64</td><td>0</td></tr><tr><td>75</td><td>0</td></tr><tr><td>87</td><td>4</td></tr><tr><td>100</td><td>14</td></tr></table>$sfc_{eng} = sfc_{optimal} + sfc_{added}$
$fc = P_b * \left(\frac{sfc_{eng}}{1000}\right) * t_t$
Where **Pb:** is the effective break power of the engine,
t_t : travel time
Sfc: 208g/kWh [2]</td><td>Caterpillar. (2001). Caterpillar Marine Populsion Engine 3406E.
Bolt, E. (2003). Schatting energiegebruik binnenvaartschepen.</td><td>Medium</td><td>2</td></tr>
<tr><td></td><td>SS</td><td></td><td>The two differences between the calculation for IWT fuel consumption and the SS are the data used and the operational speed of the vessels.
The sfc for the short sea vessels were taken directly from the vessel specifications.</td><td>Yes</td><td>**Mak M25 E**<table><tr><th>% MCR</th><th>Added fuel compared to 85% MCR (g/kWh)</th></tr><tr><td>21</td><td>51</td></tr><tr><td>29</td><td>36</td></tr><tr><td>43</td><td>16</td></tr><tr><td>50</td><td>9</td></tr><tr><td>57</td><td>6</td></tr><tr><td>75</td><td>0</td></tr><tr><td>85</td><td>1</td></tr><tr><td>100</td><td>3</td></tr></table></td><td>MaK. (2003). MaK M25E.</td><td>Medium</td><td>2</td></tr>
<tr><td></td><td colspan="2">VT Dues</td><td>Large</td><td>VT dues are the fees that need to be paid by the vessel owner/operator of the FVs to the vessel operator of the LV. The VT operator can be either a large shipping company creating a VT using its own vessels or a third party service provider. In the former case, the cost of operating the LV will be included in the cost of the LV. In the latter case, the VT operator’s costs are to be transferred to the FVs. The VT dues are determined by the marginal cost per FV. For the application in this model (see van Hassel et al., 2018), the VT dues are determined by an average cost plus a mark-up (the profit margin in the case the VT operator is not the same as the FV operators). The VT dues are determined with the equation shown in the column “formula to calculate or specific reference data”.
Due to highly competitive market, the profit margin for the VT operator is expected to be small. Thus, for the purpose of these</td><td>Yes</td><td>$VT_{DUES} = AC_{VT} . (1 + PM)$
ACVT: average VT cost; PM: Profit Margin (van Hassel et al., 2018: D2.2, Annex C).</td><td>Blauwens, G., De Baere, P., & Van de Voorde, E. (2016). *Transport Economics.*</td><td>High</td><td>2</td></tr>
</table>

Module 1: A Vessel Operator				calculations, the cost that the LV encounters is considered the VT due sum of all the FVs in the VT.					
	Port dues	Ship related service costs	Medium	There are large differences in port dues dependent on the location, as seen from the sample table. The port dues that will most likely be used in the model are from ports with high cargo volumes such as Antwerp, Rotterdam or Duisburg. Port dues can be categorised into port dues for ship-related services and for crew-related services. The service level for vessels of different size may differ, depending on the number of crew members and the technology on board. Many of the port services, such as for example the storage of cargo, are not related to the vessel operations as such but need to be added to the overall system analysis, thus these are not added to the model at the first stage of the calculations (van Hassel et al., 2018: D2.2, Annex B).	Yes	See annnex I from D2.2 (van Hassel et al., 2018) 	van Essen et al. (2012). An inventory of measures for internalising external costs in transport : Final report, 127. van Hassel et al., 2018: D2.2	High	1

PORT DUES		M5 - Self-propelled motor vessel (MGS)	M8 - Self-propelled motor vessel (MGS)	C3-L - Motor vessel +1 pushed barge (MGSS)	BII-4 - Push boat + 4 barges (MSS)
		AVERAGE COST in €			
City - Port	Country	CEMT III - 1250 tons	CEMT Va - 2500 tons	CEMT Vb - 5200 tons	CEMT VIb - 9200 tons
Krems	AT	525	1050	2184	3864
Antwerp	BE	203	370	635	1175
Gent	BE	115	203	450	863
Liège	BE	221	443	920	not applicable
Vidin	BG	275	525	1065	1865
Decin	CZ	48	48	not applicable	
Duisburg	DE	353	707	1470	2601
Frankfurt am Main	DE	550	1100	2288	not applicable
Hannover	DE	750	1500	3120	not applicable
Mannheim	DE	350	700	1456	2576
Le Havre	FR	Free of charge			
Lyon	FR	Charge is included in the commercial handling charge			
Paris (Gennevilliers)	FR	91	183	380	673
Strasbourg	FR	280	560	1166	2061
Budapest	HU	375	750	1560	2760
Mantova	IT	35	not applicable		
Mertert	LU	Charge is included in the commercial handling charge			
Amsterdam	NL	47	94	196	346
Hengelo	NL	139	not applicable		
Nijmegen	NL	266	531	1105	1955
Rotterdam	NL	116	233	484	856
Utrecht	NL	125	250	520	not applicable
Szczecin	PL	55	not applicable		
Constanza	RO	27	53	111	196
Bratislava	SK	260	513	1071	1906
London	UK	240	487	987	not applicable

<table>
<tr>
<td rowspan="2">Module 1: A Vessel Operator</td>
<td rowspan="2"></td>
<td>crew related service cost e.g. waste discharge
- SS</td>
<td>Low</td>
<td>Oil waste is counted as part of the cargo-associated waste, whilst domestic and plastic wastes are part of the ship generated waste category. Within that latter category, one can split this again into ship operations related waste and the waste created by the crew. SS vessels have the possibility to dispose of waste, such as grey water in the sea, as long as it is more than 12 nm away from the coast. Even though the impact of these costs is estimated to be low compared to the operating costs of the vessel, these costs will still change with the number of crew on board and will thereby provide better information on the impact of crew reduction. This is the reason why it is kept for a later integration into the model.</td>
<td>Yes</td>
<td>

Waste Reimbursement Annex I: Oily waste
<table>
<tr><td>Fixed amount</td><td>€ 200.00</td></tr>
<tr><td>Variable amount</td><td>€ 25.00 / m²</td></tr>
</table>
Waste Reimbursement Annex V: Domestic and plastic waste
<table>
<tr><td>Fixed amount</td><td>€ 200.00</td></tr>
<tr><td>Variable amount</td><td>€ 25.00 / m²</td></tr>
<tr><td>Reimbursement small dangerous waste</td><td>€ 100.00</td></tr>
</table>
Table 1: Fee rates for garbage in port dues of Amsterdam and Rotterdam seaports, 2016
<table>
<tr><th colspan="2">Amsterdam</th><th colspan="2">Rotterdam</th></tr>
<tr><th>gross tonnage (GT)</th><th>rate</th><th>main engine capacity (kW)</th><th>rate</th></tr>
<tr><td>≤ 3000</td><td>EUR 100 + 0.06 x GT (*)</td><td>< 4,000</td><td>EUR 225</td></tr>
<tr><td>> 3000</td><td>EUR 280 + 0.01 x GT (*) (**)</td><td>≥ 4,000</td><td>EUR 315</td></tr>
</table>
(*) 25% reduction for vessels that use (always and only) gasoil, diesel or LNG as their main propulsion fuel.
(**) With a maximum of EUR 580.
Domestic waste: 1.5kg/person/day [4]
Ship generates oily bilge water : 20 m³ per month (0.3 m³ per day or 0.02m³ per 1000GT per day)
Oily sludge: 0.02 m³ per tonne of HFO and 0.005 m³ per tonne of MGO
Sewage waste water: max 0.45 m³ per person per day of which a maximum 0.06m³
Black water : 0.008 m³ per day per person
Food waste: 0.003 m³ per person per day (the organic parts can be let out at sea)
Domestic waste : max 0.02 m³ per person
Cooking Oil: max 0.08 l per person per day
Operations waste: max 0.1m³ per person per day (may include part of other wastes as well) [5]
</td>
<td>Oosterhuis, F. (2016). Free plastic waste disposal in the ports of Rotterdam and Amsterdam, (January), 1–8.

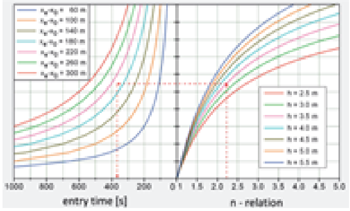
Port of Rotterdam. (2018). WASTE DISPOSAL IN THE PORTS OF ROTTERDAM-RIJNMOND, 31(January).

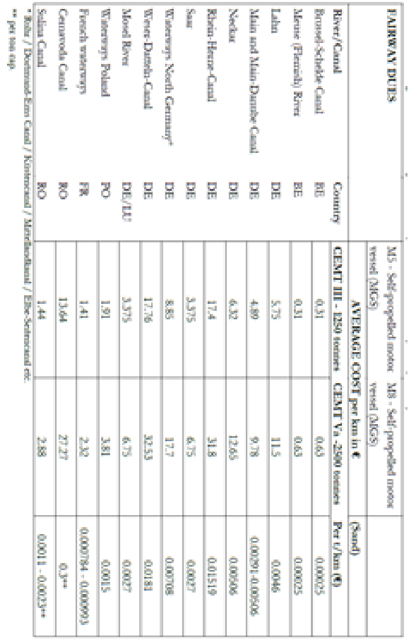
Port of Rotterdam Authority. (2015). Port Waste Reception and Handling Plan.

Maxim, L. D., Klein, A., Meyer, M. E., Kuist, C. H., & Laboratories, A. (1969). Quantitavtive estimates of garbage generation and disposal in the US maritime sector before and after marpol annexV, 205(27), 195–205. https://doi.org/10.1002/polc.5070270115

CE Delft. (2017). The Management of Ship-Generated Waste On-board Ships.</td>
<td>High</td>
<td>1</td>
</tr>
<tr>
<td>crew related service cost e.g. waste discharge
- IWT</td>
<td>Low</td>
<td>Inland vessels do not have the option to discharge their waste at sea and are hence forced to dispose of all their waste in port. No specific data on waste disposal for IWT vessels are available. Therefore, the data for the SS waste generation and charges are going to be applied.</td>
<td>No</td>
<td></td>
<td></td>
<td>High</td>
<td>1</td>
</tr>
</table>

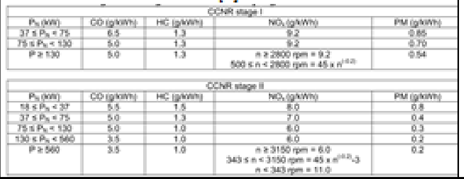
Module 1: A Vessel Operator	Waiting times	All waiting times have a direct effect and an indirect effect on the Vessel operator. In this section only the direct travel time increase that increases the cost for the vessel operator is being described.							
		Loss of time due to congestions Speed/flow relation	Medium	The increased vessel density on waterways may cause the overall traffic speed to slow down in narrow sections of the waterways. For this to be calculated, a max vessel/h rate for a specific width of waterway needs to be known. This topic becomes especially important when looking at getting closer to urban areas, where narrower canals are sailed upon. (a speed reduction down to 5-8 km/h is required when encountering another vessel, in VT formation this will take significantly longer than for a single vessel traveling). Fischer et al. (2014) have some sample max densities, as part of their model results. It may be that these max densities may not be the input, but rather the outputs of the VT transport model and create boundary conditions for the VT.	Yes	$t_{encounters} = t_t or\ distance * \left(\rho_{traffic} * \frac{L + L_{encounteringv2}}{v_{encounter} + v_{encounterv2}}\right)$ $t_{encounters}$: added time for vesse/VT encounters in canal (h) t_t: travel time (h) or distance (km) $\rho_{traffic}$: traffic density (vessel/h) or (vessel/km) L: vessel or VT length (including distances between vessels)(km) $L_{encounteringv2}$: Encountering Veseel or VT length (km) $v_{encounter}$= reducedencountering speed of vessel or VT (km/h) $v_{encounterv2}$= reducedencountering speed of encountering vessel or VT (km/h)	Fischer, N., Treiber, M., & Söhngen, B. (2014). Modelling and simulating traffic flow on inland waterways. 33rd PIANC World Congress, 1–20. BAW. (2016). *Driving Dynamics of Inland Vessels*. Retrieved from https://hdl.handle.net/20.500.11970/104201	High	1
		Waiting time cost at bridges	Medium	The waiting time at bridges is dependent on the limited capacity at the infrastructure. The response time for bridges can be quite quick during opening hours and have to be called in early afterhours. The impact will be enlarged as the VT length increases, since bridges will only be able to prohibit the road traffic for a certain period of time before they have to close to let the traffic pass. During that time, not all vessels in the train may be able to pass.	Yes	No data are available.		High	1

Module 1: A Vessel Operator	Waiting time cost at locks	Large	Information exists for different levels of detail, full queuing theory, data input for specific case studies on each lock passage stage.	Yes	**Entry Time**: xe-(0.44*(L-57)) (xe is distance from lock head to stop in lock) **Waiting cost at lock** : time dependent costs/h * waiting time at lock  	BAW. (2016). *Driving Dynamics of Inland Vessels*. Retrieved from https://hdl.handle.net/20.500.11970/104201	Medium	2
	Waiting time cost in port - IWT	Large	Port time in particular is extremely relevant for inland vessels, since IWT vessels are not given priority by the terminal operators and therefore have to wait significantly longer compared to SS vessels.	Yes	No data are available.	Malchow, U. (2010). Innovative Waterborne Logistics for Container Ports. *Port Infrastructure Seminar 2010*, 17.	High	2
	Waiting time cost in port - SS	Large	For SS vessels, the waiting times in ports are closer to the actual cargo (un)loading times.	Yes	No data are available.		High	
	Total waiting time for VT service	Large	This is a cost element that is not yet known and forms a boundary condition of the VT concept, as a result of the transport model analysis. Each individual is directly affected, since they will have to wait a certain amount of time, until the minimum required VT length is reached. Since the results are obtained from the entirety of the transport model, the calculation complexity is classified as high.	No			Low	2

<table>
<tr><td></td><td></td><td>Bridge, lock passage and canal fees</td><td>Medium</td><td>Fairway dues for waterborne infrastructure vary depending on the vessel size that makes use of them and their location.
Fairway dues (which do not exist in the Netherlands and on the Rhine) for Flanders are very low.</td><td>Yes</td><td></td><td>van Essen, et al. (2012). An inventory of measures for internalising external costs in transport : Final report, 127.</td><td>High</td><td>1</td></tr>
<tr><td rowspan="8">Module 2: External Cost for Vessel Operator</td><td colspan="9">External Cost</td></tr>
<tr><td colspan="9">Congestion</td></tr>
<tr><td colspan="9">The operation of the individual vessel does not add any more congestion additionally to a currently operating vessel. It is only in the VT, where the vessels are clustered, where this may become relevant. This the reason why the external cost elements concerning congestion are found in the subsection of Module 4 that concerns the VT operator.</td></tr>
<tr><td colspan="9">Infrastructural</td></tr>
<tr><td colspan="9">Concerning this external cost element the same applies as to the congestion for the vessel operators.</td></tr>
<tr><td colspan="9">Environmental</td></tr>
<tr><td colspan="9">The reason for which the water, air, sound and light pollution is considered as part of the external costs of the vessel operator is that the creation of these pollutions is dependent on the individual vessels. If these external costs were to be internalized, they would be related to the operations of each individual vessel rather than the VT.</td></tr>
<tr><td>Water Pollution</td><td>Oily water discharge</td><td>Low</td><td>No data are available.</td><td>Yes</td><td>The CDNI had decided on a wastewater surcharge of 7.50Eur for every 1000 l of gas oil (this surcharge replaces any costs for waste water disposal and aims to eliminate illegal disposal).
This is an average surcharge of 0.082 Eur per km for a Class III and 0.134 Eur/km for a Class V vessel.</td><td>van Essen, H., Nelissen, D., Smit, M., van Grinsven, A., Aarnink, S., Breemersch, T., ... Harmsen, J. (2012). An inventory of measures for internalising external costs in transport : Final report, 127.</td><td>Low</td><td>1</td></tr>
</table>

FAIRWAY DUES		M5 - Self-propelled motor vessel (MGS)	M8 - Self-propelled motor vessel (MGS)	
		AVERAGE COST per km in €		(Sand)
River/Canal	Country	CEMT III - 1250 tonnes	CEMT Va -2500 tonnes	Per t/km (€)
Brussel-Schelde Canal	BE	0.31	0.63	0.00025
Meuse (Flemish) River	BE	0.31	0.63	0.00025
Lahn	DE	5.75	11.5	0.0046
Main and Main-Danube Canal	DE	4.89	9.78	0.00291-0.00506
Neckar	DE	6.32	12.65	0.00506
Rhein-Herne-Canal	DE	17.4	31.8	0.01519
Saar	DE	3.375	6.75	0.0027
Waterways North Germany*	DE	8.85	17.7	0.00708
Weser-Datteln-Canal	DE	17.76	32.53	0.0181
Mosel River	DE/LU	3.375	6.75	0.0027
Waterways Poland	PO	1.91	3.81	0.0015
French waterways	FR	1.41	2.32	0.000784 - 0.000993
Cernavoda Canal	RO	13.64	27.27	0.3**
Sulina Canal	RO	1.44	2.88	0.0011 - 0.0023**

* Ruhr / Dortmund-Ems Canal / Küstencanal / Mittellandkanal / Elbe-Seitencanal etc.
** per ton cap.

	Air pollution	General	Medium	There are different standards limiting the allowed emission per vessel. From these, the amount of emissions and the external costs created by a vessel can be calculated. Societal costs that are caused by the emission of most of these gases consist, for instance, of increased healthcare cost, since the emissions affect the lung function of people living in area of operations.	Yes	Eur per kg of main pollutant emitted from transport [1] [2] 	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. *Final Report*, (1), 139. https://doi.org/Ref: ED 57769 - Issue Number 1 Official Journal of the European Union, 25-6-2004, Annex XIV and XV	Medium	2
		SOx (SO2)-IWT	Low	Inland and short sea vessels have different engines, which use different fuel. The sea going vessels emit more SOx, which is why their cost caused to society is significantly higher.	Yes	See general description above **Marginal air pollution costs (2010) for inland water transport, EU average, € per 1000 tkm** **Inland Waterways** Total: 3.02 euro per 1000tkm, 2010[1] **Sea-river** Total: 2.8 (euro per 1000 tkm, 2010)[2]	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. Final Report, (1), 139.	Medium	2
		SOx (SO2) - SS	Large		Yes	**SSS** SO2: 6,080[3] (euro per tonne, 2010)		Medium	2
		NMVOC	Medium		yes	See general description above **Inland Waterways** Total: 3.02 euro per 1000tkm, 2010 **SSS** NMVOCs: 1,030[4] (euro per tonne, 2010) **Sea-river** Total: 2.8 (euro per 1000 tkm, 2010) **Urban areas** NMVOCs: 1,566[5] (euro per tonne, 2010)	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. *Final Report*, (1), 139.	Medium	2
		O3	Low		No	No data are available.			0
		NOx - Inland	Low	Together with SOx emissions, NOx emissions are a major concern for the coastal regions. This is due to the fact that shipping remains largely unregulated with regard to these emissions. Just like for the SOx emissions, the impact of seagoing vessel is significantly larger than the emissions caused by inland vessels.	Yes	See general description above **Inland Waterways** Total: 3.02 euro per 1000tkm, 2010 **Sea-river** Total: 2.8 (euro per 1000 tkm, 2010) **Urban areas** NOx: 10,640[6] (euro per tonne, 2010)	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. *Final Report*, (1), 139.	High	2
		NOx - SS	Large		Yes	**SSS** NOx: 3,790[7] (euro per tonne, 2010)		High	2

Eur per kg of main pollutant emitted from transport [1]

	PM2,5			NOx	NMVOC	SO2
	Rural	Suburban	Urban			
Average	28.1	70.2	27.0	10.6	1.56	10.24

[2]

CCNR stage I

P_N (kW)	CO (g/kWh)	HC (g/kWh)	NO_x (g/kWh)	PM (g/kWh)
$37 \le P_N < 75$	6.5	1.3	9.2	0.85
$75 \le P_N < 130$	5.0	1.3	9.2	0.70
$P \ge 130$	5.0	1.3	$n \ge 2800$ rpm = 9.2 $500 \le n < 2800$ rpm = $45 \times n^{(-0.2)}$	0.54

CCNR stage II

P_N (kW)	CO (g/kWh)	HC (g/kWh)	NO_x (g/kWh)	PM (g/kWh)
$18 \le P_N < 37$	5.5	1.5	8.0	0.8
$37 \le P_N < 75$	5.0	1.3	7.0	0.4
$75 \le P_N < 130$	5.0	1.0	6.0	0.3
$130 \le P_N < 560$	3.5	1.0	6.0	0.2
$P \ge 560$	3.5	1.0	$n \ge 3150$ rpm = 6.0 $343 \le n < 3150$ rpm = $45 \times n^{(-0.2)} - 3$ $n < 343$ rpm = 11.0	0.2

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[1] Table 23: Marginal air pollution costs (2010) for inland water transport, EU average, € per 1000 tkm. (p.46). Motor vessels and barges: 650-1000 (average of the values).

[2] Table 25: Marginal air pollution costs (2010) for maritime transport (average load), EU average, € per 1000 tkm. (p.47). Average of all data.

[3] Table 16: Damage costs of main pollutants in sea areas, in € per tonne (2010) (p.37). Average of the five data.

[4] Table 16: Damage costs of main pollutants in sea areas, in € per tonne (2010) (p.37). Average of the five data.

[5] Table 15: Damage costs of main pollutants from transport, in € per tonne (2010) (p.37).

[6] Table 15: Damage costs of main pollutants from transport, in € per tonne (2010) (p.37).

		GHG mainly CO2	Large		Yes	See general description above **Climate change-GHG emissions mostly CO2** **Inland waterways:** 3[8] (euro/1000 tkm, 2010) **SSS:** 1.8[9] (euro/1000 tkm, 2010)	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. *Final Report*, (1), 139.	High	2
		VOC	Medium	No data are available.	No	No data are available.			0
		PM (25)	Low	The emission of PM is similar to SOx and NOx. Whilst inland and sea-river vessels have a fairly small contribution, sea going vessels have a high societal cost contribution.	Yes	See general description above **Inland Waterways** Total: 3.02 (euro per 1000tkm, 2010) **Sea-river** Total: 2.8 (euro per 1000 tkm, 2010)	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. *Final Report*, (1), 139.	High	2
		PM (25)	Large			**SSS** PM2.5: 17,240[10] (euro pertonne, 2010)		High	2
		Overall emissions: sea-river	Medium		Yes	**Sea-river** Total: 2.8 (euro per 1000 tkm, 2010)	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. *Final Report*, (1), 139.	High	2
		Urban areas	Medium	The societal cost for emissions in urban areas is naturally higher than in rural ones, since more people are affected.	Yes	**Urban areas-air pollution** **PM25**: 270,178[11] (euro per tonne, 2010) **NOx**: 10,640 (euro per tonne, 2010) **SO2**: 10,241 (euro per tonne, 2010) **NMVOCs**: 1,566 (euro per tonne, 2010) **CO2:** 3.2[12] (€ct/vkm, 2010)	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. *Final Report*, (1), 139.	High	2
		Road/Rural/ Motorways	Medium	The external costs for the road transport have been studied a lot more in depth than for the maritime industry, thus a lot more data are available concerning road transport analysis.	Yes	**Road/Rural/Motorways** **PM25**: 28,108[13] (euro per tonne, 2010) **NOx**: 10,640[14] (euro per tonne, 2010) **NMVOCs**: 1,566[15] (euro per tonne, 2010) **SO2:** 10,241 (euro per tonne, 2010) **GHG (CO2)**: 2.0 (Rural) & 2.5[16] (€ct/vkm, 2010)	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. *Final Report*, (1), 139.	High	2
		Rail	Medium		Yes	**Rail** Total: 0.6 euro ct/tkm, 2010 **CO2:** 0.26[17] (euroct/ tkm, 2010)	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. *Final Report*, (1), 139.	High	2

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[7] Table 16: Damage costs of main pollutants in sea areas, in € per tonne (2010) (p.37) Average of the five data.

[8] Table 39: Marginal climate change costs for inland waterway transport, EU average (prices of 2010), € per 1000 tkm. (p.60). Motor vessels and barges: 650-1000 (adding up all the values of the column and divide by 10=3.

[9] Table 40: Marginal climate change costs for short sea shipping, EU average (prices of 2010), € per 1000 tkm. (p.61). Adding up all the values of the Table & divide this value by 50=1.8.

[10] Table 16: Damage costs of main pollutants in sea areas, in € per tonne (2010) (p.37) Average of the five data.

[11] Table 15: Damage costs of main pollutants from transport, in € per tonne (2010) (p.37).

[12] Table 35: Marginal climate change costs for road transport (cars and light commercial vehicles), EU average (prices of 2010). (p. 58). Average data of Light commercial vehicles at Urban areas.

[13] Table 15: Damage costs of main pollutants from transport, in € per tonne (2010) (p.37).

[14] Table 15: Damage costs of main pollutants from transport, in € per tonne (2010) (p.37).

[15] Table 15: Damage costs of main pollutants from transport, in € per tonne (2010) (p.37).

[16] Table 35: Marginal climate change costs for road transport (cars and light commercial vehicles), EU average (prices of 2010). (p. 58). Average data of Light commercial vehicles at Rural and Motorways.

[17] Table 37: Marginal climate change costs for diesel trains, EU average (prices of 2010). (p.60). Freight-Locomotive: Urban and Non-Urban.

	Sound pollution	In ports	Low	Sound pollution in ports or terminals becomes more relevant as vessels deliver their goods closer to urban areas. By implementing the VT concept, individual vessel owners may end up increasing the sound pollution in a specific area around the port.	Yes	No data are available for INI, sea-river & SSS. Only for urban areas, road/rural/motorways & rail. **Urban areas**[18] Day 75.5 Night 137.5 **Road/Rural/Motorways**[19] Day 0.6 Night 1.1 **Rail**[20] Day 827.2, Night 1977.6 in urban areas Day 43.85, Night 97.7 in rural areas (euro per 1000 vkm)	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. *Final Report*, (1), 139.	Medium	0
		On waterways	Low	Compared to the sound created in ports by the (un)loading of cargo, the actual operation of the vessel along the waterways is minimal.	No	No data are available.			0
		Inside nuisance	Low	This depends on the number of the crew, as it represents the amount of noise created by the work on board.	No	No data are available.			0
	Land use / landscape and soil quality	Outside nuisance	Low	This depends on the characteristics of the surrounding area. Underwater noise: not specified impact but is caused by the propellers.	No	No data are available.			0
	Impact on natural habitat	Animals	Low	The increase in number of vessels sailing can have a negative impact on the nesting places of birds for instance due to noise creation of the increased human activities. This could also impact aquatic species that are affected by water pollution.	No	No data are available.			0
		Ballast water	Medium	The impact on the natural habitat by the discharge of ballast water from different geographical areas is a concern for seagoing vessels. They take species from their natural environment in one area of the world and bring them to another, which can cause an unbalance in the ecosystem. There are strict regulations set concerning ballast water treatment systems required on board to minimize the impact.	No	No data are available about this topic concerning external costs created from it.			0
	Accident								
	Accidents	In port	Low	External costs due to accidents in ports are mainly related to water pollution.	No	No data are available.			0
		In locks	Low	These accidents would be under very specific circumstances and have no public record of it.	No	No data are available.			0

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[18] Table 28: Illustrative marginal noise costs for the EU*, € per 1000 vkm (p.51). LCV-Urban, average of dense and thin.

[19] Table 28: Illustrative marginal noise costs for the EU*, € per 1000 vkm (p.51). LCV-Rural + average of dense and thin.

[20] Table 28: Illustrative marginal noise costs for the EU*, € per 1000 vkm (p.51). Freight train-Urban and rural, average of dense and thin.

		In coastal areas	Low	Accidents can cause significant external costs, however large accidents are fairly rare in the waterborne modes of transport. So, the assessment of such circumstances is kept to a later stage in the model development.	Yes	No data are available. Data are only available for urban areas, motorways and rail. Urban areas[21]: 1.1 (euro ct per/vkm, 2010) Road/Rural/Motorways[22]: 1.2 (euro ct per/vkm, 2010) Rail[23]: 0.2 (euro per 1000 vkm)	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. *Final Report*, (1), 139.	High	1
Module 3: Cost of A Vessel Train Operator	**Capital Cost**								
	The costs of the VT operator include the operations of the LV. Such operations are for the most part calculated in a similar way with the FV in Module 1 and 2. These cost elements will not be repeated in the next section. The next section will however emphasise additional cost elements that may affect the VT operator as well as differences in cost element calculations.								
	Depreciation	General	Large	The investment cost for the VT operator comprises more than just the investment into the LV. The investment would also comprise of a shore control station that oversees the operations of the VTs.	Yes (partial)	See below.		High	**2**
		Depreciation of the ship	Large	The depreciation cost for the vessel is highly dependent on the business case of the VT operator. If the operator decides to provide a dedicated service, then a special dedicated vessel will have to be built to conform with the requirements. Since such a vessel will be smaller than a cargo vessel, it will also be cheaper, yet there will still be an investment requirement. If the operator decides to use a cargo vessel that has the ability to lead on the other hand, the vessel could be a refit and thus the depreciation may no longer be applicable. In case a new vessel were to be used, then the same depreciation calculations as for the vessel operator would apply.	Yes (partial)	For the deprecation calculation of a cargo vessel, see the description for the Vessel operator. For the estimation of a dedicated LV, a Damen FCS2610 fast crew supplier is sued as guidance vessel which is estimated to cost around 3 million Eur.	http://products.damen.com/en/ranges/fast-crew-supplier/fcs-2610 HOEKSTRA, T.J. (2014), *Optimizing Building Strategies for Series Production of Tugs under Capital Constraints*, Gorinchem	High	2
		Depreciation of the VT technology	Large	The VT technology imbedded into the LV is expected to be more complex than for the FV, since the LV will need to monitor and guide all FVs. It is therefore expected that the investment cost for the technology will also be larger.	No	This is a new technology, so only estimations for the NOVIMAR VT system can be made by the developers, on what this technology would actually cost. These experts expect the cost to be around 40,000-60,000Eur.		High	2

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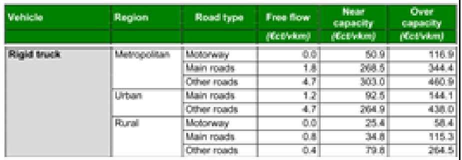
[21] Table 12: Marginal accident cost estimates, €ct/vkm (prices of 2010) (p.25). HGV-Urban road.

[22] Table 12: Marginal accident cost estimates, €ct/vkm (prices of 2010) (p.25). HGV-Motorway.

[23] For freight rail transport, the value is €0.2 per 1000 vkm. (p.26).

		Depreciation of an shore control station	Medium	Dependent on how the VT operator will be set up, it is likely that some forms of a shore control station will need to be set up to oversee and manage the different VT.	No	Information on this is yet to be known. Throughout the development of the system, more detailed information concerning such a station will become clear.		High	1
	Operational Cost								
	The operational cost relevant for the VT operations changes dependent on the purpose of the LV. For a dedicated LV, all the in module 1 mentioned cost elements are relevant in addition to the ones mentioned in the next section. For cargo vessels, only the cost elements in this section are of relevance.								
		Monitoring crew	High	The exact requirements for the monitoring crew are not known, however one can take general estimates on monitoring crew cost from highly skilled existing crew cots on a vessel. The amount of monitoring crew will also depend on whether or not those crew members can perform other tasks on board and on the number of operating hours within the VT.	Yes (partial)	As an initial estimate, a crew cost of 13.32 Eur/h is assumed from the SS crew cost given in module 1.		High	2
	Cost for VT consolidation and operation	Overhead cost	Medium	The overhead cost of the VT depends on the business case and the kind of service that it ends up providing. The pre-sorting of the cargo may fall under the additional administrative responsibility of the operator.	No	See notes on data for repair and maintenance of VT technology. Since no information is available on the VT technology, any implementation of this cost element will need to be pushed back into a later stage of the research. The data that will most likely be used for this will be annual percentage estimations of the capital cost.		High	1
		Repair of VT Technology	Medium	Repair costs of the new VT technology are dependent on the skillset of the monitoring crew. Most likely this role will fall to the VT guidance software developer.	No			High	1
		Maintenance of VT Technology	Medium	The Maintenance cost is highly dependent on the type of technology that is installed on board and design interface with the user. The interface may be designed in such a way that updates can simply be downloaded by the user, which would keep the maintenance minimal.	No			High	1
	Voyage Cost								
	With respect to the VT cost calculations of a cargo LV, the voyage costs are irrelevant, since they are covered by the income of the cargo transport. Only in a situation in which a LV would increase its fuel consumption due to the operations in the VT or would have to pay more port dues for waiting for FVs would make these voyage cost become relevant within the VT concept viability calculations. For the dedicated vessel, all the same cost elements are of relevance and are calculated in the same manner, as have been described in module 1. The only cost element that changes is the VT dues, which instead are actually a revenue for the VT operator.								

Module 4 : External costs of a Vessel Train Operator

External Cost								
Congestion								
Each individual vessel does not create more congestion than any current vessel does. When they are however clustered into a VT, congestion may cause cost for third parties. It is therefore important to understand the external cost created through congestions by the implementation of the VT. If these costs were to be internalized, they would have to be added to the VT Dues of the FVs.								
Congestion on the waterway	Created due to clustered arrival at infrastructures	Medium	On high demand routes the clustering of vessel in VT may cause longer waiting times at locks and ports for third party users.	Yes (partial)	Inland waterways: 0.4[24] euro/TEU*km SSS: 0[25] Sea-River: 0[26]	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. *Final Report*, (1), 139.	High	1
	Speed/ flow relations on the water	Low	Especially for inland navigation the VT may cause changes for the speed/flow relations and overtaking opportunities for third party users.	No	No data are available. However, speed-flow relations are considered the best method to calculate the external costs of congestion. Thus, it is taken indirectly into consideration via the external cost values of congestion given above.			0
Congestion on the road	Due to opening of bridges	Medium	Keeping a bridge open for too long may cause a ripple effect on the road traffic jams, hence it is possible that for long trains the may have to close to let some of the road traffic pass before it can open again to let the full VT pass.	Yes (partial)	Urban-areas: 1.8[27] euro ct per vkm, 2010 Road/Rural[28]/Motorways: 0.4 euro ct per vkm, 2010 Rail[29]: 0.2 euro per 1000 vkm, 2011 Knowing these values is only the first part of the external cost calculation. It will be more of a challenge to estimate the additional congestions created by longer or more frequent bridge opening times due to the VT.	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. *Final Report*, (1), 139.	Medium	1
	Due to short interval cargo arrival	Medium	The clustered arrival of large amount of vessels can not only cause congestions within the port but also in the roads around it. This means that society is impacted, since the roads in that area become busier. This also needs to be considered when looking at the increase in traffic around terminals closer to urban areas.	Yes (partial)	One can deduct from speed/flow charts, which commonly exist for road traffics, what the increase in external costs for an increase in cargo traffic can mean. 	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. *Final Report*, (1), 139.	Medium	1
Infrastructural								
Decay to waterways cause by changes in displacement		Low	The closer 'vessel to vessel interaction' in the VT may cause changes on the waterway borders.	No	No data are available.			0

Vehicle	Region	Road type	Free flow (€ct/vkm)	Near capacity (€ct/vkm)	Over capacity (€ct/vkm)
Rigid truck	Metropolitan	Motorway	0.0	50.9	116.9
		Main roads	1.8	268.5	344.4
		Other roads	4.7	303.0	460.9
	Urban	Main roads	1.2	92.5	144.1
		Other roads	4.7	264.9	438.0
	Rural	Motorway	0.0	25.4	58.4
		Main roads	0.8	34.8	115.3
		Other roads	0.4	79.8	264.5

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[24] Based on the Low Water Surcharge, which has to be paid on the river Rhine when water levels fall below a certain value, GRACE estimates scarcity costs between €0.38 to €0.50/TEU*km at Kaub (...) (p.18).

[25] the UNITE project (Doll, 2002) concludes that there are no external congestion costs in seaport operations (p.17).

[26] the UNITE project (Doll, 2002) concludes that there are no external congestion costs in seaport operations (p.17).

[27] Table 9: Efficient Marginal Congestion Costs, €ct per vkm, 2010, EU average* (p.16). Data of rigid truck at metropolitan main roads: for urban main roads: 1.2 and for urban other roads: 4.7.

[28] Table 9: Efficient Marginal Congestion Costs, €ct per vkm, 2010, EU average* (p.16). Average of rural data by rigid trucks.

[29] The marginal cost estimate for freight rail congestion as contained in the most recent version of the Marco Polo calculator (Brons and Christidis, 2013) is €0.2 per 1000 tkm (average for EU27, in 2011 prices). (p.17)

	Marginal external infrastructure costs (extra: reduction of infrastructure costs for road due to modal shift in favor of IWT)		Low		Yes (partial)	The data available are the following: Inland waterways: 1.92[30] (€ct/tkm, 2010) Urban areas: 1.5[31] (€ct (2010) per vkm) Road/Rural/Motorways: 0.6[32] (€ct (2010) per vkm) Rail: 0.45[33] (euro per train-km)	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. *Final Report*, (1), 139.	High	2
	Environmental								
	The environmental external costs caused by pollutants of course also apply to the LV operations, hence they are the same as it was described in module 1.								
	Impact on natural habitat		Low	The modal shift caused by a successful implementation of a viable VT business concept can cause an impact on the natural habitat.	No	No data are available.			0
	Accident								
	The accident costs for the VT operator are considered the same as for a vessel operator.								
Module 5: Cargo Handling & Pre/ End Haulage	**Capital Cost**								
	Depreciation	**Shore Control Station**	Medium	The cargo handling may fall under the VT operator, if the sorting and storage of the cargo is considered as part of the VT service. If this is concluded to be a viable business case, then the shore control station would need to invest into monitoring systems that allow an overview of the sorting and storage	**No**	Since no information is available on the VT technology, any implementation of this cost element will need to be pushed back into a later stage of the research.		**Low**	**1**
	Operational Cost								
	Cargo handling	Cargo handling at port	Large	Cargo handling is a cost that can only be estimated. Due to the high competitiveness of the business companies are not willing to share their data.	Yes (estimates)	See Annexes I & J from D2.2.	(van Hassel et al, 2018, D2.2.)	Low	2
		Sorting Cost	Large	As previously mentioned the cargo sorting is a possible add on of the VT service that intends to improve the efficiency of the vessels that are used by pre-sorting the cargo that goes onto different vessel. That way it may be achieved that vessels only discharge at a single port. The logistics and technology of such a system is developed by a NOVIMAR project partner and thus may be integrated into different business cases at a later stage of the VT development.	No	Any of these data are dependent on the Tool that MARLO creates for the pre-sorting of the cargo	(van Hassel et al, 2018, D2.2.)	Low	1
		Storage costs		Storage cost may be a cost that is influenced by the pre-sorting service that is being developed. Therefore it will be kept as a possible cost created by the implementation of the VT.	No		(van Hassel et al, 2018, D2.2.)	Low	1

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[30] Table 53: Infrastructure costs of inland navigation in France (price-level 2010), Table 54: Infrastructure costs of inland navigation in the Netherlands (price level 2010) & Table 55: Infrastructure costs of inland navigation in Belgium (price level 2010) (p.75-76) (1.99+1.58+2.19)/3=1.92 Average Costs (€ct/tkm).

[31] Table 51: Illustrative marginal infrastructure costs for EU*, €ct (2010) per vkm (p.74). HGV 7.5 - 12 t, 2 axles-All roads.

[32] Table 51: Illustrative marginal infrastructure costs for EU*, €ct (2010) per vkm (p.74). HGV 7.5 - 12 t, 2 axles-Motorways.

[33] Section 8.2.2 (p.74) €0.2 to €0.7 per train-km for freight trains. taking the median value 0.45.

	Pre/end haulage	Distance cost	Large		Yes	See Annexes K & L from D2.2.	(van Hassel et al, 2018, D2.2.)	Medium	2
		Time cost	Large		Yes	See Annexes K & L from D2.2.	(van Hassel et al, 2018, D2.2.)	Medium	2
		Cargo handling at destination	Large		Yes	See Annex K from D2.2.	(van Hassel et al, 2018, D2.2.)	Low	2
		Waiting costs during cargo handling	Large		Yes	Annex K from D2.2.	(van Hassel et al, 2018, D2.2.)	Low	2
	External Cost								
	Congestions & Infrastructure								
	The external costs created through congestions and infrastructure are covered by the elements in module 4 of the VT operator.								
	Environmental								
	Air Pollution	Of work vehicles in port	Medium	The external cost values for the pollution of the different gases are the same as for the existing vessels. The main difference is in the type of gasses that are emitted. Road transport emits mostly CO2, whilst ships also emit SOx.	**Yes**	See air pollutant values from Module 1.		High	**2**
		Of truck and train at end delivery	Large		**Yes**	See air pollutant values from Module 1.		High	**2**
	Accident								
	Road accidents		Medium		**Yes**	Urban areas: 1.1[54] (euro ct per/vkm, 2010) Road/Rural/Motorways: 1.2[55] (euro ct per/vkm, 2010)	Korzhenevych et al. (2014). Update of the Handbook on External Costs of Transport. *Final Report*, (1), 139.	High	**2**
	Operational Cost								
Module 8: Cargo owner	Stock	Stock in transit	Large	The stock in transit takes into consideration that the good is also part of the owners' stock, whilst still being transported, yet not providing the owner with access to the good. The longer the good takes to reach the owner, the more expensive it becomes for the shipper.	Yes	$L * v * \frac{h}{365}$ L: average lead- time(days) v: value of goods(EUR/unit) h: Holding cost (%/ year)	(Blauwens et al., 2006)	Medium	1
		Safety stock	Large	Safety stock is a buffer of inventory that helps dealing with fluctuations in demand. Value is influenced by the amount of risk that an individual shipper is willing to take and is thereby very case dependent.	Yes	$\frac{1}{R} * v * h * K * \sqrt{Ld + D^2 l}$ R: Annual volume (units) K: Safety factor d: variance of daily demand(units^2/day) D: Average daily demand(units/day) l: variance of lead-time (days^2)		Medium	1
		Cycle stock	Large	In general, the cycle stock considers the amount of time during which a good spends in stock before it is consumed. Cycle stock declines with the rate of the demand. When a new shipment delivers the goods, the stock rises back to its initial level.	Yes	$\frac{1}{R} * \frac{Q}{2} * v * h$ Q: Loading capacity (units)		Medium	1

8.3 Annex C: Insurance costs of the VT

Interviews have been conducted with four insurance companies (Marsh, Aon, Vanbreda and Havrico) to which we asked the following questions:

1. Do you think that the insurance costs will increase, stay the same or decrease for the vessel operator of a vessel that can sail as part of the VT? For replying this question please keep in mind that for the VT vessels an IT technology will be installed on board that will result to the reduction of the crew. We assume that the safety level is the same. **(vessel operator's insurance costs)**
2. Could you provide a % of change (if any) in the insurance costs? **(vessel operator's insurance costs)**
3. Is the insurance from the perspective of the VT operator/organizer different than the one of the vessel operator? For the VT operator, the key question is 'Does he/she need to have an additional insurance for all the follower vessels?'; If yes, 'How much will this insurance cost'? **(VT operator's insurance costs).**

Vanbreda

"The VT would probably lead to lower insurance premium level, however Hull underwriters would have additional uncertainties (i.e. what will happen when the system fails etc.). We suppose that a risk analysis will be made by underwriters and non-follow up guarantees should be given in order to remove these uncertainties for Hull and P&I liabilities as well. The use of less crew will lead to less risks for crew claims and/or negligence or similar faults. But on the other side, the IT system on board may lead to additional risks. Influence on insurance premium is currently an open question, as this depends on too many factors and underwriters do not have any experience yet in this type of shipments. There will certainly be a higher exposure for "cyber risks"" (René, 2018).

Aon

"We believe that in the first instance the costs will rise in the range of 5% to 10% because there is no track record of this new technology claims wise, so in the beginning very few underwriters will be keen to take on the risk. If after several years the technology proves to be less claims active, the insurance costs can decrease dramatically with even 50% because of the crew risk / human failure is the biggest risk in the marine insurance market. The % of change if the technology proves itself to be safer/less claims intensive is:

Year 0 : +7%
Year 1 : +3%
Year 2 : -4%
Year 3 : -7%
Year 4 : - 8%
Year 5 : -9%
Year 6 : -10%

The VT organizer, if not the ship owner of the full train, will have to take out a liability cover for this project, this is currently available under the charterers liability insurance solution. The cost is roughly to be indicated between EUR 1,000 to EUR 5,000 depending on the amount and size of vessels involved and the contractual exposures." (van Geyte, 2018).

Havrico Insurance

“The same liabilities as for ordinary vessels will apply to the vessels individually of the VT. The introduction of unmanned vessels will change the profile of risks:

- A higher level of automatization in unmanned vessels will eliminate an important number of claims partly due to human error. The Shipowners’ Club states that around 47% of the claims the Club deals with involve some degree of human error.

- Claims relating to crew (injury, death and repatriation) will reduce. The Shipowners’ Club states that such claims represent 34% of the Club’s claim expenditure.

- Systems failure is a potential challenge. The liability of autonomous products could be linked to different actors: the owner, the user, the manufacturer of the product or the manufacturer of individual components.

- Higher vulnerability to cyber-attacks.

Bearing in mind the above mentioned considerations:

- One may expect that the vessel operator’s (being the leader vessel) insurance cost, regarding hull and machinery insurance and regarding P&I insurance, will at first remain the same and will later likely decrease. However, the decrease in insurance cost will probably partly be balanced out by an increase in premium relating mainly to cyber risks. This will also apply to the follower vessels.

- I do not think that the vessel operator (being the leader vessel) will need an additional insurance for all the follower vessels. In case of damage to third parties caused by the follower vessel, the liability will rest on the follower vessel, even if the damage is attributable to human error or technical failure of the leader vessel, because the follower vessel is manoeuvred by the leader vessel, which is actually an agent or servant of the follower vessel. As regards the leader vessel, same will be held liable for damages caused directly to third parties by its crew or because of its own technical failure. The recovery action between the vessels of the VT mutually will be governed by contract.” (Vrints, 2018).

Marsh

“Hull & machinery insurance: VT ships will be more expensive, thus premium will be more because the value of the ship will be higher and the hull & machinery premium is calculated based on the value of the ship. The increase because of the ship value is almost linear: e.g. 100 million vs 10 million ship will have 10 times more expensive tariff. The leader vessel will not take higher tariff because there will be crew on it. But the follower vessels with no crew or even with one member crew, who is there but ‘does nothing’, in the sense that is led by the leader, will take a lower tariff. This is because when there is no crew, you exclude the human errors because there are no people on board to make mistakes. But this is based on the assumption that there is no technological error. But this assumption is not true because technology always breaks down. But we do not know what this risk is because it is a new technology. For medium vessel sizes of a cost of 10 million, the premium per year will be between 50,000 and 100,000 (always 0.5%-1%). But cyber risks are very new and are excluded. These vessels are ‘floating computers’ and thus there is programming risk. Cyber risks maybe in the future will be involved in the ‘hull & machinery’.”

"<u>Liability insurance:</u> We do not know if there *will be new liabilities. It will depend on regulation. I think that it will not be needed to change the law to make new liabilities. E.g. maybe they will say that the leader of the vessel train will be liable for the rest of the train. If they do that, they will introduce new liability and thus this means higher premium. For a medium size vessel: 150,000 euro per year for all liabilities. For VT ships, you have:*

- *low crew liability because you have less crew.*
- *high cargo liability. Thus the tariff will be less.*
- *high cyber risks but these are excluded from the liability.*
- *high technology risks.*

However, for the liability you do not pay a separate tariff per element but it covers everything. The premium is for all. My opinion is that I do not see an increase of liability. But my concern is the following: "will you find a Club to take this risk (a P&I Club) and if so in what price?". It will be difficult a P&I Club to accept you. If you are in the Club, they can pay/cover up to 3.1 billion US dollars (this is the liability insurance that they give).

So as to sum up, as the size of the ship increases, so the hull and machinery insurance costs do.
- *Liability: we do not know about liability.*
- *For a 10,000,000 ship, maybe you see a difference of 30,000 and 40,000 only. Marine insurance is cheap. For the VT, the tariffication[5] will be still between 0.5%-1.0% but it will be marginal."* (Moens, 2018).

<u>Summary</u>
So as to sum up, based on the information taken from all the four interviews presented above, it is observed that the common element among all the four interviews is that less insurance premium is expected thanks to the less crew on board and thus the less risks for crew claims and increased cost due to the additional (unknown at the present time) IT system-related additional risks (exposure to cyber risks).

The insurance costs will either remain almost the same (decrease that might be balanced out by the increase of the related cyber risks) (Vanbread & Aon), or they will initially increase from 5% to 10% and after some years, if/when the technology proves to be less claims active, insurance costs might decrease (10% at year 6), or they will marginally increase due to the higher cost of the ship (the hull & machinery premium is calculated based on the value of the ship) (plus the expected cyber risks and the unknown liability). Therefore, no big changes are expected in the insurance costs of the VT compared to the insurance costs of conventional existing vessels.

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[5] **Tariffication = value * % tariff**. It can be close to 0.5% or 1.0% but Mr. Moens do not see much change.