A Multi-Scenario Simulation Transport Model to Assess the Economics of Semi-Autonomous Platooning Concepts

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Abstract

The Vessel Train (VT) concept, aims to increase the level of autonomy of ships in order to develop a competitive low-manned waterborne transport concept. A transport model has been developed to determine the concept's performance. In this paper, that model is used to assess the impact of the concept for the lead vessel on the overall performance of the VT. If one knows the cost of the Lead Vessel, the required benefit for the follower vessels can be determined. The model uses multiple scenario simulation to gather data for a sensitivity study of the LV features. The insights gained into the behavioural properties of the VT leads to recommendations on boundary conditions for a profitable implementation of the VT.

1. Introduction

The NOVIMAR (NOVel Iwt and MARitime transport concepts, https://novimar.eu/) project develops a waterborne transport system called the Vessel Train (VT) that is based on the platooning principle that is also researched in the trucking industry. The train is commanded by a lead vessel (LV) that is fully manned and takes over navigation, communication and situational awareness responsibilities for the follower vessels (FV), Fig.1. The aim of the concept is to create a transportation solution for the European transport sector that makes use of the existing waterborne transport potential to help expand the transport chain up and into the urban environment. Although the concept is being considered for both the Inland Water Transport (IWT) and the Short Sea (SS) Shipping sector, this paper will mainly focus on its application for the inland navigation.

Fig.1: Vessel train (VT) Concept**,** https://novimar.eu/concept/

A FV needs to be equipped with the technology to make it possible for the LV to monitor and control the navigation and parts of machinery systems. This enhancement of automation on the FVs allows lower manned vessels. Increased automation on board of the FVs lead to the possibility to reduce crew and thereby, operational cost. Such a cost reduction will allow especially smaller class II inland vessels, where crew cost may be as high as 56% of the fixed cost *(Beelen, 2011)*, to become more attractive. This should lead to increased use of these small vessels and increased use of small waterways.

The VT is a means to achieve increased autonomy of ships, without having to address the big challenges of autonomous navigation and communication in confined and busy waters.

The concept for the LV is just as important for the VT as the FVs, since it determines the additional cost that have to be overcome by cost savings of the FVs. Therefore, the LV is the main focus of the study in this paper. For the case study, a purpose-built model in which the mentioned lead vessel features are embedded, is used to calculate cost for various scenarios. The data obtained allows an impact assessment to be made that helps understand the economic viability of the VT concept.

This paper first explains the background and method according to which the transport model is set up. It then moves on to desribe the input data used for this specific case study and states the scenarios that are used to help assess variations within the cost.This is followed by the presenation of the results and a discussion section in which particulatities about assumptions and the application of the concept in different sectors is mentioned. The final section summarizes the main conclusions that were drawn from the simulations and informs on the next steps taken within the research of the VTs viability.

2. Modelling the Lead Vessel Cost

This section starts by introducing the different LV types, then moves on to describe the cost features than influence the LVs and explains the alterations in cost features dependent on the application of the LV. The last part of this section explains the structure of the cost model and the type of data it provides for analysis purposes.

2.1. LV Vessel Types

Dependent on the desired business application for the LV, the role of it may differ. The focus of this paper’s case study is placed on the LV either being a dedicated vessel or a cargo vessel. The dedicated vessel refers to a vessel whose sole purpose is to provide a service of leading other vessels. It can be any type of vessel, e.g. a refit cargo vessel or a vessel that may have been designed for speedy transportation of people. Its only restriction is that it needs to be able to meet the operating speed of the fastest FV and support the required control systems as well as the additional crew on board. By using a vessel that has been designed to only carry people, the vessel operating cost can be reduced, since the hull shape can be optimized for speed instead of for cargo carrying. It is yet to be decided whether the dedicated LV will be specific to a sector or can operate for both the IWT and the SS sector. For the sake of comparison to demonstrate the property differences between the dedicated and the cargo vessel; the specs of the Damen FCS2610 fast crew supplier, http://products.damen.com/en/ranges/fast-crew-supplier/fcs-2610, has been chosen as a sample base-case LV in this paper. This would theoretically allow the LV to lead at SS operating speeds as well.

Table I: Benefits and Drawbacks of Different LV Types

LV Type	Benefits	Drawbacks
Dedicated	• Available when needed (suitable for both liner and tramp services) • Flexibility in choice of sector (IWT or SS) application, since operating speeds can adapt to any vessel type	• Costlier for the user, since the total LV operating cost has to be compensated for by the FVs.
Cargo	• Lower FV contribution cost since, the income from cargo partially covers operating cost of the LV	• Availability restricted by loading of the cargo (not suitable for liner service) • Less attractive to FV due to more restrictions in destination and departure • Space required on board for the VT monitoring personnel

The cargo vessel refers to a vessel that has normal income from transporting cargo and the added benefit of proving a service as a LV. For the case of the simulations of this specific research, a class V inland vessel of 110 m long and 11.4 m wide has been chosen as vessel type. The reasoning behind it is that such ships are fast enough to lead any inland VT without restricting its speed. If a different vessel were to be chosen, that is not able to operate at the speed of the larger inland vessel, a disadvantage could be created to the business case, since the VT operating speeds may be restricted by the speed of the LV. The cargo LV only leads other vessels if they fit in the LV operator's schedule. In essence, the lead vessel acts as a normal cargo ship but allows others to tag along to generate additional income. As a result, only the additional cost of the monitoring & control equipment and associated crew need to be charged to the followers.

Both business cases have their benefits and drawbacks, Table I. Choosing between these two business cases is a trade-off between service reliability and cost.

2.2. Cost Features of the dedicated and the cargo LV

The two vessel types make up an important part of the cost elements. However, as can be seen from Fig.2, there are four other main factors that influence the LV cost. The five main cost elements are identified to be: 1) extent of automation, 2) vessel type, 3) operating times 4) manning 5) investment. Within these five factors there are two dominant features:

I) ***Vessel type:*** Dependent on the type of vessel the cost are influences differently:

  a. fuel cost will differ dependent on the size and performance properties of the LV. This cost influence is considered within the vessel type sphere in Fig.2. The fuel cost is only of relevance to the dedicated LV cost, since for the cargo LV this cost element falls under the standard operating cost that is covered by the cargo transport income.
  b. manning requirements and resulting crew composition are different for both types of vessel as well as per operational regime (14,18 or 24 h/day). Hence this cost is considered under its own category 'manning'.
  c. investment cost for a modified cargo ship are likely to be lower than for a dedicated ship, since the ship does not need to be constructed, just refit.
  d. operating time of the LV can be limited for the cargo vessel since it needs (un)load cargo.

II) ***Extent of automation/monitoring:*** Identifies how much of the monitoring and control tasks are transferred from FV to LV. This influences:

  a. manning requirements, since different crew members may be needed to monitor and control the automated tasks of the follower vessels.
  b. investment cost may be different dependent on the functionality and type of technologies used for the monitoring and control of the vessel.

This description shows a strong interrelation between the different factors. The investment cost element is composed of the capital cost requirement for the ship construction and the cost for the investment of the VT technology together with it being imbedded on board.

Similarly, the manning cost of the LV is split into the crew that allows the sailing operations to be performed and the crew that allows the LV service to be performed, which is referred to as the monitoring crew.

As seen from the dominant feature description, the two vessel types create different cost. For the VT concept to be economically viable, the FVs need to compensate for any cost created by the implementation of the VT and simultaneously benefit from sailing in the VT. To make it possible to compare the two vessel types it is thus important to have a clear understanding on what cost actually influence the specific LV type.

The cost created by the implementation of the VT only directly comprises of the VT tech cost and the monitoring crew cost for the cargo vessel, since the general operating cost are covered by the income created through the cargo transportation. Yet, the investment in ship and/or control system leads to several costs that would have to be regarded within the cost breakdown of the total cost. These are all time dependent cost, being depreciation, insurance, interest. Even though the maintenance cost is technically separate from the investment cost, in this case it is calculated as a function of the investment cost, which is why it is counted under this same category.

The dedicated vessel has all the same cost elements as the cargo vessel and more, since the FVs also have to compensate for the general operation of the vessel. The depreciation, insurance, interest and maintenance cost are significantly higher than for the cargo LV. They are not only based on the investment cost of the VT technology, but also the investment cost of the ship. The two operational cost elements that are added to the dedicated vessel are the operating crew and the fuel cost. Both of these cost elements are influenced by the properties and size of the dedicated vessel chosen. A summary of all cost considered in either business case application is provided in Table II.

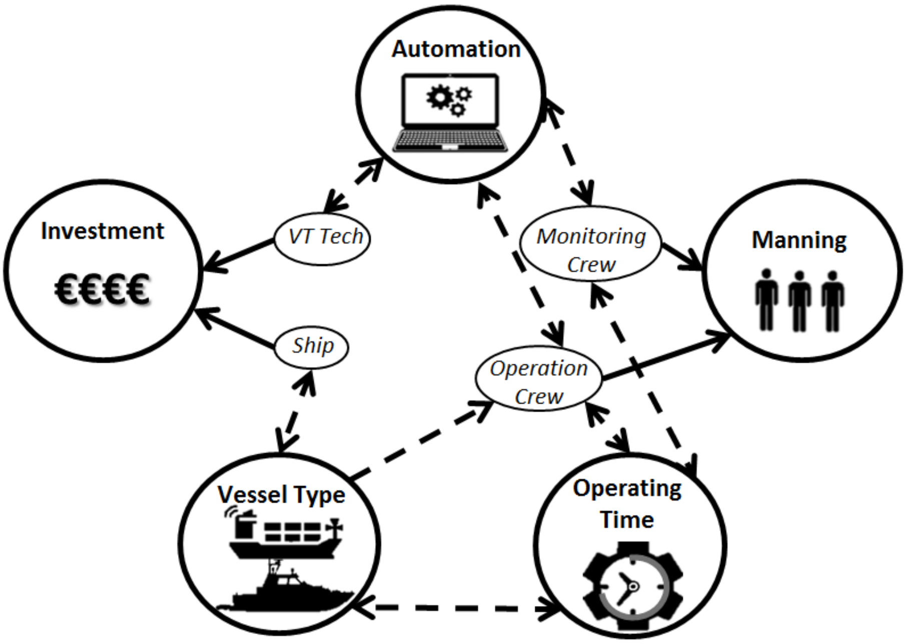

Fig.2: Influence of LV Type on LV Features

Table II: Cost Element Breakdown for LV Type

Cost	Dedicated	Cargo
Ship Investment	✓	X
VT Technology Investment	✓	✓
Operating Crew	✓	X
Monitoring Crew	✓	✓
Fuel	✓	X
Depreciation	✓	✓
Insurance	✓	✓
Interest	✓	✓
Maintenance	✓	✓

A cost feature that has deliberately not been mentioned in is overhead cost. It is disregarded since it largely dependent on factors that are not directly linked to the LV’s technical.

2.3. Model Structure

A transport model has been developed to help assess the overall performance of the VT. Not all elements that are calculated in the model are addressed in this paper. This section aims to explain part of the VT transport model that provides the data used for the multi-scenario analysis of the LV. Fig.3 shows the model set up. It is split into three different entities; external data, decision steps and actions performed to calculate the cost. The external data are case study dependent and values are presented in the next section, while the other two entities are further elaborated upon in this section.

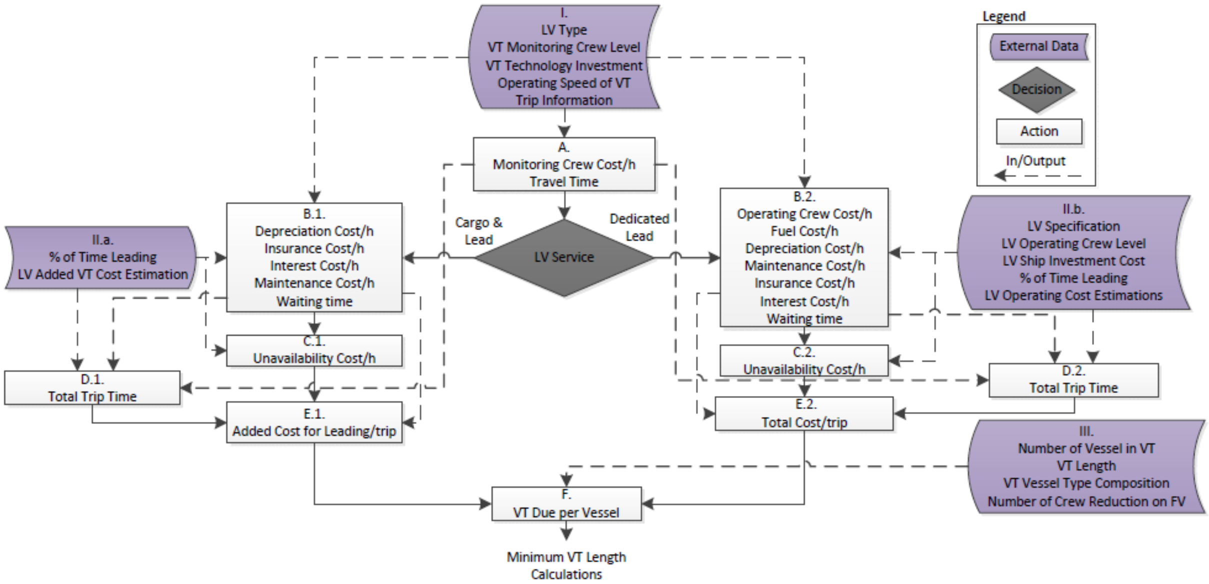

Fig.3: Flow Chart of LV Cost Calculations of the VT transport Model

The calculations of the hourly monitoring crew cost and the travel time (A) are independent of the vessel type. It is only after the decision step, that the calculation for each LV type differ. The cost estimation of the dedicated LV requires the determination of all operating cost elements i.e. crew, fuel, depreciation, maintenance, interest and insurance cost per hour (B.2.). All but the fuel cost are calculated based on a constant percentage from the input data, referred to as the ‘LV operating cost estimations’. The fuel consumption is estimated on the basis of the vessel’s engine data, assuming the engine never runs at more than 85% MCR, and a cubic power-velocity relationship. When combining the power data that is deduced from the speed-power curve, with the fuel consumption data of the ship’s engines (Caterpillar Marine Populsion Engine 3406E), the fuel cost and the trip time, the hourly fuel consumption of the dedicated LV can be calculated.

A high availability of the dedicated LV is expected. It is assumed the dedicated LVs service is immediately available and hence provides an availability of 100% for 360 days a year. However, there may be instances where the LV will have to wait for all FVs to be ready to depart, since exact operations surrounding the train are unknown. These waiting times or unavailability create extra cost the FV’s have to compensate for. So, a variation of availability is built into the model (C.2.). The waiting time is simply deduced from the input data, ‘percentage of time leading’. Once the total trip time is known, one can use it together with all the previously calculated hourly cost elements to calculate the total cost per trip.

The cost that the FVs needs to compensate for the cargo vessel (B.1.) are fewer than for the dedicated case. The main difference between the two calculation paths is that some cost elements are omitted. Furthermore, the waiting times of the cargo vessel (C.1.) also comprises the times spent in port, where it might be bunkering or (un)loading cargo. 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, *(Malchow, 2010)*.

The final step (F.) of the models first stage is to determine the added cost each FV has to pay for the use of the VT. Shipping is a highly comparative market, where the profit margins are low *(Blauwens et al., 2012)*. It is, therefore, assumed that the operating cost of the LV or the additional cost of VT operations for a cargo vessel need to be compensated for by the FV. This ensures a profitable scenario for the VT operator. Thus, the simplest representation of the VT dues are the total cost/added cost for leading of the respective LVs, divided by the number of FVs.

Simultaneously, these individual VT dues have to be less than the savings achieved by sailing in the VT. Hence, a minimum VT length has to be found in which both of these conditions are met.

Up to now, the description only covered the cost calculation stage of the model. The cost alone are not useful unless they are put into perspective of the overall VT concept by comparing them to the cost savings of the FVs. Fig.4 describes the reasoning behind the determination of the cost savings and the minimum viable VT length calculations.

The main cost saving that the VT concept aims to achieve is a reduction in crew cost by the FVs. Comparing the current base case conditions to the FV scenario with crew reduction allows a cost savings for the entire trip to be calculated. This does not only include the time the vessel spends sailing in the VT, but also the time it spends in port. Making use of the VT should allow less crew to be on board for the same operating conditions, while sailing in- and outside of the VT.

With increasing number of FVs in the VT, the required VT dues of each individual FV reduces. The point at which the cost saving of the FV is larger or equal to the VT dues, is identified to be the minimum required VT length to make the concept economically viable.

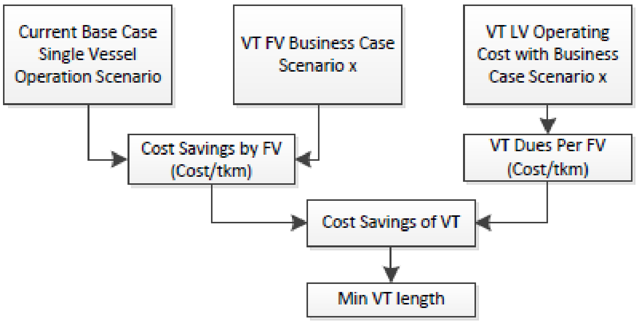

Fig.4: Flow Chart of Minimum VT Length Determination

3. Case study

This section describes the input data that is used in the model and explains the specific scenarios that are set up to allow a spread of results to be analyzed and conclusions to be drawn from them. The last section has already described some of the differences in data requirement dependent on the role of the LV. The underlying values that are used, as presented in Table IV, are based on existing inland navigation cost models *(Beelen, 2011; Hekkenberg, 2013; van Hassel, 2011)*.

3.1. Input Data

The data in Table IV provides the information referred to as external data in the flow chart of Fig.4. The input differences between the dedicated and the cargo vessel are presented in Table IV. Most of the data is self-explanatory. There is, however, some information that requires some further commentary.

The hourly crew cost for the LV are based on the crew cost provided in Table III (data is currency converted and inflation adapted from *Stopford (2009)*). Since the exact specs for the dedicated LV are not known, it is assumed that the operating crew will also fall under the SS vessel crew cost, that for certain roles is larger than the average expected for the IWT vessels. It is also not known what size the LV will have. Hence Table III also provides the crew composition assumptions, that have been set for a crew requirement of 4, 6, 7 or 8 operating crew on board of the dedicated vessel.

The monitoring-crew cost is considered equivalent for the cargo and the dedicated vessel, but since the job description does not yet exist in practice, the cost has to be estimated. It is set to a cost of 13.32€/h per person, which is equivalent to the cost of a seagoing chief officer and can hence be classified as a highly skilled crew member.

Table III: Crew Cost for a Sea Going Crew Member

Crew Role	Wage	Operating Crew Level			
	€/h	4	6	7	8
Master	17.54	1	1	1	1
Chief Engineer	17.11	1	1	1	1
Chief Officer	13.32	1	1	1	1
Second Engineer	13.32	1	1	1	1
Second Officer	8.11	0	0	0	1
Cook/Bosun	4.22	0	2	3	3

Table IV: Input Data for base case scenario

I	**Trip Information**	Distance (km)	325km (Antwerp to Duisburg)	
		Current (km/h)	4	
	LV Type		**Dedicated**	**Cargo**
	VT Monitoring Crew Level		2	
	VT Monitoring Crew Cost		13.32€/h/person	
	Operating Speed of VT		7.5	
	VT Tech Investment Cost		60 000 €	
II	**LV Specification**	Design speed (kn)	20	Not applicable, since fuel cost falls under standard operational cost
		Installed power (kW)	2237.5	
		Sfc (g/kWh)	208	
	LV Operating Crew Requirement		6	4
	LV Ship Investment Cost		3 000 000€	0€
	LV Operating Days		360 (99%)	128 (35%)
	LV Cost Estimation	Insurance	0.75% annually of total investment	0.75% annually of VT technology investment
		Depreciation	5% annually of ship investment 20% annually of VT technology investment	20% annually of VT technology investment
		Interest	5% annually of total investment	5% annually of technology investment
		Maintenance	2% annually of total investment	Not applicable, falls under standard operational cost
III	**Number of FV**		5	
	Type of FV		IWT Class IV	
	Number of Crew Reduction on FV		2	

In Table IV, the percentage behind ‘LV operating days’ denotes the percentage of time these number of days make up the total year. This percentage will later be taken as a variation to analyse the effects of a variations cause by the percentage of time leading. This percentage includes waiting times that have to be attributed to the leading of a VT.

Special attention also has to be paid to on the different depreciation rates of the ship and the VT technology. The steel of a ship hull is more durable than technology which is constantly evolving and will need updates. Hence, it is not surprising that ships investment is depreciated over a period of 20 years (5% per year), while the technologies investment is depreciated over 5 years (20% per year).

The data, that allows the cost savings by FVs to be calculated, is based on the crew cost provided in *Hekkenberg (2013)*. In contrast to the sea going crew cost, the IWT crew cost in this data source, are not differentiated by role, since there is no information available yet, that indicates which crew member will be taken from board or even what the crew members jobs will entail. Taking the average crew cost is therefore the best starting point. The crew cost per IWT class also change dependent on the class of the vessel. The corresponding hourly cost are presented in Table V.

Table V: Crew Cost for an IWT Crew Member

IWT Vessel Type	Average Crew Cost per Member
Class V	9.45 €/h
Class IV	8.84 €/h
Class II	8.29 €/h

The last input data to mention, is the time not spent leading, which is identified as un/loading time, waiting time in port or times during which there are no FVs following the lead vessel. For this specific case study, the travel time of the distance between Antwerp and Duisburg (see distance in Table IV) of 23h (at 7.5kn) is approximately equal to the time spent in port at the start or end of the trip. Hence, the total port time was simply set to equal twice the travel time to mimic both the pre-departure and post arrival time needed. Assuming that the LV is always leading followers when it is sailing, this causes the sailing time in the VT to only make up one third of the total trip time.

3.2. Scenarios

Some of the input data provided in Table IV varies dependent on the different assessment scenarios that are set. These variations are based around the following factors:

- Investment Cost
- Crew Cost
- % of Time Leading

To keep an overview of the variations of each of these factors, three scenarios have been set: An expected, a best and a worst-case scenario.

All factor variations are run from the base case, which is the ‘expected’ scenario. This means that if, for instance, the investment cost is varied, only those values are altered from the expected case, all others stay as they are indicated in the expected scenario.

Hoekstra (2014) identifies the cost for a tug boat of a similar size to the parent vessel, used for the dedicated vessel, to be between 3.5 to 5 million €. A tug boat has a large amount of installed power on board to be able to tow other ships. A dedicated LV does not require this much power. Hence, a first cost estimation for the vessel is set at 3 million €. The best-case scenario is set to half and the worst case to twice this cost estimation.

The estimation of the technology investment cost was given by experts from the NOVIMAR consortium, who provided a preliminary rough estimate of 60000 € for a LV. The best-case and worst-case scenarios are set in the same way as for the ship investment cost, i.e. half and double the reference value.

Concerning the crew cost, the number of operating manning is set to six, which is the minimum number of crew members on a small short sea vessel needed to operate it continuously. This excludes the crew for cargo handling. The best-case scenario takes off two crew members from that value and the worst case adds two. The same principle is applied for the monitoring crew, where three crew members are needed to cover 24h monitoring with 8h shifts per crew member. The last variation is done in the monitoring crew cost where the worst case assumes a master level skill set, instead of a chief officer, and the best case assumes a lowered crew cost of about 20% from the expected value.

Table VI: Scenario Set-up for Investment and Crew Cost Variation

Scenario	**Investment Cost**		**Crew Cost**		
	Ship	**Tech**	**Operational Manning**	**Monitoring Manning**	**Monitoring Crew Cost per operator**
Expected	3 000 000 €	60 000€	6	3	13.32 €/h
Best	1 500 000 €	30 000€	4	2	10.50 €/h
Worst	6 000 000 €	120 000€	8	4	17.54 €/h

The availability or the so called ‘percentage of time leading of the LV’, is a matter of business case application of the operator. Thus, values have been picked to be representative for a range of possible operations. The reasoning behind the chosen percentage lead times are as follows:

- The expected lead time for the dedicated vessel assumes 10% of time spent waiting for all FV’s to gather at the departure location before sailing operations can be stared.
- The expected lead time for the cargo vessel assumes the same 10% of time spent waiting for all FV’s, but also factors in the port time required to (un)load the vessel. If the class V vessel where to lead full time directly when it leaves port it can achieve an availability of 45%. This is why that value has been set to the best-case scenario. This percentage is based on the assumption that there it continuously operates on this trip with 70% utilization of cargo space and a cargo handling rate of 400t/h.

Note that 100% availability is assumed to be equivalent to 360 days of operations per year.

Table VII: Variations for LV % of time Leading

Scenario	**Dedicated Service**	**Cargo Service**
Expected	90%	35%
Best	100%	45%
Worst	80%	25%

Finally, the input data provided in section III of Table IV will be varying with every simulation case. The model calculates all values for 1 to 30 FVs with a crew reduction from 1 to all crew members on the specific FVs, for IWT Class II, IV and V vessels. This is done to be able to provide the necessary data presented in the result section. The last point to be noted in this case study is that for purpose of simplification and to place focus on the LV features only, all VTs modelled are composed of the same class FVs.

4. Results

The first part of the results demonstrates the cost breakdown of the two LV types, Figs.5 and 6. Both of these assume the best-case availability for the LV type. The values provided are given in cost per hour of operation in the VT. The cost provided are the hourly rate of that specific cost element. The sum of the pie charts differs between the two LV types. The cargo vessel is clearly creating less cost for the FVs to compensate. The cost breakdown comparison makes it clear that the time related cost impact is dominated by the crew rather than the combined cost for the depreciation, interest, insurance and maintenance cost estimation.

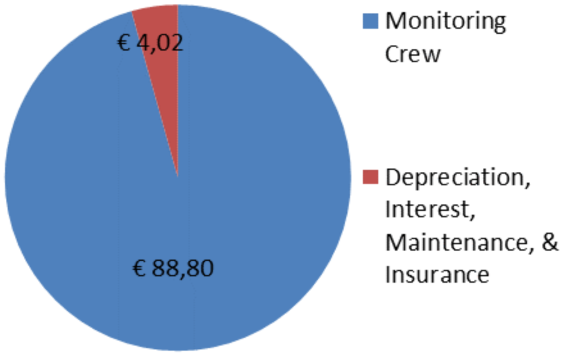

Fig.5: Cargo LV Additional Cost Breakdown

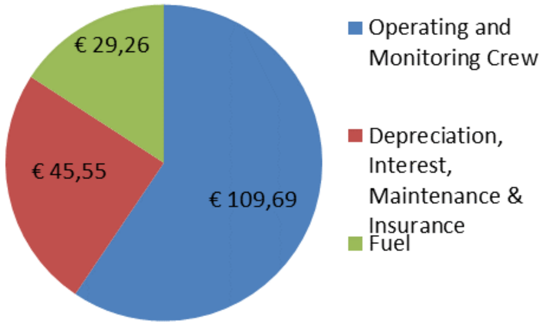

Fig.6: Dedicated LV Cost Breakdown

To provide a picture on what these costs represent in terms of required FV crew reduction, the individual cost structures have been translated into cost equivalents to crew reduction, assuming a crew cost of a standard class IV IWT crew member. Fig.6 total cost for the dedicated vessel adds to 184.5 €/h. The FVs only operate one third of their time in the VT but do profit from a reduced crew reduction the rest of the time as well. Therefore, the required savings for a FV per operational hour in the VT drops to 61.83€/h. To achieve these savings, at least seven crew members need to be taken off in the VT. This value is indicative over the entire spread of the VT not just one FV. This value is of course highly dependent on the wage of the crew member that is being reduced. Table VIII summarizes this calculation procedure for both LV types.

Table VIII: Sample of Required Crew Reduction for a Dedicated LV VT

Required Savings in VT /h	184.50
% of time FVs spent in VT/h	33%
Savings/operational h of FV	61.5
Average Crew Cost/h	8.84
Required Crew reduction while in VT	**7**

The results from the model simulation in Figs.9 to 11 are all presented in the same manner. Up top, one can identify two sections that denote the difference between the dedicated and the cargo vessel. The next line indicates the number of crew members that were reduced at that particular simulation. The different scenario descriptions are lightly shaded, while the class type of the FVs in the VT are presented in the right most column. The actual values that are presented determine the minimum of FVs needed in the VT to be able to make it an economically viable solution. The dash indicates that there is no relevant value for that category, since the vessel class does not have that number of crew members on board.

The comparison between the three different scenarios of Table IX shows that the maximum variation in investment cost between the best and the worst case causes an increase in the VT length of at most three FVs for the dedicated LV. The cargo LV on the other hand barely undergoes any changes across the versions in technology investment, implying that the impact of a cheaper or more expensive control system on viability of the VT will be limited.

Table IX: Multi-Scenario Analysis Results of the Impact of LV Investment Cost Variations on the Minimum VT Length

	Dedicated LV Investment Cost					**Cargo LV Investment Cost**				
Crew Reduction	1	2	3	4	5	1	2	3	4	5
Best Scenario	1 500 000 € + 30 000 €					30 000 €				
Class V FV	6	3	2	2	2	5	3	2	2	1
Class IV FV	6	3	2	2	-	6	3	2	2	-
Class II FV	7	4	3	2	-	6	3	2	2	-
Expected Scenario	3 000 000 € + 60 000 €					60 000 €				
Class V FV	7	4	3	2	2	6	3	2	2	2
Class IV FV	7	4	3	2	-	6	3	2	2	-
Class II FV	8	4	3	2	-	6	3	2	2	-
Worst Scenario	6 000 000 € + 120 000€					120 000€				
Class V FV	9	5	3	3	2	6	3	2	2	2
Class IV FV	9	5	3	3	-	6	3	2	2	-
Class II FV	10	5	4	3	-	6	3	2	2	-

The scenarios that vary the crew cost, Table X, demonstrate a larger impact on the minimum VT length. The direct comparison between the two LVs types makes it visible that the cargo vessel is much more affected by a variation in crew composition. While the FV requirements for the cargo vessel at least treble, between the best-case and worst-case scenarios, the requirement for the dedicated vessel less than doubles. This is an expected outcome, since it was seen from the cost breakdown that the crew cost makes up a much larger part of the cargo vessels cost than it does of the dedicated LV.

Table X: Multi-Scenario Analysis Results of the Impact of LV Crew Cost Variations on the Minimum VT Length

	Dedicated LV Crew Cost					**Cargo LV Crew Cost**				
Crew Reduction	1	2	3	4	5	1	2	3	4	5
Best Scenario	4 Operating Crew and 2 Monitoring Crew at 10.5 €/h					2 Monitoring Crew at 10.50 €/h				
Class V FV	6	3	2	2	2	3	2	1	1	1
Class IV FV	6	3	2	2	-	3	2	1	1	-
Class II FV	6	3	2	2	-	3	2	1	1	-
Expected Scenario	6 Operating Crew and 3 Monitoring Crew at 13.32 €/h					3 Monitoring Crew at 13.32 €/h				
Class V FV	7	4	3	2	2	6	3	2	2	2
Class IV FV	7	4	3	2	-	6	3	2	2	-
Class II FV	8	4	3	2	-	6	3	2	2	-
Worst Scenario	8 Operating Crew and 4 Monitoring Crew at 17.54 €/h					4 Monitoring Crew at 17.54 €/h				
Class V FV	9	5	3	3	2	9	5	3	3	2
Class IV FV	9	5	3	3	-	10	5	4	3	-
Class II FV	10	5	4	3	-	10	5	4	3	-

The last collection of simulation results regards the availability of the LVs in Table XI. Even though the changes in scenario results for the availability are less impactful than for the crew variation, the need for FVs still increases by two vessels for the cargo LV at a single crew reduction per vessel.

Table XI: Multi- Scenario Analysis Results of the Impact of LV Availability on the Minimum VT Length

	Dedicated LV Availability					Cargo LV Availability				
Crew Reduction	1	2	3	4	5	1	2	3	4	5
Expected Scenario	90%					35%				
Class V FV	7	4	3	2	2	6	3	2	2	2
Class IV FV	7	4	3	2	-	6	3	2	2	-
Class II FV	8	4	3	2	-	6	3	2	2	-
Best	100%					45%				
Class V FV	6	3	2	2	2	4	2	2	1	1
Class IV FV	7	4	3	2	-	5	3	2	2	-
Class II FV	7	4	3	2	-	5	3	2	2	-
Worst	80%					25%				
Class V FV	8	4	3	2	2	8	4	3	2	2
Class IV FV	8	4	3	2	-	8	4	3	2	-
Class II FV	9	5	3	3	-	8	4	3	2	-

5. Discussion

The higher the required number of FVs is, the less advantageous it is for the business case, since there is a higher risk that the minimum required number of vessels is not met. Not having enough FVs could either mean a loss for the LV operator, an increase in VT dues or the cancellation of the VT, implying that the followers would have to make their journey on their own.

Having a small dependence on the numbers of FVs in the VT improves the business case for routes that have smaller and more sporadic cargo flow requirements. Routes that are known to have a large and constant cargo flow are, however, ideal for the dedicated LV business, since it can provide a high availability and prompt departures. This line of thought leads to the contemplation of choosing a style of operational service, such as tramp or liner shipping, for different LV types to achieve the most benefits in certain areas. Even though this aspect has high importance for the successful application of the VT concept, it is not directly related to the vessels properties and is therefore not further elaborated in the research of this paper.

As discussed briefly in the input data section, the effectiveness of the reduction of crew members on the FVs is dependent upon the type of crew member taken off board. This case study assumes the average crew cost of all roles on board of an IWT vessel. In reality however, the removal of a deck results in a much smaller cost savings than removal of e.g. a helmsman, thus increasing the required number of followers in a commercially attractive VT. This is especially an important aspect to note when looking into applying this concept in the Short Sea sector. That sector has large differences in cost between different crew members on board. The crew cost vary between 4€/h and 17€/h *(Stopford, 2009)* as shown in Table III. The FV requirement can thus either double or half dependent on what the cost of the reduced crew member may be. This implies that the identification of the correct crew role reduction is of high importance in the determination of the concept's viability. Such a characteristic falls under the FV features and is not investigated in this paper. It is however important to acknowledge the awareness of this point of influence on the LV results obtained.

The results presented are representative of the economic viability of the concept. There may, however, also be technical reasons why exceeding a certain number of FVs may not be viable, especially when considering the IWT sector. The economic and technical limitations are likely not to be equivalent to one another. For instance, two to four FVs can reasonably be expected to follow one another when navigating along busy waterways. However, eight or even nine FVs could create some technical challenges. Not only would overtaking manoeuvres be reaching kilometres in length, but also the navigational awareness for the LV may be impacted by a possible absence of a line of sight between the LV and the FVs towards the end of the train. This demonstrates that even though the values provide economic viabilities of the concept, the physical constraints the concept will have to deal with, are yet to be elaborated and may further impact the obtained results.

The evaluation of cost related to the investment, crew and availability shows that a reduction of more than three ‘average crew members’ has very little or no additional benefit for the VT economic viability. This shows that that full automation of inland vessels is not necessary to achieve a competitive concept.

6. Conclusions

The assessment performed emphasises the complexity of the challenges the development of the VT concept brings along. Comparing the multiple different scenarios made it possible to realize that the cost priorities for the two vessel types are different from one another as seen in Table XII.

Table XII: Cost Prioritization

Dedicated	**Cargo**
1) Crew Cost	1) Crew Cost
2) Investment Cost	2) Availability
3) Availability	3) Investment Cost

Minimizing the human effort of the monitoring and control system of the VT is the most important aspect to achieve in the development of the VT concept with regards to the LV. Doing so will also reduce the cost created due to unavailability, since the crew with no task during those unavailable times will be reduced. A further conclusion that can be drawn from this analysis is that the effort in the development of the VT concept should be especially focused on adjusting the roles of crew members on-board to create a smaller multi-purpose crew. Such a crew should be able to perform tasks for the VT control but also vessel operational tasks if need be. Thus, while a very accurate cost estimation for the required VT technologies is of limited importance, the understanding of the operating of the control system is vital.

In case of misestimations in any of the cost factors, the results show a maximum increase in the required number of FVs of four, when comparing it to the expected scenario. For the application in the IWT sector, required follower numbers of approximately of eight vessels may become questionable for applications due to technical challenges. Even though these boundary conditions of minimum VT length will still change with the further assessment of the VT features, it is expected that at least two crew reductions will be needed to provide a successful implementation of the concept in the IWT sector.

It also became apparent that the step, leading from semi-to full automation, by reducing the last crew member on the FV, is economically speaking does not make a large difference. Most scenarios have the same FV requirement for an unmanned or a single crew member on board of the FV. The results from the multi-scenario assessment provide an underlying understanding that the concept will be dealing with a size of roughly half a dozen followers at that form the platoon. The next step in the viability research of the VT is to gain an understanding of the FV features. Special emphasis will be placed on the identification of the most suitable crew role that is to be taken from board, without impacting the independent capabilities of the lone travel leg of the FVs.

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