Developing performance indicators for a logistics model for vessel platooning

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Abstract. The H2020 Novimar project introduces the innovative concept of vessel trains (VT) that resembles the concept of truck platooning and aims "to adjust the waterborne transportation such that it can make optimal use of the existing short-sea and inland waterways and vessels (…)'. The triple bottom line performance of the concept is assessed and compared to the performance of the current transport system. This paper focuses on the economic performance and sets the foundations for its measurement by 1) describing the current situation of inland navigation, shortsea shipping and sea-river transport; 2) analysing the railway and road operations as the main competitors so as to take lessons; 3) presenting a review of the data sources available with respect to cargo flows and collecting the current cargo flows that will be used to set up the Origin-Destination (OD) matrix of the Antwerp case, 4) determining the geographical scope of a second case study area; 5) conducting a literature review of supply chain performance indicators (PIs) and 6) identifying the key PIs. The results will be input to the Novimar transport system model based on which the new VT concept will be evaluated compared to the current transport system.
Keywords: vessel train; economic performance; inland navigation; shortsea shipping; sea-river transport; performance indicators; transport system model.

1 Introduction

In the [1], modal shift to more environmentally friendly modes including rail and waterborne transportation is among the main ten key goals to be achieved by 2030 and 2050. Specifically the goal that is related to shift to waterborne transportation is the following: "*Thirty per cent of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50% by 2050, facilitated by efficient and green freight corridors. To meet this goal will also require appropriate infrastructure* *to be developed."* However, according to [2], the evolution of the modal split of land transport of goods in the European Union (EU) from 1999 till 2014 shows no significant change between road, rail and inland waterways transport modes. There is no sign of any shift of transport from truck to rail or ship in the recent years. Also the increased port volumes during the last four decades in the ports of Hamburg, Bremen, Rotterdam, Antwerp, Zeebrugge and Le Havre indicate the increased need for hinterland transport [3]. Thus, solutions that can contribute to the modal shift from road or rail to waterborne transportation are needed. Furthermore, economies of scale is a dominant factor in all transport modes. In waterborne transport the increased vessel sizes aim to reduce costs. However, the big vessel sizes that are economically competitive cannot access smaller inland waterways and smaller short sea ports or terminals. "*On the other hand, vessels that can access these infrastructures are, due to their limited (economies of) scale, less or not economically viable. This has reduced waterborne transport competitiveness and modal share. An approach providing economies of scale effects on the one hand but at the same time enabling waterborne transport to access smaller waterways, terminals and urban areas is presently missing."*

The innovative concept of vessel train (VT) that is introduced by the H2020 Novimar project (NOVel Iwt and MARitime transport concept) comes to fill this gap and contribute to the modal shift in favor of waterborne transportation. Particularly the VT concept aims *"to adjust the waterborne transportation such that it can make optimal use of the existing short-sea, sea-river and inland waterways and vessels, while benefitting from a new system of waterborne transport operations that will expand the entire waterborne transport chain up and into the urban environment."* VT could become a new waterborne transport system, which could fit into the current and well-developed system. But what is the VT? The VT is a waterborne platooning concept featuring a manned lead ship and a number of follower ships that follow at close distance by automatic control.

The evaluation of the current situation is necessary for the integration of the VT concept into the existing transport system. Thus, an analysis of the current situation in inland waterway transport, shortsea shipping (SSS) and sea-river transport has been performed.

Apart from the analysis of the current situation, the working principles of the main competitive modes of transport, rail and road transport, have been analyzed to transfer knowledge and experiences to the VT concept.

The aim of this paper is to identify the main performance indicators (PIs) for measuring the economic performance of the transport system with and without the VT. The current situation will be used as a benchmark against the VT concept. The basic work of this paper consists of desk research.

But how is the good performance defined in this study? Success is defined based on the following two objectives of the VT concept:

"A minor success will be achieved, when the VT concept is able to fill gaps in the existing transport concept of inland navigation, shortsea shipping or sea river transport or when it is able to perform better in economic and environmental aspects. For example by penetrating into urban areas due to the use of smaller vessels or improving the linking within waterborne transport modes. Further improvements within the waterborne transport sector might be a reduction of cost due to potential crew reduction."

"A full success will be achieved, when the VT concept improves the total waterborne transport (economically or environmentally) in such a way, that it will lead to a modal shift form road or rail to the waterborne transport."

As [4] state, a project is deemed successful when it meets its goals. Thus, based on the achievement or not of the expected project goals, the project success can be assessed.

Based on the PIs, conclusions can be drawn on the introduction of the VT as a new logistics system in the SSS, sea-river and IWT markets. Using PIs for performance measurement ensures that one always evaluates business activity against a basic benchmark. PIs provide visibility of the business performance and allow for objective quantitative and qualitative evaluation [5]. It is not the purpose to develop an endless list of PIs to evaluate the VT concept but we need to stick with the main goals and objectives [5]. Therefore, a very good definition of the main objective of the PIs needs to be developed. The main objective is: *"The evaluation of the transport system (including the VT) based on the broad economic, environmental, energy and social requirements."* These elements and their values that benchmark the VT concept transport characteristics need to be included in the Performance Indicators (PIs). The main purpose of this paper is to research the business economic aspects of the VT. Therefore, the focus will be on the development of business economic performance indicators. The welfare economic indicators will be developed in future research work. The economic performance of the VT concept is evaluated in the broader supply chain (SC) because the decisions are taken based on the complete SC.

The paper is structured in the following way: in section 2 the current situation of the inland navigation, SSS and sea-river transport system is described, in section 3 a literature review with respect to the SC performance measures is conducted, in section 4 the three main PIs are developed and in section 5 conclusions are presented.

2 Current situation of the inland navigation, SSS and sea-river transport system

Since the goal is to measure the economic performance of the transport system with and without the VT (current situation) through the PIs developed, firstly the current situation of the inland navigation, SSS and sea-river transport system is examined. The evolution of the modal split of land transport of goods in the European Union (EU) since 1999 shows no significant change between road, rail and inland waterways transport modes. There is no sign of any shift of transports from truck to rail or ship in the recent years. The modal share for inland navigation is quite inhomogeneous within the EU, mainly due to the inland waterway infrastructure. The Netherlands, Romania, Bulgaria, Belgium and Germany have a very good inland waterway network and thus a high modal share in comparison with all EU members [2]. With respect to the cargo, 'the share of transport of containers on total inland waterways transport' in the total EU (in tkm) is quite low but constantly rising from around 7.8% in 2009 to 10.2% in 2015 [6]. Containers and Ro-Ro cargo will be considered at first for the VT concept, considering that for the expected modal shift from road and rail to inland navigation, container and Ro-Ro cargo are the most suitable [7]. With respect to the fleet, in 2016 the three countries with the highest performance in transport are the Netherlands, followed by Germany and Belgium and the majority of the cargo is transported either via self-propelled barges or tanker barges [8]. The current situation of the labor market in the inland navigation sector is also examined because labor costs, which depend on different factors such as the type of vessel, and therefore the number of crew members and salary levels per country etc., contribute to the total costs quite significantly, varying around at least 30% [9]. However, for being unmanned or with reduced crew, additional equipment will be needed, so as to be as safe as being with the crew.

The available data for SSS[1] are not that extensive as for inland navigation. In 2012 the SSS in the EU-28 represented 60% of the total maritime transport of goods within Europe [10]. The distribution among different countries or sea areas differs strongly [11] and in particular in 2012 most freight transport takes place in the Mediterranean Sea (29%), followed by the North Sea (26%) and the Baltic Sea (22%) [12]. The most common cargo in SSS is liquid bulk and dry bulk cargo. Containers and Ro-Ro cargo make 30% of the total cargo transport with regional variations [13]. With respect to the SSS fleet, Russia holds the highest number of SSS vessels, followed by Germany and Norway [14].

Sea-river transportation is possible on inland waterways of sufficient size with open access to the sea. The most important limiter is the allowable air draught under bridges and overhead cables followed by the water depth. According to market analysis of the CCNR, about 90-100 million tonnes of cargo are transported annually by means of sea-river transport [15, 16]. Unfortunately, more detailed and recent data sources are not known. Boxed cargo is rare in sea-river cargo flows [16].

3 Literature review of supply chain performance measures

The literature review has been conducted with respect to the supply chain performance measures (SCPM) in order to identify potential appropriate business economic measures/PIs and lessons learned that can be applied for the development of new economic PIs and for evaluating the transport system with and without the VT. The reason why is that there are no sets of PIs that can be applied equally well under all conditions and organizations. Thus decision makers should select performance measurement approaches, methods and indicators that suit their SCs [17].

The papers that are reviewed[2] with respect to the supply chain performance measurement systems (SCPMS) show that the focus is on 1) clearly defining what are the key terms they are working with, such as PMS, SCPMS, metrics etc., 2) providing recommendations on how to develop own key performance measures, 3) categorizing the SCPM that are most widely used, 4) presenting also the existing SCPMS frameworks and the techniques that are used. Therefore, attention is not only paid to the specific existing SCPM as such.

Lessons learned from the literature review

- Less is better (with respect to the number of the indicators to be used) [18].
- Categorize key PIs (KPIs) in primary and secondary [18].
- Develop KPIs for each of the critical operations of the supply chain (see four SCOR processes) [18].
- From a logistic service provider's point of view, performance is measured through timeliness and accuracy, delivery performance, personnel scheduling, safety measures, customer satisfaction and loyalty [19].

1 *"Shortsea shipping (SSS) means the movement of cargo and passengers by sea between ports situated in geographical Europe or between those ports and ports situated in non-European countries having a coastline on the enclosed seas bordering Europe. SSS includes domestic and international maritime transport, including feeder services along the coast, to and from the islands, rivers and lakes. The concept of SSS also extends to maritime transport between the Member States of the Union and Norway and Iceland and other States on the Baltic Sea, the Black Sea and the Mediterranean."* [20]

2 [17, 18, 21, 19, 22, 23, 24]

- Consider developing PIs based on the perspectives of the different stakeholders [19].
- Effectiveness, efficiency, satisfaction, IT & Innovation are key performance overall categories for measuring performance from a management point of view [19].
- From the perspective of the customer, three PIs mainly matter: costs, performance and flexibility. Costs are measured as costs per stored unit; performance is measured as On-Time and In-Full (OTIF) and flexibility measures the ability to accommodate decreases and increases in the flow of goods [19].
- Keep in your mind the change of the environment: the level to which SC management takes place shifted from an internal business level to the enterprise management level of the SC. Thus, it is significant to consider the SC as a whole when designing a SCPMS [17].
- It is critical that PIs are based on a clear definition of scope and on suitable data and calculation methods [17].

The main conclusions of the literature provide the foundations for developing the PIs.

4 Developing main PIs for the VT concept

In order to research the viability of the VT concept, a (limited) set of PIs needs to be developed. In order to develop the KPIs of the VT, only those elements that are influenced by the implementation of the VT are to be taken into account. Therefore, the PIs to assess the VT need to include at least: Transport cost; Total transport time (including delays and waiting times at deep-sea and inland terminals); Transport reliability; Inventory cost (both in-transit and in a warehouse); Flexibility and External cost (Welfare assessment of the VT that will be assessed in a future work).

In the present paper, the main focus is on the business-economic aspect of the VT. Therefore, the main KPIs will be related to this. One of the main features of the VT is that cargo flows with different origin and destination pairs are combined, because the VT has an impact on multiple cargo flows. This means that the evaluation of the VT needs to be determined for each cargo flow with origin and destination (OD).

The first PI will be based on a more macro-based approach. According to this approach, the difference in **generalized cost** (see for instance [25]) is taken for the movement of a containerized load (TEU) between the base case and the new situation in which the VT is implemented.

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

In which:

$GC_{i,j}(IWT/SSS/SEA\text{-}RIVER)$ is the current generalised cost per TEU for IWT, SSS or sea-river transport between origin i and destination j.

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

In which GCi_j is the generalised cost per TEU from i to j, $OPC_{i,j}$ is the out of pocket cost per TEU from i to j, $T_{i,j}$ is the average transport time from i to j, VoT is the value of time per TEU, $\sqrt{VAR(T_{i,j})}\sqrt{VAR(T_{i,j})}$ is the standard deviation of the total transport time from i to j[3].

If the PI turns out to be positive, then the VT concept leads to a lower *GC* per transported container. This will result in modal shift for all containerised cargo flows from origin i to destination j if the generalised cost of the alternative modes are constant.

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

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

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

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

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

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

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

In which $\Delta TLC_{i,j}$ is the **difference in total logistics cost** [26] from origin i to destination j. $TLC_{i,j}(IWT/SSS/SEA\text{-}RIVER)$ is the total logistics cost from origin i to destination j for the current situation and $TLC_{i,j}(+VT)$ is the total logistics cost when the VT is included.

The *TLC* can be calculated based on the following formula [26]:

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

In which:

Goods flow parameters		Transport mode parameters	
Annual volume (units)	R	Transportation costs (euro/unit)	
Average daily demand (units/day)	D	Loading capacity (units)	
Variance of daily demand (units²/day)	d	Average lead-time (days)	
Value of the goods (euro/unit)	v	Variance of lead time (days²)	
Holding cost (% per year)	h		
Safety factor	k		

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

3 The variation in time can be determined via a Monte Carlo Simulation (see for more information project task 2.2).

In Table 1, an overview of the developed PIs is given.

Table 1: Overview of proposed Performance indicators

PI	Calculation	Meaning	Impact
Generalized cost	$\Delta GC_{i,j} = GC_{i,j}(IWT/SSS/SEA-RIVER) - GC_{i,j}(VT)$	Difference in generalised cost per TEU	Attractiveness of the new transport system on an aggregated level.
Modal share	$\Delta P_{Waterborne,i,j} = P_{SSS/IWT/SEA-RIVER+VT,i,j} - P_{SSS/IWT/SEA-RIVER,i,j}$	Increase of modal share	Effective use of waterborne infrastructure (also in urban areas).
Total logistics cost	$\Delta TLC_{i,j} = TLC_{i,j}(IWT/SSS/SEA-RIVER) - TLC_{i,j}(VT)$	Difference in total logistics cost	Attractiveness of the VT at Micro level to assess the VT on a company level.

Other KPIs, such as the external cost and other social requirements, are also planned to be developed, where the welfare evaluation of the VT concept will be performed.

The above main PIs are used to assess different constellations of the VT[4]. Based on a sensitivity analysis, the main impact of changes to the VT transport system can be assessed and those VT solutions that have the best scores on the developed KPIs can be developed into concrete business cases. The developed KPIs can also be used as inputs for the development of the business case. The perspective of these PIs is the perspective of the cargo owner (customer), the ship owner and the middle man that brings together the first two stakeholders.

5 Conclusions

The innovative concept of VT is introduced in this paper mainly aiming at contributing to modal shift in favour of waterborne transportation. The VT is a waterborne platooning concept featuring a manned lead ship and a number of follower ships that follow at close distance by automatic control. The aim of this paper is to develop the main PIs for measuring the economic performance of the transport system with and without the VT (current situation); the latter will be used as a benchmark against the VT concept. The analysis of the current situation showed that a lot of data on waterway structures, fleets and transported cargo can be found for inland waterway navigation, but hardly for SSS and sea-river transport. The analysis of the competitive transport modes of road and rail in order to take lessons showed that rail transport is quite different from the VT concept and the transfer of relevant information is difficult. Whereas, in the road transport sector truck platooning is currently investigated and already highly developed, thus knowledge might be gained from a technical and logistics point of view. A full success of the VT concept will be achieved, when the concept improves the total waterborne transport (economically or environmentally) in such a way, that it will lead to a modal shift form road or rail to the

4 The VT can be composed of vessels of the same size/type, of different vessel types or of newly designed and built vessels.

waterborne transport. The three proposed economic PIs are the 1) Generalized cost; 2) Modal share and the 3) Total logistics cost. The identification/development of PIs related to the impact on the social and environmental welfare will be conducted in future research work.

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