Evaluating the performance of the vessel train concept

Hilde Meersman, Eleni Moschouli[*], Loghman NanwayBoukani, Christa Sys, Edwin van Hassel,
Thierry Vanelslander and Eddy Van de Voorde

Abstract

Objective: To improve safety and address current employment challenges in the waterborne transport sector, the VT concept is developed. The VT is a vessel platooning concept that is semi-autonomous. The VT is composed by one Leader Vessel (LV) and Follower Vessels (FVs) that will be connected with each other with sensors. The research examines from a business-economic and societal perspective, whether it is interesting to invest in and use the VT, instead of sailing with a conventional vessel.

Methods: The business-economic performance of the VT is tested from theperspective of the vessel owner (VO) for the inland navigation trajectory Antwerp – Rotterdam – Duisburg, using a relevant transport model. With this research, the results allow comparison of the total costs of the reference scenario with alternative VT scenarios and thus allow to see which of the scenarios are interesting for the VOs to invest in and use the VT. From a societal perspective, the expected modal shift from road (and possibly rail) to inland waterways and the external cost savingsfor the society are calculated.

Results: The results show that for some scenarios the expected benefits of the society are high, thanks to the modal shift from road (and rail) to inland waterway transport (IWT) mode and to the reduced external costs. However, for the scenarios with negative business-economic cost savings, negative welfare gains are found due to the likelihood of reverse modal shift from IWT to road (and rail), because the VT is found more expensive than the conventional sailing.

Implications for research/policy: If all the actors of the VT project have benefits, being theVO, the VT organizer (VTO) and the cargo owner (CO), the implementation of the VT concept will be decided. The implementation of the concept can still be decided, if the loss of one of the actors is compensated by the other(s) actor(s). Thus, subsidies by the government are not needed. However, what is needed is the change of the current legislation that would allow the sailing of the VT with reduced crew on board in inland waterways.

Keywords: Vessel train, Platooning, Semi-autonomous sailing, Business-economic performance, Societal performance, Project evaluation, Inland navigation
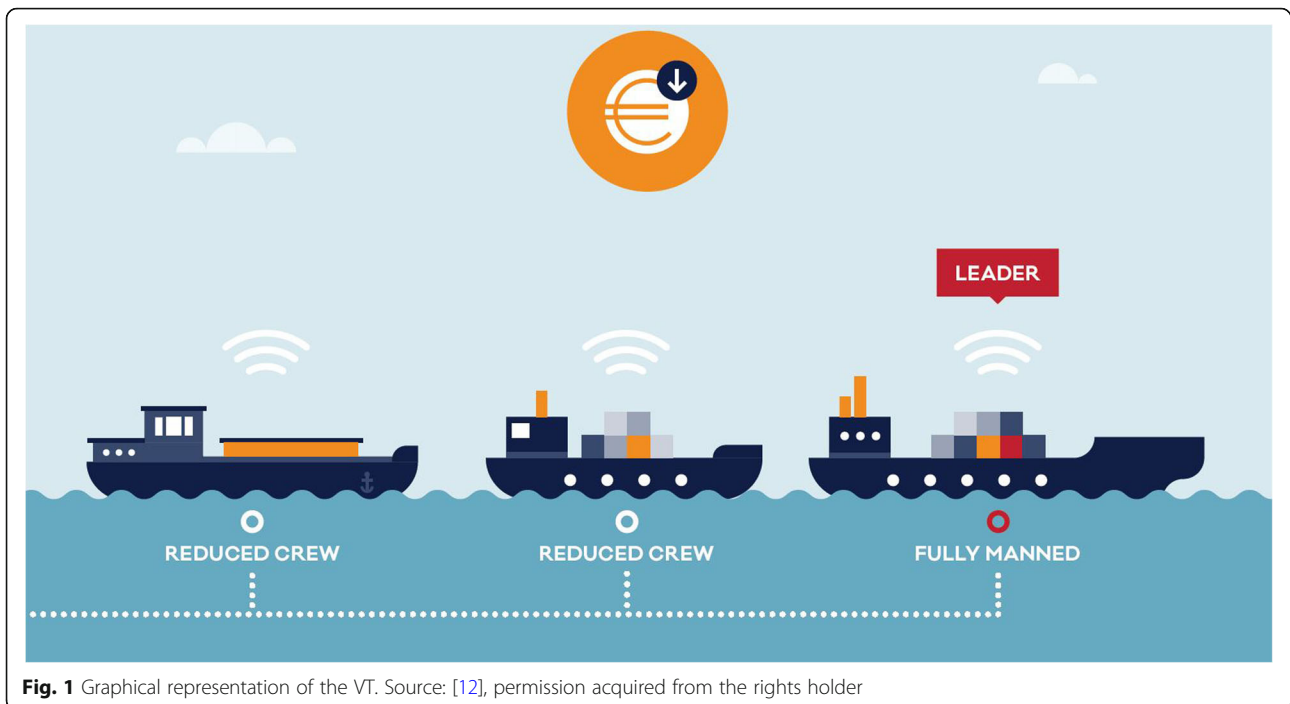
1 Introduction

European Commission [6] aims to the achievement of a more environment-friendly transport system via shifting traffic from road to rail and waterborne modes, among them also to inland navigation, which is one of the ten key transport goals of the European Commission. Therefore, the European Commission funds innovative transport concepts that have as a main aim to contribute to this modal shift. NOVIMAR is one of these concepts. NOVIMAR stands for Novel Inland Waterway Transport and Maritime Transport Concepts.

The main aim of NOVIMAR is the modal shift in favor of waterways (inland waterways (IW), sea-river and shortsea shipping (SSS)). Besides to that, it also aims at improving the

* Correspondence: eleni.moschouli@uantwerpen.be
Department of Transport and Regional Economics, University of Antwerp,
Prinsstraat 13, 2000 Antwerp, Belgium

Fig. 1 Graphical representation of the VT. Source: [12], permission acquired from the rights holder

existing waterborne transportation system and allowing access into small waterways, while achieving at the same time economies of scale without the use of big ships. The means for the achievement of the above aims is the vessel train (VT). The VT is a semi-autonomous vessel platooning concept that resembles the truck platooning. The VT is composed by one leader vessel (LV) and follower vessels (FVs) (Fig. 1). Information Technology (IT) equipment, which has been already developed by Argonics, will be installed on all vessels that will allow the semi-autonomous sailing of the FVs and enable the LV to monitor and communicate with the FVs. The vessels are connected in a non-tangible way (i.e. not with a rope) but via sensors. The LV has full crew on board and probably one additional person (still to be decided) that will be in charge of monitoring the VT. The FVs could have reduced crew on board, which is a main research assumption and one of the main economic advantages of the VT. At least one crew member will be on board in the FVs, but this person will not be in charge of the navigational tasks of the vessel, since the LV will guide them, but will be in charge of other tasks, such as maintenance of the engine or for emergency reasons. Sailing with reduced crew could be a solution for labor shortage in the inland waterway transport (IWT) sector [19]. FVs' role is to transport cargo from A to B and they should be ready to depart (arrive) on time, so as not to delay the whole VT.

A key actor of the VT concept, apart from the vessel owners (VOs) and the cargo owners (COs), is also the VT organizer (VTO). The VTO is either a third-party logistics service provider or a shipping company that is responsible for composing and managing the VT. The VTO does the matching between the VOs and COs and between the LV and the FVs. For providing this service, the VTO receives a fee by the FVOs.

The expected benefits of the VT concept are twofold: business-economic and societal. From the business-economic perspective, fixed costs of the FVs are expected to decrease thanks to the reduced number of crew members on board, which could lead to a reduction of crew costs. Also, productivity could increase thanks to the longer sailing hours of the VT compared to the sailing hours of the conventional vessels, due to the fact that the FVs will not need to stop for the crew members to rest, as it happens for the conventional vessels. From the societal perspective, the expected benefit is the reduced external costs. The expected positive societal impact of the VT concept, thanks to the expected modal shift from road to waterways, is of high importance considering the high energy and carbon dioxide intensity in road transport and as a result the need for sustainable development [2].

Although in general the VT is examined for the IWT, sea-river and SSS transportation and for different types of cargo, this research focuses on inland container (TEUs) shipping for the trajectory 'Antwerp – Rotterdam – Duisburg'. This case has been selected because it is a case with high IWT density of traffic.

There are several waterborne modes: the maritime, the IWT, the sea-river and the SSS. Given the focus of this paper on IWT, a description of all waterborne modes, including IWT to a more detailed extent, is presented.

The maritime transport concerns the transport of passengers and cargo with ships by sea between two or more seaports. Different types of cargo are transported via sea, such as containers (i.e. clothing, computers, meat etc.), dry bulk

(i.e. grain, coal, iron ore, cement, sugar, salt and sand), liquid bulk (i.e. fuel oil, crude oil, petrol, vegetable oils etc.), break bulk (i.e. cargo packaged in pallets, boxes, bags etc.) and neo bulk (i.e. cargo that is not packaged in boxes like the break bulk, such as paper (rolls), wood, steel (rolls), lumber and vehicles etc.). There are two cargo handling systems for loading and unloading the sea vessels, roll on-roll off (RoRo) and load on-load off (LoLo). The former system is used when the vessel's cargo is wheeled cargo (i.e. vehicles), which can roll on and off the vessel without the need of a crane and the latter system makes use of a crane for the shift of cargo between land and sea vessels.

The same types of cargo handling are also applicable for the IWT. The types of cargo transported via IWT are dry bulk, liquid bulk, heavy cargo, vehicles and containers [17]. The IWT concerns the transport of cargo (or passengers for recreational purposes) with vessels via IW (i.e. rivers, canals etc.) between inland ports. They are called inland because they are waterways that are within the territory of a country. The vessels that are used in IWT are either motorised or non-motorised, which are pulled or pushed by another vessel, i.e. a tugboat. IWT is an environment-friendly transport that is a competitive alternative to rail and road transport [8]. It is a safe, quite noiseless mode and with low infrastructure costs. Six classes (sizes) of vessels operate in IWT, class 6 of a cargo capacity up to 350 TEUs, class 5 of a capacity up to 200 TEUs, class 4 of a capacity of up to 50 TEUs, class 3, 2 and 1 of a capacity up to 30, 20 and 10 TEUs respectively [4]. There are different modes of exploitation/operation, namely A1, A2 and B that refer to the maximum number of hours allowed for sailing per day, being up to 14, 18 and 24 h a day [15]. The mode of exploitation and the type of equipment of vessels affect the number of crew members on board [1, 16]. A resting period is required for the crew members on board, which differs based on the mode of exploitation [16]. In the VT, the crew on board can rest while the VT is sailing because the crew members on board the FVs do not have navigational tasks. The vessels operate as liner service providers, i.e. sailing regularly based on a schedule, or as tramp service providers, i.e. not sailing regularly but based on demand.

The six classes of vessels differ not only for the number of containers that can transport, but also for the minimum required crew members on board, the sailing regimes and their dimensions (L: Length) [4, 16].

- Class 1, 2 and 3: L < =70 m
- Class 4: 70 m < L < 86 m
- Class 5 and 6: L > 86 m

Sea-river transport is a branch of the IWT that refers to transport via the rivers and sea, and thus the vessels that are used for this waterborne mode of transport can navigate in both rivers and the sea (to a restricted extent) [5]. SSS is a branch of the maritime transport that refers to the transport of goods over relatively short distances, compared to the intercontinental cross-ocean deep sea shipping [9].

The research of the present paper examines from a business-economic and societal perspective whether it is interesting to invest in and use the VT instead of sailing with a conventional vessel. The transport model developed by van Hassel et al. [17] is used for answering the former research question. For answering the latter research question, the external cost savings are calculated, taking into consideration the expected modal shift from road (and potentially rail) to IWT. The paper is structured as follows. Section 2 describes the methodological approach, data and case study that are used. Section 3 presents the scenarios used. Section 4 shows the results and discussion and section 5 formulates the conclusions.

2 Methodological approach, data and case study

Section 2 presents the methodological approach and data that are used for both the business-economic and societal-environmental perspective. The case study is applied for both perspectives. On the one hand, the business-economic perspective shows which the cost savings are for the VOs of the VT. On the other hand, the societal perspective shows which the external cost savings are for the society.

2.1 Business-economic perspective

The applied transport model is a version of the model of van Hassel et al. [17] that is adapted to the VT needs. The transport cost model allows calculating the generalized chain cost from a selected point of origin, via a predefined container loop, to a destination point. The main elements that are taken into consideration for the adaptation of the existing model are the: geographical scope; cargo types; number of calls at ports of LVs and FVs and different VT business models (BMs). Specific data needs concern (a) transport network (Origins-Destination (ODs), inland terminals etc.), b) different transport modes (including intermodal) and c) logistics costs for each mode (transport cost and time, inventory cost etc.) [17].

The total transportation costs of the VO are calculated taking into account the following cost elements:

- **Store cost:** lubricant oil and other costs (e.g. cleaning products, washing machine, vacuum cleaner).
- **General cost:** administration costs that include registration, communication and management costs.
- **Insurance cost:** Protection and Indemnity (P&I) and Haul & Machinery (H&M). P&I is the liability insurance that covers all the liability risks associated with the operation of the vessel and H&M is the insurance for the hull and machinery of the vessel.
- **Repair and maintenance cost:** on board repair and maintenance costs.
- **Drydock cost:** vessels depending on their age need to go to a dry dock, every 2–4 years for inspecting their condition and repairing its hull.

- **Crew cost**: wages, social contribution, other expenses for: a) all the crew members: skipper, chief officer with patent, chief officer without a patent, full sailor, sailor, light sailor, b) inland vessels of Class 1–6, c) for three different sailing regimes of 14, 18 or 24 h sailing maximum per day, d) vessels with or without bow thruster.
- **Fuel cost:** fuel for the main engine and for the auxiliary engine (A/E). The former is used to allow the vessel to sail and the latter is used to generate power (electricity).
- **Capital cost:** a) construction cost/vessel value; b) interest: it is a function of the amount of money that is borrowed from a bank, and when this amount is known, a standard default interest rate of 4.5% will be used as an estimate to calculate the interest cost; c) depreciation is also used for the values of the vessel and VT IT machinery [19].

All these costs are expressed in EUR/h. Thus, by knowing the distance that the vessels need to travel and their sailing speed, the sailing time (t) in hours (t = distance/speed) can be computed. Next, multiplying the sailing time with the total transportation costs of the VO in EUR/h results in the total transportation costs of the VO for a specific trip.

Equation 1 shows the difference in costs (or in other words the cost savings) between a conventional vessel and an FV in the VT, while Eq. 2 shows similar results between a conventional vessel and an LV in the VT. Equation 3 adds the cost savings of Eqs. 1 and 2 to show the total cost savings of the VT. However, apart from the cost savings thanks to the less crew on board and the longer sailing hours thanks to the semi-autonomous sailing, there will be an additional cost for both the LV and the FV, which is the cost of the VT equipment that will be installed to allow the vessels to sail semi-autonomously. Its cost is estimated at 40,000 euro for each of the vessels of the VT, either an FV or an LV. This cost will be also considered for calculating the final cost savings for the FV, the LV and the whole VT. Since the LV will have full crew on board and the additional technological equipment cost, cost savings are expected to be negative, but these costs could be recovered by the FVs via a fee, i.e. a payment that could be made from the FVOs to the LVOs. This fee is calculated by dividing the additional new costs of the LV by the number of the FVs (and on top of that adding a markup, depending on the business model (BM) used). The higher the number of the FVs, the lower the fee.

$$\Delta C_1 = C reference - C_{FV} \qquad (1)$$

$$\Delta C_2 = C reference - C_{LV} \qquad (2)$$

$$\Delta C_{VT} = \Delta C_2 + (\Delta C_1 * no.FV) \qquad (3)$$

where ΔC: difference in costs, $C_{reference}$: costs of the reference situation vessel; C_{FV}: costs of the FV; C_{LV}: costs of the LV; ΔC_{VT}: difference in costs for the whole VT; no. FV: number of FVs.

For the VT situation, some of the above-mentioned cost elements need modifications. The main cost element that will be modified is the 'crew costs', due to the crew reduction in the FVs of the VT. Also, an additional cost for the purchase of the IT VT equipment of 40,000 euro will be added. Afterwards, the total transportation costs of an individual vessel for the reference situation and for the VT situation will be compared, to see if the VT total transportation costs are less than the ones of the reference situation. In this way, it is examined if it is interesting from a business-economic perspective for the VO to shift from using a conventional vessel to using a VT vessel.

The data that are used in the transport model can be categorized into five main blocks. These are: cargo flow data ((OD-matrix estimated by making use of the ASTRA model, which is a 4-step model [10]), distance data, inland terminal/port data, cost data and cargo related data [1, 4, 14, 17, 18]. A transport network of 46 regions and 27 ports is used for different transport modes: rail, road & waterborne (IWT, SSS, sea-river) (see Tables 4 and 5 in Appendix). Each region is connected to a few ports, while each port is connected to several regions, thus making the calculations more complex.

The case study that is used in the present paper is the Antwerp – Rotterdam – Duisburg area. More specific, three different waterborne routes will be tested per scenario (see section 4, Table 3), Route 1: Antwerp – Rotterdam, Route 2: Rotterdam – Duisburg and Route 3: Antwerp – Duisburg.

2.2 Societal perspective

The societal perspective is examined by calculating what the external cost savings could be, if traffic is shifted from road (and rail) to IWT mode. The research aim is modal shift from road to IWT but the modal shift from rail to IWT is also examined because it is also possible to happen. For this reason, cross elasticity of demand is used, which shows how much the quantity of one good will change when the price of the other good changes, and the price of the first good does not change. In this paper, cross elasticity of demand is used to show how much the traffic demand could change/decrease for road and rail modes of transport, if the price decreases for the IWT mode of transport, thanks to the usage of the VT; road and rail prices being constant. According to Beuthe et al. [3], a 5% total cost reduction leads to a traffic demand decrease (in tons) of 0.44 in road and 0.18 in rail transport and an increase of 0.59 in IWT transport (for a distance range below 500 km; tons are used because modal shift is calculated in TEUs). Thus, road mode shows a higher responsiveness than rail to the price changes of IWT mode.

Then, using the cross elasticity values of Beuthe et al. [3] for road, rail and IWT and the expected cost reductions thanks to the VT, the modal shift from road to IWT,

Table 1 Scenarios that are tested for the reference situation of IWT

Scenarios of a conventional IW vessel in the reference situation	Vessel class	Sailing regime	Maximum capacity of containers (TEUs)	With/without bow thruster	Crew members on board in the reference situation	Speed (km/h)
1.	6	B	350	Bow thruster	5	13
2.	5	B	200	Bow thruster	5	13
3.	4	A2	50	Without[a]	3	13
4.	3	A1	30	Without[b]	2	10
5.	2	A1	20	Without[c]	2	10
6.	1	A1	10	Without	2	10

Source: own composition based on Al Enezy et al. [1]
[a]There are no data for bow thruster, thus the non-bow thruster data are used
[b]There are no data for bow thruster, thus the non-bow thruster data are used
[c]There are no data for bow thruster, thus the non-bow thruster data are used

from rail to IWT and for the IWT itself are calculated. Then, the external costs data per mode are collected, i.e. air pollution, climate change, accidents, noise, congestion and infrastructure costs [11]. Using the external costs data and the modal shift to IWT values, the total external cost savings (summing all external costs) are calculated in euro per TEU and in euro per voyage for each of the scenarios, as presented in Section 3 below (see Table 3). The total VT cost savings ($T\Delta C_{VT}$) are calculated by adding the business-economic VT cost savings (ΔC_{VT}) and the VT external cost savings (ΔEXT_{VT}) (Eq. 4).

$$T\Delta C_{VT} = \Delta C_{VT} + \Delta EXT_{VT} \qquad (4)$$

3 Scenarios

In total, six scenarios are tested for the reference situation (Table 1). There is one scenario for each of the vessel classes (1–6), with different sailing regimes (maximum hours of sailing per day) for each of them: sailing regime B (sailing up to 24 h a day), A2 (sailing up to 18 h a day) and A1 (sailing up to 14 h per day). Bow thruster[1] equipment is present for the vessel classes 5 and 6. A different number of crew members on board is assigned to each vessel class, respectively also the different role and wages per crew member, according to Al Enezy et al. [1]. Finally, the average speed for the IW vessels of the classes 1–3 is assumed to be 10 km/h, while for the classes 4–6 13 km/h. It is furthermore assumed that the vessels sail with full capacity.

For each scenario, the reference situation is compared to the VT situation, as shown in Table 2.

There are two main differences in the VT situation, as shown in Table 2, compared to the reference situation. The first difference is that the sailing regime is upgraded by one level; sailing regime A1 is upgraded to A2 and B, sailing regime A2 is upgraded to B. This happens because one of the two main economic advantages of the VT are the increased sailing hours thanks to the technological equipment installed

in each vessel (LV and FV). The second difference is that the crew members of the FVs are reduced one by one for each of the scenarios, reaching up to one crew member on board. This one crew member, being a skipper, is on board not to navigate but to provide other tasks, such as maintenance of the engines or help in an emergency case; thus, revealing the nature of the VT concept as a non-fully autonomous concept. Crew could not be reduced for the LV though. Full crew is on board the LV because the LV oversees the FVs. The LV communicates with the FVs for navigational aspects, e.g. about the distance and speed in which the FVs should sail and communicates with the 'outside of the VT' operational environment, being other vessels, the infrastructure manager, etc. At the current stage, it is assumed that the VT is composed by four vessels (one LV and three FVs) and that the LV is a cargo vessel due to data availability.

However, at later stages, the costs will be calculated also for LVs that do not have cargo capacity/do not carry cargo and their role is purely to guide the FVs. Thus, based on these scenarios, VOs do not need to invest in building a new vessel that will have no cargo capacity. However, using a cargo vessel as a LV has its advantages and disadvantages. On the one hand, investment costs are lower for the VOs and the fees that the FVs need to pay to the LV are also lower because part of the costs of the LV are covered by its own revenues from transporting cargo itself. On the other hand, a cargo carrying LV might cause delays[2] in the departure times of the FVs because the FVs need to wait for the LV to load/unload. Therefore, 12 scenarios are tested for the VT situation.

4 Results and discussion

This section calculates the cost savings of the FV, LV and VT, using the Eqs. 1, 2 and 3 and scenarios presented above. It also discusses how the extra costs of the LV compared to the reference situation could be compensated via a fee paid by the FVs and calculates the VT external costs' savings using the Eq. 4 and the respective scenarios.

---

[1]Bow thruster is a propulsion device built into either the bow or stern of a ship to make it more maneuverable.

[2]The waiting times of the FVs for the LV are not included in the cost calculations at the present stage. They will be included at a later stage.

Table 2 Scenarios that are tested for the VT case for IWT

Scenarios	Vessel class	Sailing regime	With/without bow thruster	Crew members on board on the LV	Crew members on board on the FVs after crew reduction in the VT			
1.	6	B	Bow thruster	5	4[a]	3	2	1
2.	5	B	Bow thruster	5	4	3	2	1
3.	4	B	Bow thruster	4			2[b]	1
4a.	3	B	Bow thruster	4				1
4b.	3	B	Without	4				1
4c.	3	A2	Without[c]	2				1
5a.	2	B	Bow thruster	4				1
5b.	2	B	Without	4				1
5c.	2	A2	Without	2				1
6a.	1	B	Bow thruster	4				1
6b.	1	B	Without	4				1
6c.	1	A2	Without	2				1

Source: Authors' composition based on Al Enezy et al. [1]
[a]The crew members on board for the FVs are reduced one by one starting from the cheapest to the most expensive and at the end the most skilled and expensive crew member is kept (the skipper). The crew costs are in function of the crew members and are not added as an average in the calculations. The maximum number of crew members on board of the FVs is one crew member less than the crew members for the reference situation, to have a cost advantage for the VT FVs
[b]Some cells are empty because the number of crew members on board is different depending on the vessel class and sailing regime
[c]There are no data for bow thruster, thus the non-bow thruster data are used

4.1 Main results from the business-economic perspective

Table 3 summarizes the results per vessel class, route, sailing regime and members of crew on board. For each scenario (row of the Table 2), the Eqs. 1, 2, and 3 are applied.

For the reference situation, the results show that the costs per TEU vary between 6.67[3] and 34.83 (2018 euro) for Route 1; between 12.95 and 67.42 for Route 2 and between 14.21 and 73.94 (2018 euro) per TEU for Route 3 for the different scenarios (Table 3). The higher the class of the IW vessel is, the lower its total transportation costs are in euro per TEU, thanks to the economies of scale.

For the FVs in the VT situation, the costs are found to be lower than the costs in the reference situation for all the routes and all scenarios, thanks to the crew cost reduction. The cost savings for the FV of the class 1 vessel when sailing up to 24 h are found to be less (and equal to 8.84 euro/h) than the cost savings of the FV of the class 1 vessel when sailing up to 18 h (and equal 11.85 euro/h), while the opposite was expected due to the longer sailing hours and higher productivity of the vessel. The reason why is that the skipper's crew cost is higher for the sailing regime B (sailing up to 24 h) than for the sailing regime A2 (sailing up to 18 h). The increased crew costs as a result lead to less cost savings when sailing with a regime B instead of A2.

By reducing the crew to one member on board in the VT situation, the costs per TEU (in 2018 euro) were reduced by between 0.72 (10.83%) (for a class 6 vessel) and 11.85 euro (16.03%) (for a class 1 vessel). The longer the trip, the higher the cost savings for the FVs in euro per TEU, because the total transportation costs increase when the trip is longer, including the crew costs. The smaller the vessels, the higher the cost savings per TEU, because the total costs are divided by a smaller amount of TEUs or, the higher portion of the total cost per TEU is determined by the crew cost for smaller vessels.

For the LV in the VT situation, the costs are found to be higher than the costs in the reference situation for all routes and scenarios, with additional costs per TEU from − 0.02 (class 6) to − 43.56 euro (2018 euro) (class 1), meaning a cost increase by 0.31% and 58.91% respectively. The LVs with the highest increased costs compared to the reference situation are the ones whose sailing hours increased from 14 h to 24 h and thus the crew costs are also higher. The smallest increase of LV costs compared to the reference situation is found for the classes 5 and 6, for which the crew structure and crew costs remain stable and the very small cost increase found is caused by the 40,000 VT IT equipment that is installed. However, the total cost savings per voyage is rather small (see Table 3).

The highest total cost savings per voyage (in 2018 euro) (see Table 3) are found for vessel classes 5 and 6: although the cost savings per TEU are small for these classes, the amount of TEUs transported is high and thus the total cost savings are high. This can be explained by the fact that the crew structure and cost remain stable for these two classes 5

---

[3]All the monetary values are indexed values for 2018. The Product Price Index (PPI) was used to convert past values of 2015 into present values of 2018 for the business-economic values and to convert past values of 2008, 2010 and 2011 into present values of 2018 for the external cost values, based on OECD data [13] https://data.oecd.org/price/producer-price-indices-ppi.htm#indicator-chart.

Table 3 Total transportation costs for the VOs for the reference situation vs the VT situation and external costs savings for the society

Vessel Class	Route no.	Sailing regime	Reference (Euro[a]/TEU)	CLV Full crew (Euro/TEU)	CFV Crew 4	CFV Crew 3	CFV Crew 2	CFV Crew 1	$\Delta C1$ (Eq. 1)	$\Delta C1$ *no. FVs	$\Delta C2$ (Eq.2)	ΔC_{VT} (Eq.3)	Total cost savings per voyage for the VO	$\Delta C_{VT} + \Delta EXT_{VT}$ (Eq. 4) (Euro/TEU)	Total cost savings of the VO+ext. cost savings per voyage	Total VT business-economic cost savings of a 10-year period (2018 euro)	Total VT business-economic and societal cost savings of a 10-year period (2018 euro)
6	Route 1	B	6.70	6.72	6.55	6.37	6.19	5.98	0.72	2.15	−0.02	2.13	744.26	123.52	9111.09	454,737	7,954,634
	Route 2		12.95	12.99	12.66	12.34	11.97	11.58	1.37	4.11	−0.04	4.06	1422.20	245.57	17,868.69	661,983	11,602,248.01
	Route 3		14.21	14.25	13.90	13.53	13.14	12.70	1.52	4.55	−0.04	4.51	1576.95	212.12	15,860.67	700,247	9,787,864
5	Route 1	B	8.92	8.96	8.66	8.36	8.03	7.67	1.24	3.73	−0.04	3.68	736.89	125.08	6957.32	631,433	8,327,958.51
	Route 2		17.26	17.33	16.76	16.18	15.55	14.85	2.41	7.23	−0.06	7.17	1433.78	248.67	13,868.93	845,535	11,266,925
	Route 3		18.94	19.01	18.38	17.75	17.05	16.30	2.64	7.93	−0.07	7.85	1570.63	215.47	12,246.14	871,337	9,339,563.10
4	Route 1	B	22.89	24.82			23.36	20.28	2.61	7.83	−1.94	5.90	294.76	127.29	1264.11	386,796	2,376,121
	Route 2		44.29	55.16			45.22	39.23	5.05	15.16	−10.87	4.28	214.23	245.79	938.51	136,717	981,939.92
	Route 3		48.58	60.51			49.60	43.03	5.55	16.64	−11.93	4.72	235.81	212.33	860.58	139,106	822,834
3	Route 1	B	21.67	28.50				20.28	1.39	4.17	−6.83	−2.66	−79.90	118.73	−357.47	−165,555	−781,490.64
	Route 2		41.93	55.16				39.23	2.70	8.09	−13.23	−5.15	−154.43	236.36	−705.92	−173,361	−844,684
	Route 3		45.99	60.51				43.03	2.96	8.87	−14.52	−5.64	−169.27	201.97	−643.03	−174,098	−712,421.06
	Route 1	A2	21.67	22.42				1.86	19.80	5.59	−0.76	4.83	144.96	126.23	648.54	187,785	1,305,235
	Route 2		41.93	43.40				3.61	38.32	10.83	−1.47	9.36	280.76	250.86	1283.36	202,449	1,422,911.76
	Route 3		45.99	47.60				3.96	42.03	11.87	−1.61	10.26	307.92	217.88	1169.70	203,928	1,183,156
2	Route 1	B	30.32	40.57				2.08	28.23	6.25	−10.25	−4.00	−80.01	117.39	−278.62	−143,132	−514,089.96
	Route 2		58.68	78.53				4.03	54.65	12.10	−19.85	−7.76	−155.17	233.75	−551.12	−146,728	−540,382
	Route 3		64.36	86.14				4.42	59.94	13.26	−21.78	−8.52	−170.33	199.10	−510.97	−147,159	−464,346.40
	Route 1	A2	30.32	31.47				2.79	27.53	8.37	−1.15	7.22	144.43	128.62	502.98	146,180	815,857
	Route 2		58.68	60.89				5.40	53.28	16.20	−2.21	13.99	279.81	255.49	993.81	152,459	862,317.813
	Route 3		64.36	66.79				5.93	58.44	17.78	−2.43	15.35	306.97	222.96	920.89	153,124	724,766
1	Route 1	B	34.83	55.34				4.17	30.67	12.51	−20.51	−8.00	−80.01	113.39	−252.87	−146,869	−485,866.089
	Route 2		67.42	107.12				8.07	59.34	24.22	−39.71	−15.49	−154.85	226.02	−498.79	−148,536	−501,476
	Route 3		73.94	117.50				8.84	65.10	26.53	−43.56	−17.03	−170.33	190.58	−466.84	−149,019	−434,424.99
	Route 1	A2	34.83	37.12				5.59	29.24	16.77	−2.28	14.49	144.85	135.88	457.83	153,490	767,257
	Route 2		67.42	71.84				10.81	56.60	32.43	−4.42	28.01	280.12	269.52	902.30	156,339	794,800.65
	Route 3		73.94	78.80				11.85	62.09	35.56	−4.85	30.71	307.07	238.32	841.64	156,545	671,087

Source: Authors' composition

[a] All the monetary values are indexed values for 2018. The Product Price Index (PPI) was used to convert past values of 2015 into present values of 2018 for the financial economic values and to convert past values of 2008, 2010 and 2011 into present values of 2018 for the external cost values, based on OECD data [13].

The symbol * shows the multiplication of the $\Delta C1$ by the number of the FVs

and 6 in the VT situation for the LV. The lowest total cost savings per voyage, being negative, are found for the vessel classes 1–3, when the sailing hours increase from 14 h to 24 h, which means that crew costs are higher for the VT situation (for the LV) compared to the reference situation. This is the case because in the current situation (sailing up to 14 h day), a vessel of class 1–3 needs on board one sailor and one skipper, while in the VT situation, the LV would need on board two skippers for sailing up to 18 h a day and two skippers and two light sailors up for sailing to 24 h a day, which more than doubles the crew costs. This is the reason why the VT situation (for the LV) is found to have higher costs than the reference situation.

The business-economic costs presented in Table 3 are the sum of both the fixed and variable costs of IW vessels in the different scenarios. The business-economic cost savings of the VT are thanks to the reduced fixed costs[4] (mostly thanks to the reduced crew costs), while the variable costs of the VT are not different from the ones of the current situation (fuel costs do not change). Thus, the VT cost savings show the fixed cost savings of the VT compared to the current situation.

4.1.1 Internal compensation procedure
The negative cost savings of the LV could be recovered by the FVs: they could pay a fee to the LV. For example, for the scenario of a vessel of class 3, with a sailing regime B, for the Route 2, the VT cost savings are negative and equal to – 5.15 (2018 euro)/TEU. This means that for a capacity of 30 TEU on board, the total cost savings of the VT per voyage equal – 154.43 (2018 euro). This cost could be divided by the number of the FVs being three in the present analysis and a profit margin could be added to that. Thus, each FV would need to pay 51.48 (2018 euro) as a fee to the LV (plus a markup). The positive cost savings of the FV for this voyage are 80.85 (2018 euro). Since in the present analysis, a cargo LV is used, this means that its costs are mostly covered by itself, because it also transports cargo and does not only provide the service of leading the FVs. Thus, in this case of a cargo LV, it is assumed that the fee that is paid to the LV by the FVs will not include any additional profit. Particularly for this scenario, the cost savings per FV equal 80.85–51.48 = 29.37 (2018 euro) per voyage for each FV. The small savings in euro per voyage for FVs point out the need for a longer VT in the scenarios with negative VT cost savings, so as the negative cost savings to be split among more FVs and to increase as a result the cost savings of the FVOs.

4.2 Main results from the societal perspective
Results show that the external cost savings of the VT are expected to be much higher than the private cost savings of the VT (business-economic cost savings). For example, for an

IWT vessel of class 6, for the Route 1, the VT business-economic cost savings are 2.13 (2018 euro) per TEU for the VOs, while for the society they are equal to 121.39 (2018 euro) per TEU, thanks to the external cost savings. For longer routes, the external cost savings increase. The negative values found (see Table 3 'total cost savings of the VO + ext cost savings per voyage') are due to the expected reverse modal shift from IWT to road and rail, when the VT is found more expensive than the conventional sailing. This means that in these cases, it is not possible to implement the VT.

4.3 Business-economic and societal benefits of the VT in a 10-year horizon
Assuming that the VOs are the investors, the main investment is the purchase of the IT VT equipment that needs to be installed in each vessel, to allow it sailing semi-autonomously. Knowing the business-economic benefit of the VT for the VOs for 1 year, i.e. 2018, a 10-year period is assumed to examine what the VT's business-economic benefit would be for this period of time. A discount rate of 10% is used. Thus, the present value of the VT economic benefits for a 10-year period could vary between approximately 137,000 (2018 euro) and 871,000 (2018 euro) for the different scenarios that showed positive VT cost savings per voyage. While for the scenarios that showed negative VT cost savings per voyage, the losses for a 10-year period are expected to vary between approximately - 143,000 and - 174,000 (2018 euro) (see Table 3).

Apart from finding the private net benefit of the VOs for a 10-year time horizon, the benefits of the VOs and of the society together are calculated as well for a 10-year time horizon. A discount rate of 4% is used, which is in line with EU benchmark set by the Commission for the financial analysis [7]. The present value of the VT economic and societal benefits for a 10-year period varies between approximately 671,000 (2018 euro) and 11.6 million (2018 euro) for the different scenarios that showed positive VT cost savings per voyage. The same scenarios that showed negative business-economic benefits in a 10-year period showed also negative total benefits (business-economic and societal), ranging between approximately 434,000 and 845,000 (2018 euro). The negative total cost savings are due to the expected reverse modal shift from waterborne transport to road (or/ and rail), since costs of the VT are found to be higher for certain scenarios than the costs of the conventional sailing.

5 Conclusions
NOVIMAR (Novel IWT and maritime transport concepts) examines the innovative concept of the VT. The VT is a vessel platooning system that resembles track platooning and is composed by one LV and FVs. The VT concept aims at modal shift from road to waterborne transportation (IWT, sea-river and SSS), to provide economies of scale without using bigger ships, to improve the waterborne transportation system and to allow access to smaller waterways, and to

---

[4]The fixed costs increased a bit by the installation of the VT equipment (40,000).

provide solution to the current issue of insufficient sailing crew, since one crew member will need to be on board on the FVs. The research examines whether it is interesting from an economic perspective for the VO to use the VT instead of sailing with a conventional vessel and whether it is beneficial from a societal point of view.

Firstly from the business-economic perspective, the main economic advantages that this vessel platooning concept offers are lower fixed costs, thanks to reduced crew on board and longer sailing hours (increased from 14 to 18 or 24 h a day). Findings show that, the transportation costs for the FVOs are less when using the VT. The VT concept could provide lower transportation costs for all classes of FVs, thanks to the reduced crew members on board and thus the reduced crew costs. It is recommended to the FVOs to reduce their crew members on board in the VT vessel to one member, to enjoy the maximum possible economic benefits of being in the VT. In contrast to that, LVOs have higher transportation costs being in the VT than sailing conventionally. The additional cost might be very small, 0.02 (2018 euro)/TEU (0.31% increase of costs) for the vessels of Class 6, because the sailing regime remains stable and thus the number of crew members on board does not increase. The only additional cost is the additional capital cost of 40,000 required for the VT technology. However, the additional costs in euro per TEU of the LV compared to the costs of the reference situation can reach up to 43.56 (2018 euro)/TEU (58.91% increase of costs) for the vessels of class 1, when the sailing regime changes from A1 to B, which means that crew costs increase significantly in the LV situation. In the present paper, it is assumed that all the vessels are the same in the VT. However, if an FV of any class (depending on the case) is added to a VT in which the LV is class 5 or 6, this would create cost advantages. When summing the cost savings of the FVs and the LV to find the total cost savings of the VT compared to the reference situation from a business-economic perspective, it is found that the total VT cost savings are positive for all scenarios, except for the scenarios in which the sailing regime is upgraded from A1 to B, for the vessels of class 1, 2 and 3. This means that for these scenarios, the VT costs are higher than the costs of the reference situation, which is logic considering the longer sailing hours and as a result the higher number of crew members on board and thus the higher crew costs (for the LV). This does not mean that the LVOs should avoid joining the VT in the scenarios that showed negative VT cost savings, but it means that these increased costs that could be caused due to the increased crew costs in the LV would need to be compensated for by the FVs via a fee. The additional costs that the LV bears compared to the costs of the FVs, could be divided by the number of the FVs (assumed to be three in the present study) and could be charged to the FVs as a fee. The more the FVs, the lower the fee per FV. Also, when the LV is a cargo carrier, the extra costs are expected to be less, considering that the LV also pays part or all its expenses via transporting its cargo and does not only sail to provide the service of leading the FVs. To sum up the findings from the business-economic perspective, cost reductions compared to the current situation could vary depending on the different scenarios and can be positive, reaching up to 41.58%, or negative, reaching up to − 23.04%. The business-economic benefits of the VT concept for a 10-year period are estimated between approximately 137,000 (2018 euro) and 871,000 (2018 euro) for the different scenarios that showed positive VT cost savings per voyage. While for the scenarios that showed negative VT cost savings per voyage, the losses for a 10-year period could vary between approximately - 143,000 and - 174,000 (2018 euro).

From a societal perspective, the external cost savings are expected to be positive ranging between 121.39 euro per TEU and 241.50 euro per TEU depending on the different scenarios (in 2018 euro). The VT economic and societal benefits for a 10-year period could vary between approximately 671,000 (2018 euro) and 11.6 million (2018 euro) for the different scenarios that showed positive VT cost savings per voyage. The same scenarios that showed negative business-economic benefits in a 10-year period showed also negative total benefits (business economic and societal benefits), ranging between approximately 434,000 and 845,000 (2018 euro).

If all the actors of the VT project have benefits, being the VO, the VT organizer (VTO) and the cargo owner (CO), the implementation of the VT concept will be decided. The implementation of the concept can still be decided, if the loss of one of the actors is compensated by the other(s) actor(s). Thus, for the scenarios for which negative cost savings are found for the VOs, if compensation is given by the VTO or/and the COs to the VO to recover these negative cost savings the concept could be still implemented. Therefore, further research on the business-economic performance evaluation of the VT concept is also needed for the COs and VTOs, in the case that they are not the same actor with the VOs. As soon as it is proved that there is a net present benefit > 0 for all the private actors (even after compensation), the findings, showing high positive external cost savings for the society when cost savings from the business-economic perspective are positive, are important. This means that if there are positive cost savings for the VO, there would be also positive external cost savings for the society, thanks to the expected modal shift from road to waterborne transportation. Therefore, for these positive scenarios no subsidies are needed. However, what is needed is changing of the current legislations to allow the sailing of the VT with reduced crew on board in IW. For the scenarios with negative VO cost savings and societal cost savings, VOs could keep using conventional sailing. The findings of this research are of interest for scholars, VOs and the government. Additional future research from the business-economic perspective includes adding: 1) waiting times, 2) extra crew costs for (un) mooring, 3) BMs, 4) different compositions of VTs, 5) LV with no cargo carrying capacity and 6) more routes.

6 Appendix

Table 4 46 Regions of the transport network that is used in the Antwerp case study area

Name	Code	Name	Code	Name	Code	Name	Code
Bruges	BE251	Prov. Liege	BE33	Ghent	BE234	Mid Limburg	NL422
Diksmuide	BE252	Zeeuw Vlaanderen	NL341	Oudenaarde	BE235	South Limburg	NL423
Ypres	BE253	Overig Zeeland	NL342	Sint-Niklaas	BE236	Dusseldorf	DEA1
Kortrijk	BE254	Zuid Holland	NL33	Antwerp	BE211	Koln	DEA2
Ostend	BE255	Noord Holland	NL32	Mechelen	BE212	Koblenz	DEB1
Roeselare	BE256	Utrecht	NL31	Turnhout	BE213	Rheinhessen-Pfalz	DEB3
Tielt	BE257	Gelderland	NL22	Hasselt	BE221	Darmstadt	DE71
Veurne	BE258	West North Brabant	NL411	Maaseik	BE222	Karlsruhe	DE12
Aalst	BE231	Mid North Brabant	NL412	Tongeren	BE223	Freiburg	DE13
Dendermonde	BE232	North-East North Brabant	NL413	Halle-Vilvoorde	BE241	Alsace	FR42
Eeklo	BE233	South-East North Brabant	NL414	Leuven	BE242	Basel	CH03
		North Limburg	NL421	Brussel	BE10	Mid Limburg	NL422

Source: van Hassel et al. [17]

Table 5 Inland ports

Inland ports		
Utrecht	Leuven	Koblenz
Nijmegen	Grimbergen	Mannheim
Tilburg	Vilvoorde	Frankfurt
s-Hertogenbosch	Angleur (Luik)	Karlsruhe
Born	Vlissingen	Neuf-Brisach
Duisburg	Rotterdam	Basel
Leverkusen	Zaandam	

Source: van Hassel et al. [17]

References
1. Al Enezy, O., van Hassel, E., Sys, C., & Vanelslander, T. (2017). Developing a cost calculation model for inland navigation. *Research in Transportation Business & Management, 23*, 64–74. https://doi.org/10.1016/j.rtbm.2017.02.006 ISSN 2210-5395.
2. Ben Abdallah, K., Belloumi, M., & De Wolf, D. (2015). International comparisons of energy and environmental efficiency in the road transport sector. *Energy, 93*(P2), 2087–2101 https://econpapers.repec.org/article/eeeenergy/v_3a93_3ay_3a2015_3ai_3ap2_3ap_3a2087-2101.htm.
3. Beuthe, M., Jourquin, B., & Urbain, N. (2014). Estimating freight transport price elasticity in multi-mode studies: A review and additional results from a multimodal network model. *Transport Reviews*. https://doi.org/10.1080/01441647.2014.946459.
4. CEMT classification (1992). Classification of vessels.
5. Chatelier, J.-M., Nzengu, W. N., & Cocito, R. (2017). *Stability and seakeeping of river-sea vessels: classification rules* (p. 10) Retrieved from https://shipstab.org/files/Proceedings/ISSW/ISSW_2017_Belgrade_Serbia/Papers/Session_6_Stability_and_safety_of_inland_and_river-sea_ships/6_2_Chatelier_et_al_ISSW2017.pdf.
6. European Commission. (2011). *White paper on transport: roadmap to a single European transport area: towards a competitive and resource-efficient transport system*. Publications Office of the European Union Retrieved from Mobility and Transport—European Commission website: https://ec.europa.eu/transport/themes/strategies/2011_white_paper_en.
7. European Commission (2014). Guide to cost-benefit analysis of investment projects. Economic appraisal tool for Cohesion Policy 2014-2020. Retrieved January, 2018, from https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf
8. European Commission (2019). Inland waterways. Retrieved November 13, 2019, from Mobility and Transport—European Commission website: https://ec.europa.eu/transport/modes/inland_en
9. Eurostat (2019). Glossary: Short sea shipping (SSS)—Statistics explained. Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Short_sea_shipping_(SSS).
10. Fiorello, D., Fermi, F., & Bielanska, D. (2010). The ASTRA model for strategic assessment of transport policies. *System Dynamics Review, 26*(3), 283–290.
11. Korzhenevych, A., Dehnen, N., Bröcker, J., Holtkamp, M., Meier, H., Gibson, G., Varma, A., Cox, V. (2014). Update of the handbook on external costs of transport. Ricardo-AEA/R/ED57769. Available online: http://ec.europa.eu/transport/themes/sustainable/studies/doc/2014-handbook-external-coststransport.pdf
12. NOVIMAR website. (2019). NOVIMAR and the vessel train concept, permission acquired from the rights holder. Retrieved from https://NOVIMAR.eu/concept/
13. OECD data (2019). Producer price indices (PPI) Manufacturing, total market, 2015=100, 2008–2017. Retrieved from https://data.oecd.org/price/producer-price-indices-ppi.htm#indicator-chart
14. Schade, W. (2005). *Strategic sustainability analysis: Concept and application for the assessment of European transport policy*. Baden-Baden: Nomos-Verlag.
15. United Nations Economic Commission for Europe, UNECE (2002). Minimum manning requirements for inland navigation vessels. Transmitted by the Central Commission for the Navigation of the Rhine (CCNR). Inland Transport Committee. Working Party on Inland Water Transport. Working Party on the Standardization of Technical and Safety Requirements in Inland Navigation, TRANS/SC.3/WP.3/2002/4, 9 January 2002. https://www.unece.org/fileadmin/DAM/trans/doc/2002/sc3wp3/TRANS-SC3-WP3-2002-04e.pdf
16. United Nations. (2011). *Recommendations on harmonized Europe-wide technical requirements for inland navigation vessels: Resolution no. 61 (Rev. 1)*. New York: United Nations https://www.unece.org/fileadmin/DAM/trans/doc/2011/sc3wp3/ECE-TRANS-SC3-172-Rev1e.PDF.
17. van Hassel, E., Colling, A., Nanwayboukani, L., Moschouli, E., Frindik, R., Thury, M., Friedhoff, B., & Vanelslander, T. (2018). *Transport system model. Deliverable 2.2, H2020 NOVIMAR project*.
18. van Hassel, E., Vanelslander, T., & Claus, D. (2018a). *The assessment of different future freight transport scenarios for Europe and the North Rhine Westphalia region, Universiteit Antwerpen, Departement Transport en Ruimtelijke Economie* (p. 66) (LowCarb RFC: European rail freight corridors going carbon neutral, working paper 7).
19. Verbergt, E. (2019). Innovative Inland Navigation: INN-IN, University of Antwerp, Department of Transport and Regional Economics. INN-IN report.

Publisher's Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.