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NOVIMAR
VESSELTRAIN

Deliverable 4.4 Vessel design

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List of abbreviations

ABL	Above base line
AC	Annuity cost
ADN	European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways
CAPEX	Capital expenditure
CEMT	Conférence européenne des ministres des Transports (Classification of European Inland Waterways)
CESNI	European Committee for drawing up Standards in the field of Inland Navigation
CP	Contrast price
CTP	Cargo Transfer Platform
DWT	Mass of deadweight
ES-TRIN	European Standard laying down technical requirements for Inland Navigation vessels
FEU	Forty-foot Equivalent Unit
FIOS	Free In Out and Stowed
FV	Follower vessel
GT	Gross Tonnage
HAZID	Hazard Identification Studies
HNWL	Highest Navigable Water Level
IMO	International Maritime Organisation
ISO	International Standard Organisation
IWS	Inland waterway shipping
IWW	Inland waterway
KPI	key performance indicator
Lolo	Lift-on lift-off
LV	Lead vessel
NCHV	NOVIMAR container handling vehicle
OPEX	Operating expenditure
PTI	Power take in
PTO	Power take off
RFR	Required Freight Rate
Roro	Roll-on roll-off
SOLAS	The International Convention for the Safety of Life at Sea
TEU	Twenty-foot Equivalent Unit
THC	Terminal handling charges
TOC	Terminal Operating Cost
VT	Vessel Train
WP	Work package

List of symbols

B	Vessel beam [m]
D	Vessel depth [m]
d	Vessel draft [m]

d_A	Air draft [m]
D_p	Propeller diameter [m]
GM	Metacentric height
GZ	Righting arm
KG	Vertical centre of gravity
L	Vessel length [m]
LOA	Length over all
m_{LIG}	Mass of lightship [t]
m_{TEU}	Average container (TEU) mass [t]
v	Vessel speed [km/h]

1 EXECUTIVE SUMMARY

The NOVIMAR project researches the vessel train (VT) concept, a waterborne platooning concept featuring a manned lead ship and a number of follower ships that follow at close distance by a control system. The potential benefit of the vessel train is the economy of scale that can be achieved with limited size vessels by operating several units in a coordinated operation. Manning is a major cost for all shipping operation and the NOVIMAR project will investigate the possibility to reduce the manning of the vessels in the vessel train

Work package 4 addresses the design of the vessels making up the vessel train. Initially it is assumed that the concept of vessel train potentially can be relevant for inland waterway, sea-river and short-sea shipping operations.

This deliverable is the fourth deliverable in WP4 of the NOVIMAR project. The first deliverable, **Deliverable 4.1 Specific requirements WP4**, addressed the general requirements for vessels that will operate in a vessel train. The second deliverable, **Deliverable 4.2 Cargo Systems Analysis**, presents the current available cargo system technology and analysis the pros, cons and limitations. The third deliverable, **Deliverable 4.3 Cargo systems development** describes solutions to problems that were identified in the earlier work in the work package. This deliverable, **Deliverable 4.4 Vessel concepts,** presents the preliminary design of **five roro vessels** that can provide an efficient and compatible inland waterway service both in a vessel train and as independent vessels. The deliverable also presents a model to compare transport and handling cost for different multi-modal door-to-door transport alternatives.

1.1 Problem definition

A waterborne transport alternative is usually the most energy efficient alternative. The cost of transport of a unit from one port to another is also almost always considerably lower than the road transport, however the cost, time and risk related to shift of the cargo unit between different transportation modes need to be reduced in order for waterborne transportation to attract more cargo from the road.

The NOVIMAR cargo handling concept, based on roro handling includes the NOVIMAR container handling vehicle, NCHV and the cross-transfer platform, CTP developed in the previous tasks of WP 4. This concept will have the potential to considerably reduce time and cost for cargo handling in the terminals. To fully utilize the concept, the ship design need to be adopted to provide easy access to the cargo space. The cargo space need also to be arranged for efficient stowage and the challenges that comes with the high loads from double stacked containers, cargo handling vehicles and rolling cargo need to be specifically considered. Furthermore there is an inherent challenge of ship stability.

The performance of the NOVIMAR handling concept together with purpose-designed vessels should be assessed and compared to current operations in order to decide where, when and how it should be applied and what the expected benefits are.

The vessels should be designed for best possible performance, but they also need to fit in the vessel train concept and be able to operate as both lead vessel and a follower vessel.

1.2 Technical approach and work plan

Three vessel categories were identified as necessary to provide cost-efficient waterborne transportation solutions for service to and from inland ports see also section 4.1.

- CEMT Class Va vessel
- CEMT Class III vessel
- Sea-river vessel

Based on the three categories, five vessel concepts were identified as relevant for the transport missions.

- NOVIMAR Class Va container roro vessel
- NOVIMAR Class Va container roro vessel, shallow draft
    - Stern access version
    - Double-end access version
- NOVIMAR Class III container roro vessel
- NOVIMAR sea-river container roro vessel

The term “container roro vessel” is used to describe that the vessels main purpose is to transport containers utilizing roro handling technology. A consequence of this is that the vessels also can load other types of rolling cargo together with the containers

All vessels can be equipped to act as lead or follower vessels in a vessel train or operate as individual units.

For the five vessel concepts, relevant main dimensions were identified, based on the fairway restriction for the intended operations. Then the design of hull, structure, cargo system, propulsion, manoeuvring, mooring, wheelhouse, accommodation, lifesaving equipment etc were developed up to a relevant conceptual level so the performance of the different designs could be compared to each other as well as to conventional alternatives.

For the vessel performance assessment, the technical design data is the foundation for the estimation of total cost of operation and cargo carrying performance.

The cargo handling cost for the NOVIMAR roro handling concept was also estimated and compared to the cost of conventional handling.

These estimates were then used in the cost model that was developed to compare the NOVIMAR roro vessels and roro cargo handling concept to conventional concepts based on vertical, lolo handling of cargo units.

1.3 Results

The work in NOVIMAR task 4.4 provides the following results.

Five vessel concepts for inland waterway operation utilizing roro handling technology have been developed.

The design data and the performance have been used to estimate capital costs, operational costs and voyage costs to calculate a required freight rate for the different vessels.

Conventional container vessels have generally larger cargo space capacity than the vessels designed for roro handling but with the features of the NCHV, the difference in number of containers that can be stowed might be only about 10%. For the vessels with a full width main deck for container loading, the vertical centre of gravity both for the ship and the cargo will be higher than for comparable conventional container vessels. Due to stability constraints, this will either reduce the weight of the cargo that can be stowed in the containers or it would require a more careful vertical distribution of cargo.

The lower cargo carrying capacity, in terms of TEU, is to some extent compensated by estimated shorter time spent in terminals, which will lead to more round trips in a year for the roro vessels.

Cost for cargo handling using the technology developed in previous tasks of WP 4 has been estimated and compared to conventional handling. The Novimar Cargo handling vehicle, NCHV is less expensive than a ship to shore container crane and it is more versatile since it also can do the work of a straddle carrier /reach stacker for handling the containers in the terminal area as well as loading/unloading trucks at the terminal gate.

The required freight rate and the cargo handling costs for the different alternatives were used to compare different intermodal transport concepts for a sample route. For this particular route, from Karlstad Sweden to Stuttgart Germany, it was indicated that the NOVIMAR concept with the cargo handling vehicle and the developed vessel concepts can provide cost savings of approximative 20 - 30% compared to conventional operation with the added benefits inherent to roro handling, i.e. flexibility and the ability to combine containers with any type of rolling and general cargo.

1.4 Recommendation

Based on the work and conclusions in NOVIMAR task 4.4 the following recommendations are made

- The NOVIMAR roro handling concept to be further developed in order to identifyhow the potential of the concept, to move cargo from road to water, can be maximized.
- For the sea-river concept, more design versions to be developed where the main dimensions are adopted so the concept can be applied to other short-sea/inland route combinations. (Similar to the work done for the CEMT class Va size vessels)
- The clear benefit of the lower energy consumption (higher energy efficiency) when transporting unitized cargo on water instead of on land should be better communicated. For this to be relevant, the waterborne alternative also needs to implement renewable fuel and reduce emissions to show that they are the best overall alternative from environmental and climate perspective.

2 INTRODUCTION

2.1 Task 4.4: Vessel concepts

The deliverable 4.4 Vessel concepts presents the results from the ship design activity in the NOVIMAR project. The requirements regarding capacity and performance of vessels that would fit into the vessel train (VT) platooning concept, were identified in the previous deliverables.

Three vessel categories were identified as necessary to provide cost efficient waterborne transportation solutions for service to and from inland ports.

- CEMT Class Va vessel
- CEMT Class III vessel
- Sea-river vessel

Based on the three categories, five vessel concepts were developed.

- NOVIMAR Class Va container roro vessel
- NOVIMAR Class Va container roro vessel, shallow draft
    - Stern access version
    - Double-end access version
- NOVIMAR Class III container roro vessel
- NOVIMAR sea-river container roro vessel

All the vessels have the ability to navigate inland waterways of different categories. The Sea-river ship can also navigate short sea shipping routes.

The designs are brought to a conceptual design level. This means that features such as cargo stowage, structural integrity, propulsion, and stability have been checked against operational and regulatory requirements.

2.2 Analysis

The NOVIMAR project researches the VT, a waterborne platooning concept featuring a manned lead ship and a number of follower ships with reduced manning that follow at close distance.

Almost all systems benefit from economy of scale and that is true also for waterborne logistic system. Cost per transported unit can be reduced if the vessel is increased in size assuming that the utilization factor of the vessel is not reduced. The continued increase of the capacity of fairways, ports, canals, and locks are enabling the sea-going vessels to grow. The same development is not taking place for inland waterway vessels. To achieve economy of scale for waterborne transport on inland waterways, the NOVIMAR project is investigating the possibilities of VT. A great application for the VT is to provide an economy of scale effect for smaller vessels operating in train formation, i.e. platoons. The VT can be made up of different size vessels with different final destinations. Larger vessels to provide high capacity and smaller vessels, which can navigate shallower water, pass smaller locks and lower bridges, to reach further out in the logistic system and also contributing to avoiding road congestion in urban areas. This can reduce the distance of the "last mile" where transport by truck often is the only option.

Transporting larger volumes with less resources is an obvious strive and a sure way to improve the competitiveness of inland waterway shipping. The VT concept can enable this. Increased speed and reduced cost for the cargo handling is also important. The flexibility to transport different kinds of cargo units in the same ship, which increases the available cargo volumes, is also an added benefit. Another thing that is always relevant for transport is to get highest possible cargo density and to maximize the utilization of transport capacity. This means both that the capacity of the cargo unit is maximized by intelligent algorithms for combination of parcels in each unit, as well as design of vessels and cargo handling systems enables maximum number of units to be carried while maintaining flexibility.

In task 4.4 of the NOVIMAR work package 4, the costs for building and operation of the four different vessels concepts have been estimated and compared to conventional designs. From the costs and cargo transport capacity the performance of the NOVIMAR vessels has been estimated by calculating the required freight rate, RFR (see section 4.3.1) .

To compare relevant transport costs, a model including both vessel and terminal related costs has been developed. Only costs related to the physical transportation and handling of the cargo units have been included, which means that the derived total cost excludes administrative costs such as bill of lading, customs clearance, insurance, etc since they, in principle, are the same regardless of the vessels and handling equipment used.

The derived numbers are quite rough estimates based on various sources. The aim is to visualize the relative differences and how the cost is accumulated in the different steps in the logistic chain.

2.3 Approach

Apart from developing and evaluating the vessel train concept, the NOVIMAR project description also requires that the potential of roro handling technology should be investigated.

Accordingly the NOVIMAR vessels are designed and optimized for loading and unloading over a ramp, i.e. roro handling instead of lifting the cargo on and off the ship, i.e. lolo handling which is the conventional way for vessels of these categories, in particular for container transport.

The ISO containers represent by far the largest volume of unitised cargo transport on the inland waterways and they are also considered to be the most important cargo units for the NOVIMAR vessel design. However other types of units such as pallet wide containers and any type of rolling cargo are considered for the designs.

The vessel designs and cargo handling concept were developed to a stage where a comparison of the principal performance between different transport modes and design concepts could be performed.

3 PLAN

3.1 Objectives

The objectives of task 4.4 are:

Vessel concepts for sea-river and inland-only operations having roro capabilities and various crewing levels and matching the identified transport missions.

3.2 Planned activities

- Using the Terms of Reference from previous design tasks to identify vessel categories and the corresponding design requirements and constraints for the transport mission(s)
- Develop vessel concepts for the identified vessel categories: main dimensions, power estimate, cargo equipment, accommodation, an outline General Arrangement and CAPEX/OPEX estimates.
- Prepare vessel concepts for assessment of performance within the transport mission(s). The principal assessment work will be done in WP1 task T1.5.

3.3 Resources and involved partners

The distribution of the activities among partners in Task 4.4 has been as follows:

- **ScandiNAOS AB (task leader)**
  Developed the design of 3 vessels and the models for performance comparison and compilation of the task deliverable.

- **University of Belgrade**
  Developed the design for the two versions of the NOVIMAR Class Va container roro vessel, shallow draft.
  Coordinated the integration of the HAZID recommendations from WP5 int the WP4 vessel design.
  Authored the technical report HAZID study recommendations relevant for design of VT vessels

  Performed the damage stability calculations

  Produced the cargo handling simulation

- **Technische Universiteit Delft**
  Provided input how the concept of automated navigation for reduced manning can impact the ship design as well as ship design data for conventional inland waterway vessels

- **Plimsoll Szolgaltato KFT**
  Provided capex/opex of conventional vessels of similar size.

- **Universiteit Antwerpen**
  Provided input regarding shipping operation organisation and related cos for transport and cargo handling

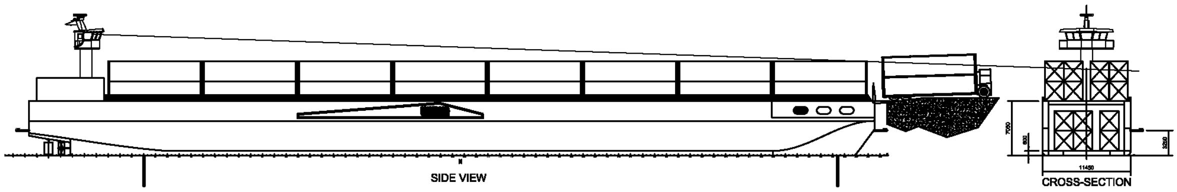
4 EXECUTION

4.1 Identified vessel categories and developed vessel concepts

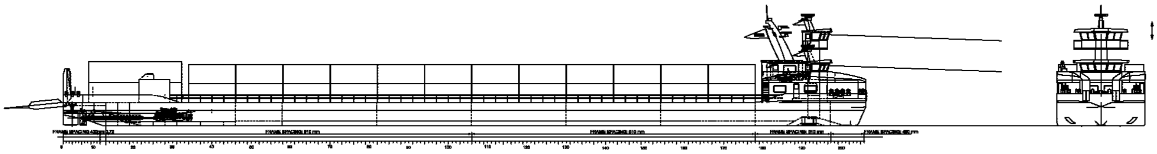
- **The CEMT Class Va vessel category** was selected since this is the size of vessel that moves most cargo on the Rhine river and it is also the size of the standard inland waterway container vessel with a container capacity of approx. 192 TEU(Bureau Voorlichting Binnenvaart, 2016). The Rhine river with its tributaries comprises by far the largest volume of the European inland water traffic. The vessel size is also relevant for operation on the Danube river but with the recurring fairway depth problems it is relevant to consider versions with limited drafts.
  - Developed vessel concepts for the CEMT Class Va vessel category;
    - **NOVIMAR Class Va container roro vessel, regular draft**
    - **NOVIMAR Class Va container roro vessel, shallow draft - stern access version**
    - **NOVIMAR Class Va container roro vessel, shallow draft - double-end access version**
- **The CEMT Class III vessel category** was selected in order to reach further out in the distribution network. A CEMT class II was originally proposed but the standard dimension for this class is *LOA* = 55 m and *B* = 6,6 m. For the container carrying version the dimensions are adjusted to *LOA* = 63m and *B* = 7 m to fit the dimensions of ISO containers(Bureau Voorlichting Binnenvaart, 2016)
  - Developed vessel concept for the CEMT Class III vessel category
    - **NOVIMAR Class III container roro vessel**
- **The Sea-river vessel category** was developed to investigate the potential of avoiding transfer of cargo at the seaports. The operation of sea-river vessels enables the direct transport of goods from an inland port in one part of Europe to an inland port in another part including a short sea voyage. Such direct transport eliminates the need for transhipment of cargo in the seaports and eliminates the related time, cost, and risk of cargo damage.
  - Developed vessel concepts for the Sea-river vessel category
    - **NOVIMAR sea-river container roro vessel**

4.2 Vessel concepts

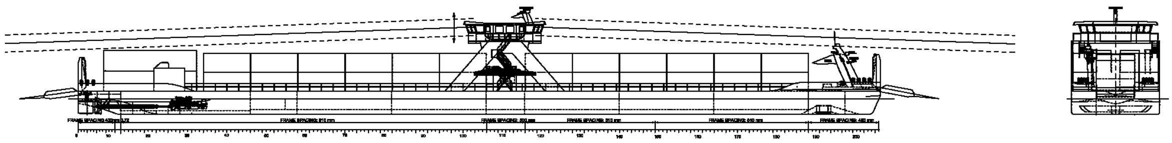
4.2.1 General description



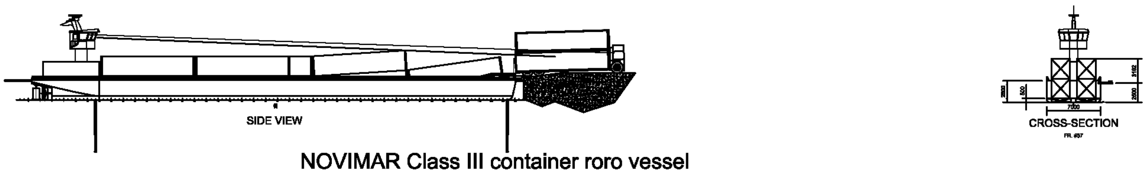
NOVIMAR Class Va container roro vessel



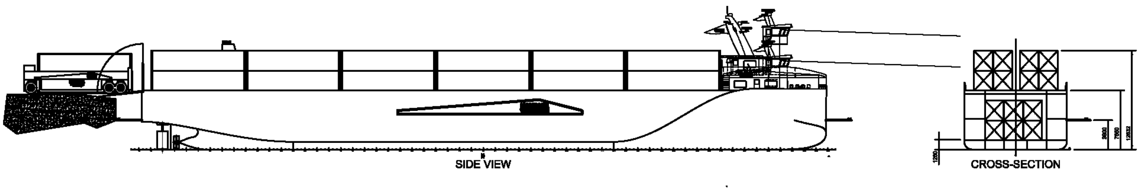
NOVIMAR Class Va container roro vessel, shallow draft - stern access version



NOVIMAR Class Va container roro vessel, shallow draft - double end access version



NOVIMAR Class III container roro vessel



NOVIMAR Sea river container roro vessel

Figure 1, NOVIMAR vessel concepts

The developed vessel concepts are conceived with the following design objectives in mind.

- The vessel should be able to act as a stand-alone cargo vessel when no vessel train (VT) is formed.
- Cargo transhipment is to be performed using the NOVIMAR container handling vehicle (NCHV).
- Specific technical requirements with respect to safety and cyber security should be fulfilled.

Additionally, if the vessel is intended to be capable of leading the VT, there are some technical requirements which are specific for the lead vessel (LV).

The effectiveness of inland navigation strongly depends on the available water depth (as it is clearly shown by the statistical data for the Rhine, provided by the Rhine Commission, see (CCNR, 2018) which varies with the navigation area and changes seasonally. According to available research (see e.g. (KLIWAS, 2016), these seasonal changes may be accentuated by climate change effects.

For this reason, both a regular draft and shallow draft concept for the NOVIMAR Class Va were developed. The shallow-draft concept is intended to be climate-change-resilient and flexible with respect to the water levels fluctuation. It also ensures availability of the service throughout the year.

The proposed concepts lever on benefits of horizontal (roro) handling of unitized cargo. The principal benefit of horizontal cargo handling is a fast cargo transhipment (see Ramne, 2004). The main part of the cargo handling systems foreseen with the NOVIMAR project is the NOVIMAR container handling vehicle (NCHV) which is presented in Figure 2. The efficiency of the system may be enhanced by using the cargo transfer platforms (CTP) in ports. Both NCHV and CTP were described in more detail in Ramne and Fagerlund (2019).

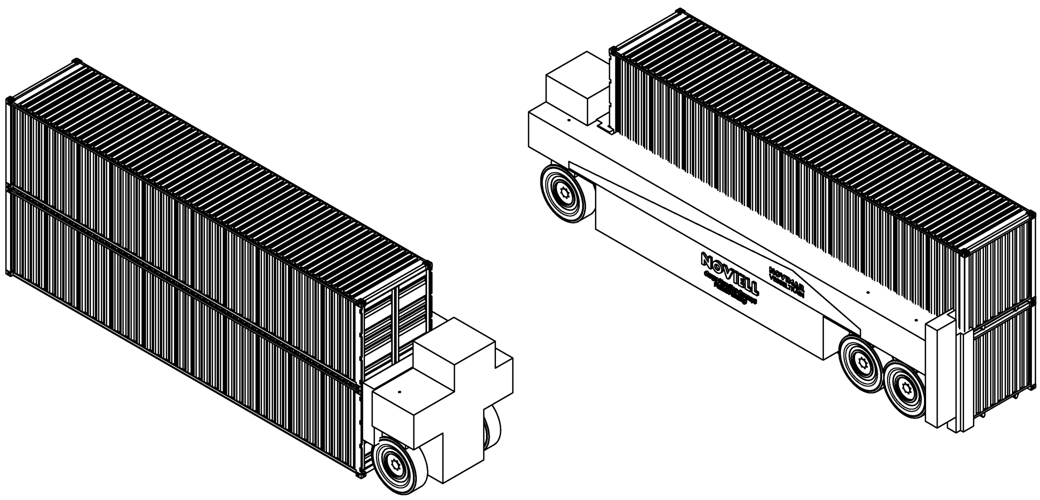


Figure 2. NOVIMAR container handling vehicle(Ramne, Bengt Fagerlund, 2019b)

The utilization of NCHV is the key feature of the designs. It has both the advantages and the drawbacks, and it considerably affects both the design and the performance of the vessels.

Naturally the five vessels share many design features since they are designed for the same cargo and the same cargo handling concepts. The size, capacity and intended service differ which of course impacts the principal dimension and power requirements. It also means that some solutions might be completely different between the vessels e.g. longitudinal vs transverse stiffening of decks, one or two engines, deck house position cargo ramps or elevators. The intention of the design work is to provide a portfolio of vessels that can serve as a platform with solutions that can be combined to optimal solutions depending on the conditions of a specific transport mission.

NOVIMAR Class Va container roro vessel, regular draft

The objective of the vessel design is to match the cargo capacity of a CEMT Va container vessel. With roro handling limited to 2 tiers in each stack, two cargo decks (lower hold and main deck) are arranged to get four tiers of containers.

The design DWT is approx. 3290 t and the design draft is d = 3.9 meters.

The wheelhouse and accommodation are located aft above the engine room. A full width (11.2 m) roro cargo ramp is located at the bow. The ramps enables loading and unloading of containers using roro cargo handling equipment and as well as loading and unloading of any other types of rolling cargo.

The lower cargo deck with maximum 64 TEU capacity is 600 mm above the baseline. The cargo space has six meters height clearance. Three containers can be stowed abreast in the rear aft, and two containers abreast besides the ramp in the forward section. The deck is accessed through a fourmeterwide fixed ramp located on the port side. To have enough height clearance, a cover on the upper cargo deck will open when loading/unloading the lower cargo deck.

The upper cargo deck is 7050 mm above baseline and can accommodate 120 TEU as double stacked containers.

The vertical centre of gravity of the vessel is higher than a conventional IWW container vessel of similar size due to the clearance required under the main deck and the structural height of the main deck itself. A considerable amount of ballast water is required to meet the stability requirements.

NOVIMAR Class Va container roro vessel, shallow draft

The objective of the vessels is to enable efficient roro service also where the water depth is limited like in parts of the Danube river and occasionally in the Rhine river due to seasonal changes which is expected to be emphasized due to the climate change. The shallow draft design comes unavoidably with a number of draw-backs. With no cargo below the main deck, the space utilization and cargo space capacity are reduced as well as the stability due to a higher centre of gravity. However, the concepts have the potential to provide attractive waterborne services, where available water depth is a significant limitation.

For the CEMT Class Va vessel category two shallow-draft concepts are developed.

- A “stern access” version with a cargo ramp at the stern and the deckhouse and wheelhouse forward see Figure 3.
- A “double-end access” version with cargo ramps both in the stern and at the bow, with the deck house and accommodation at midship. The intention of this version is to fully exploit the benefits of the Ro-Ro cargo handling, see Figure 4.

- Both vessels have a shallow design draft (*d* = 2 m as opposed to *d* = 2.7-3.2 m typical for standard CEMT class Va vessels) and the access from bow to stern arranged along the CL
- They also have lower air draft.

As described in section 4.2.3, the length of the vessel should be $L \leq 110$ m. Keeping the consistency with the previous studies (see Bačkalov et al, 2016; Bačkalov et al, 2014) it was decided to adopt L = 104 m. Based on the previous research see (Bačkalov, I., Kalajdžić, M., Momčilović, N., Simić, 2014), ; Hofman, 2006) the design draft of the shallow-draft vessels was selected to be d = 2 m. The depth of the vessels, D = 3 m, was selected iteratively considering air draft, damage stability requirements and machinery spaces arrangement.

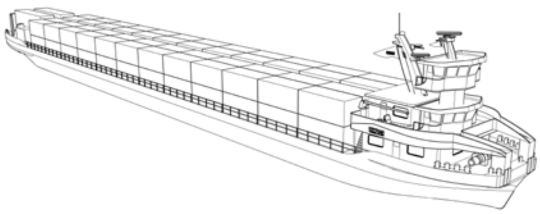


Figure 3. The "stern access" concept

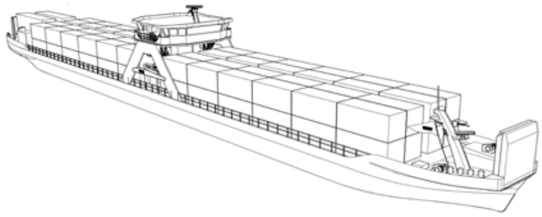


Figure 4. The "double-end access" concept

The vessels have one cargo deck. The vessels load 100 -104 TEU in two tiers with roro handling equipment. The average container mass with two tier loading is m_{TEU} = 11-12 t which provides a well-balanced vessel with respect to cargo carrying.

As indicated, both vessels have the capacity to load a third tier of containers, however there is currently no concept for horizontal (roro) handling a three tier package so the third tier will have to be loaded by means of a container crane. The TEU (space) capacity is then increased by approx. 50% but the average container mass will for this load case be reduced to approx. 8 tons. Depending on the actual transport mission, this may or may not be a critical limitation. The ability to load a third tier is a useful feature that allows the vessels to adapt to the specific situation. Two-tier loading would be preferred if handling speed is the priority, three-tier loading would be preferred if space utilization is the priority.

A very important feature with the roro concept is the ability to mix containers with trucks or other rolling cargo. Both designs can handle a mix of cargo and if only utilized for trailer transport the capacity is 24 trailers for the double-end access version and 26 trailers for the stern access version.

In addition, thanks to the bow arrangement which enables the vessel to push a barge, the "stern access version" may expand her cargo capacity by forming a coupling convoy.

NOVIMAR Class III container roro vessel

The objective of the NOVIMAR Class III container vessel is to reach as far out in the distribution network as possible and to provide a small-scale application of the NOVIMAR cargo handling concept. The vessel has an open cargo hold with a double bottom height of 500 mm and a depth to main deck of 2800 mm. The forward part of the cargo hold is a fixed ramp leading to the main deck level.

The cargo access ramp is located at the bow, deck house and wheelhouse aft. The cargo space capacity is 28 TEU, the design DWT is 697 t and the design draft is 2.5 meters.

NOVIMAR sea-river container roro vessel

The objective of the Sea-river vessel is to enable direct waterborne transport of goods from an inland port in one part of Europe to an inland port in another part including a short sea voyage. Such direct transport eliminates the cost and damage-risk related to the transhipment operation in the intermediate seaport. Sea-river vessel is a sea going vessel and needs to comply with the IMO rules as well as the rules for inland waterway vessel.

The NOVIMAR Sea-river container roro vessel can be considered as a very small short sea roro vessel loading two tiers of containers in the lower hold and two tiers on the main deck.

The cargo access is provided via a stern ramp and a cargo elevator that transfers the cargo between the main deck and the lower hold. The vessel is too short too arrange a ramp to the lower hold which otherwise would have been preferred from a cargo handling perspective. The lower hold is 1200 mm above base line with 6 meters height clearance. The main deck is 7650 mm above base line.

The accommodation is located forward with a retractable wheelhouse.

Depending on the actual water level and destination, the possibility to carry a second tier on the main deck will be affected.

The service area is limited to 20 miles from coast (Bureau Veritas “coastal area”, or DNV-GL “R3”) in order to reduce structural, stability and lifesaving requirements.

The lower cargo deck has a capacity of 44 TEU and the main deck 96 TEU. The design draft is 3.8 m and the corresponding deadweight approx. 2300 tons.

4.2.2 General arrangement

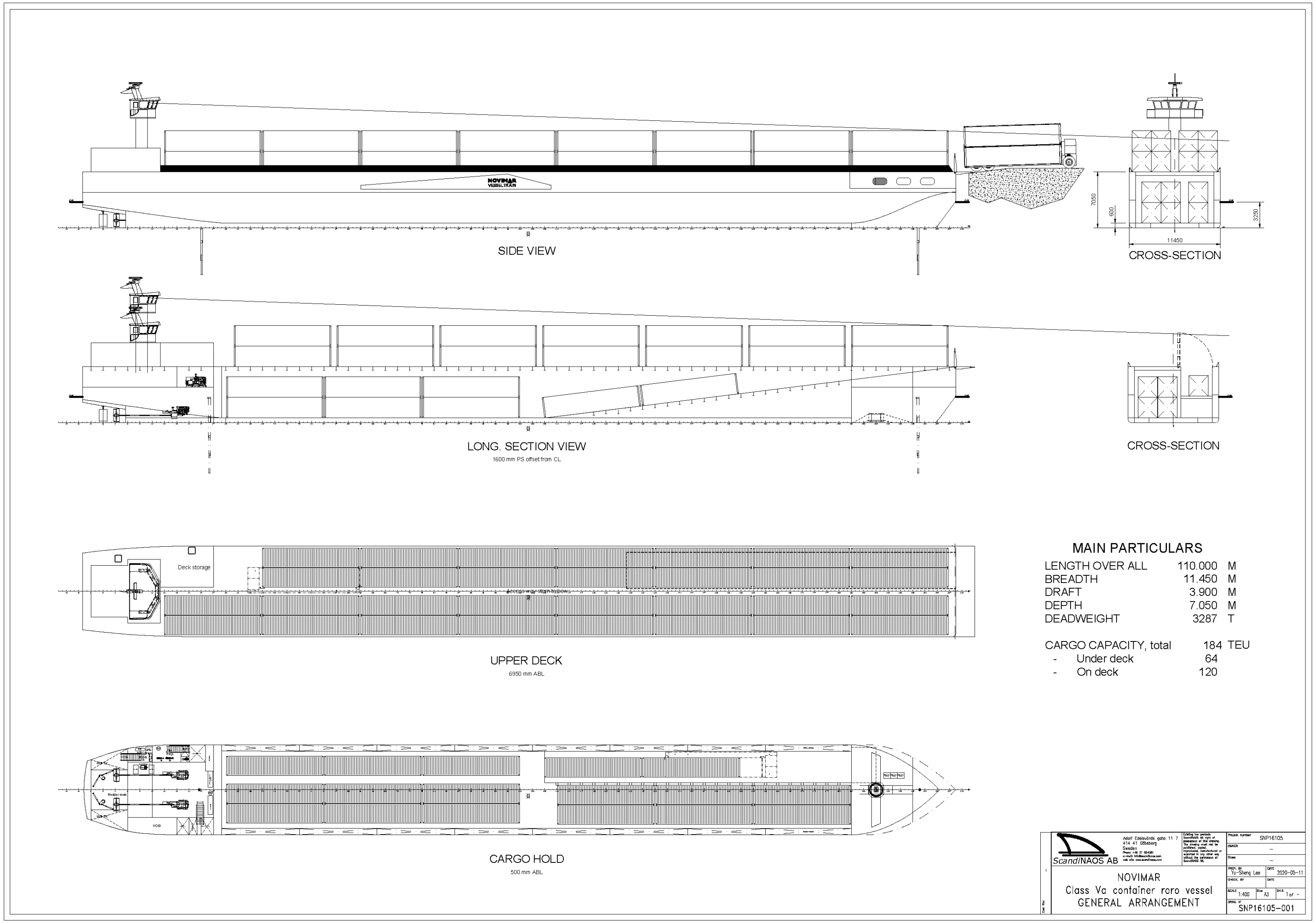


Figure 5, General arrangement – NOVIMAR Class Va container roro vessel, regular draft

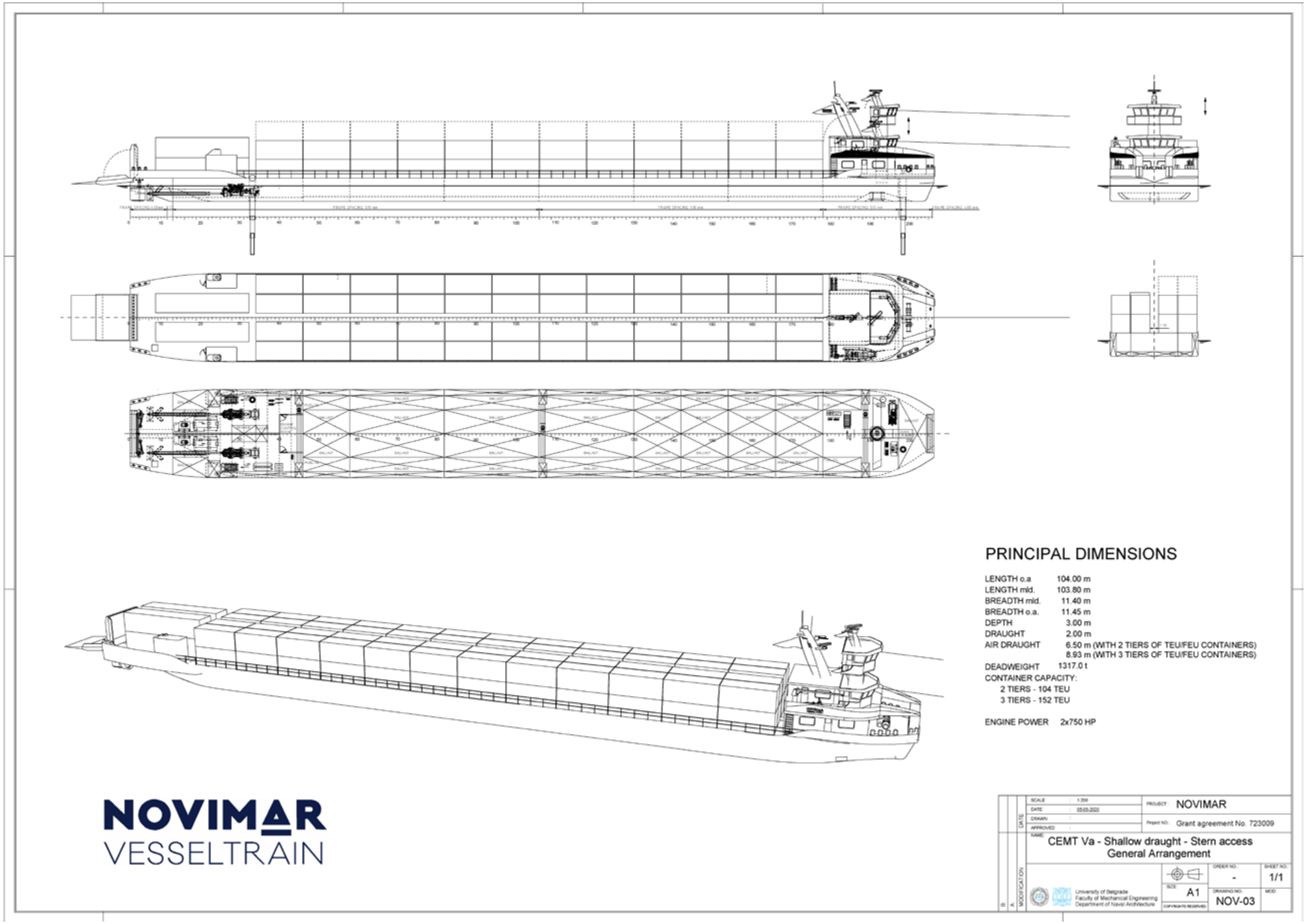


Figure 6, General arrangement – NOVIMAR Class Va container roro vessel, shallow draft stern access

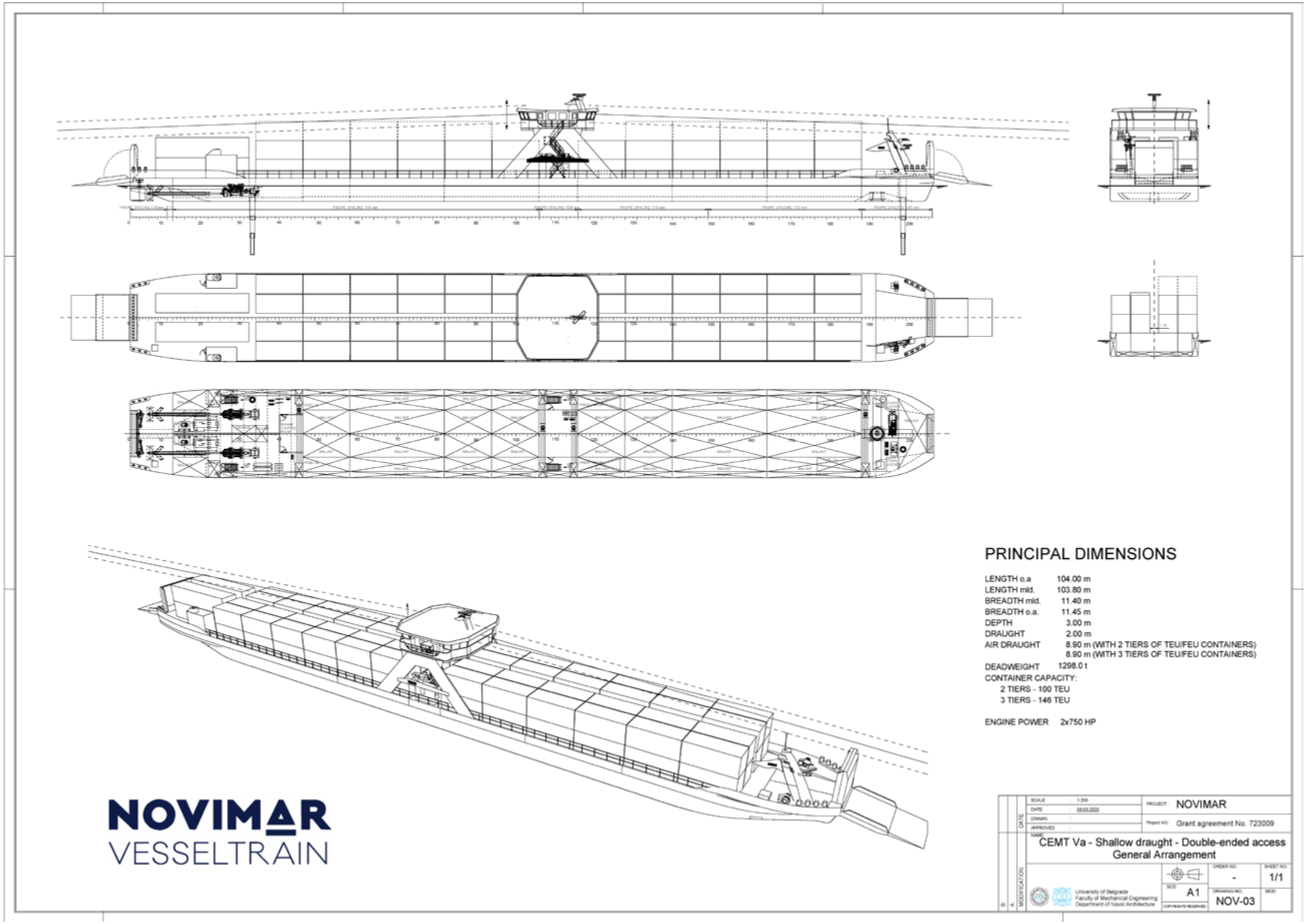


Figure 7, General arrangement – NOVIMAR Class Va container roro vessel, shallow draft double-end access

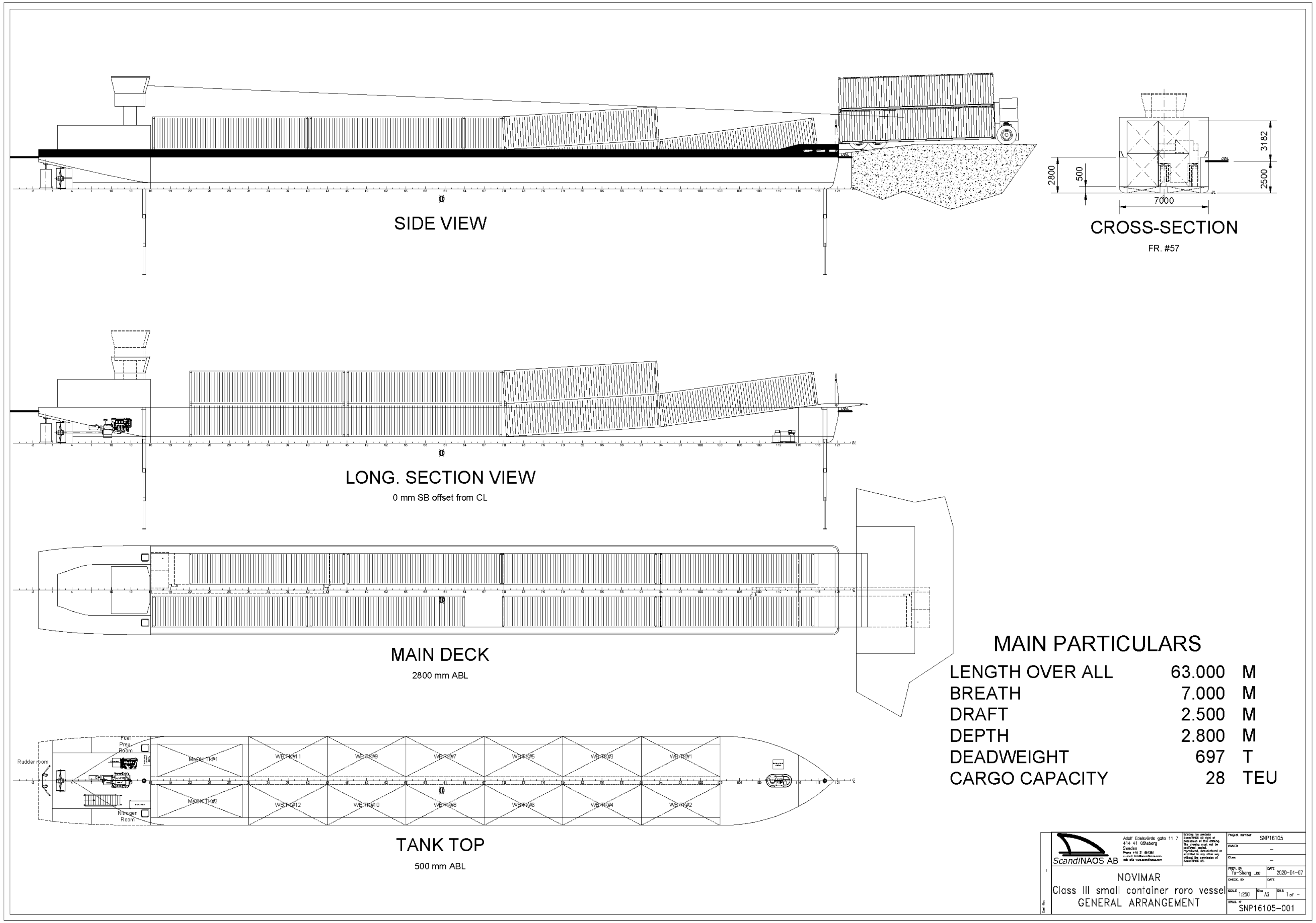


Figure 8, General arrangement – NOVIMAR Class III container roro vessel

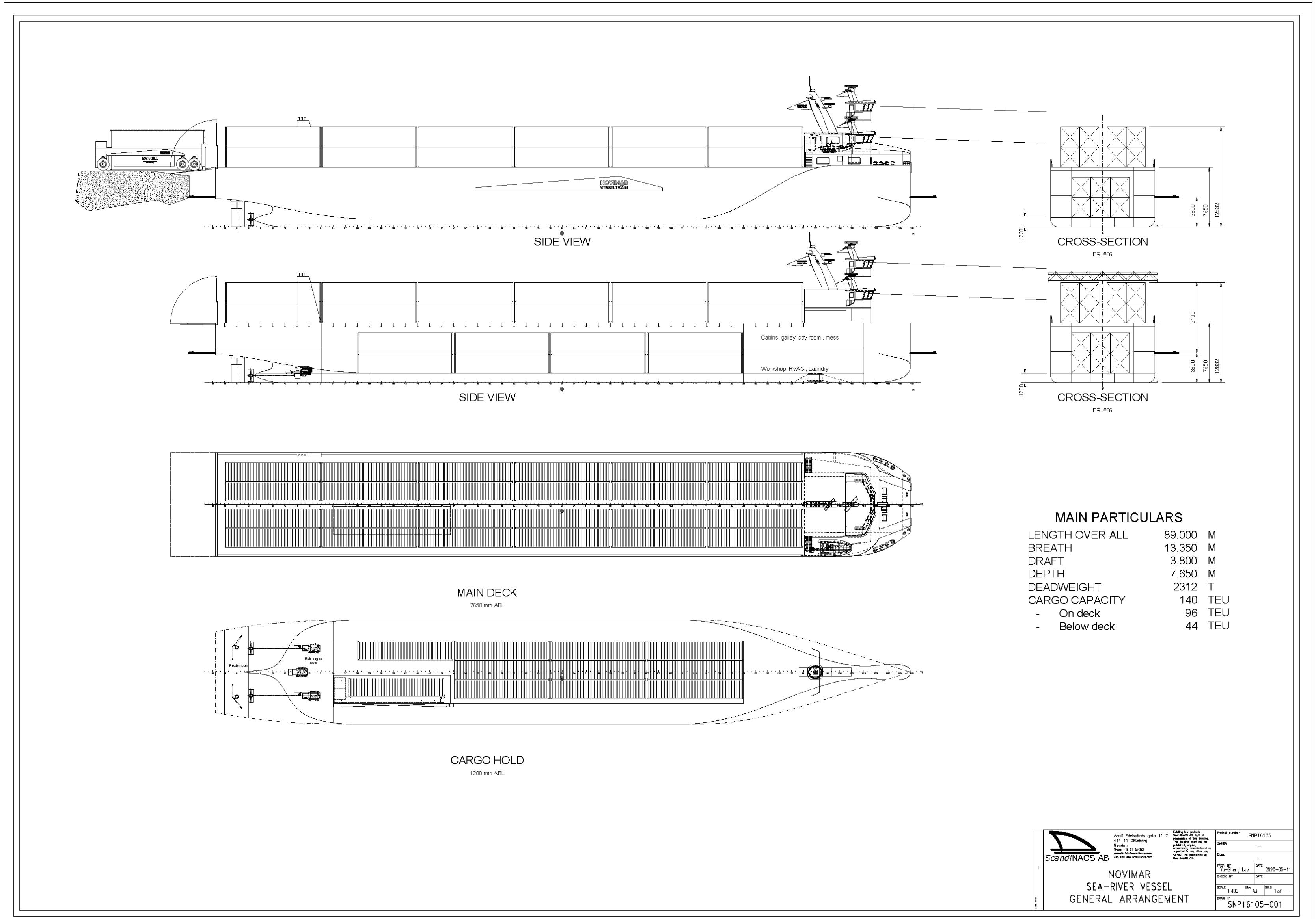


Figure 9, General arrangement – NOVIMAR Sea-river container roro vessel

4.2.3 Main dimensions - General

When selecting the main particulars of inland vessels, in addition to economy considerations and cargo handling equipment features, it is necessary to consider fairway restrictions.

From the economy point of view, it is expected that the large vessels would benefit the most from the VT concept. In line with that, the cargo vessel of the CEMT class Va (L = 110 m, B = 11.4 m) was considered as the lead vessel in the scenario (examined within the Deliverable 1.3 Mid-term assessment, see Hekkenberg et al, 2019) in which the VT was led by a cargo vessel. Therefore, the length of the vessel should be $L \leq 110$ m.

As for the vessel beam, two opposing demands were considered within Task 4.3: to maximize the number of pallet-wide containers (PWC) carried, while staying within the dimensions which enable the vessel to enter the 12 m wide lock chambers, see Ramne and Fagerlund (2019). It was concluded that the optimum in this respect could be achieved with B = 11.45 m. The vertical dimensions of a vessel (draft, depth) are to be decided considering the cargo carrying capacity on the one hand and fairway restrictions (fairway depth, but also the available air draft) on the other hand.

For any vessel operating in the inland waterway, the physical dimensions will be limited by depth and widths of the rivers, locks and canals, the curvature of the river bends as well as the free height (air draft) under bridges. The principal dimensions of the vessels designed in this WP are obtained upon following limitations.

Main dimensions - NOVIMAR Class Va container roro vessel, regular draft

- Length over all: 110 m
- Width: 11,45 m
- Draft, design 3,9 m
- Depth 7,05 m
- Air draft
- Cargo capacity 184 TEU physical positions, average weight 6,0 ton or 47 trailers
- Displacement 4300 ton
- Light ship weight 1013 ton
- Design speed 18 km/h 9,7 knots

The CEMT class Va is a standard design for the river Rhine allowing operation from the North Sea seaports to Basel at normal water depth. Larger vessels and convoys of several class Va vessels can operate on part of the river. The concept developed for the class Va vessel is also applicable for larger inland waterway vessels. Due to the arrangement with roro decks the vessel will have a higher centre of gravity than conventional Class VA container vessels. For this reason, the average container weight for full space utilization will be very low if the ship shall carry dangerous goods and/or unlashed containers since that set certain stability criteria. For operation with non-hazardous cargo and with lashed containers the average container load can be increased see section 4.2.7.

Main dimensions - NOVIMAR Class Va container roro vessel, shallow draft

	Stern access version	Double-end access version
• Length over all:	104 m	104 m
• Width:	11,45 m	11,45 m
• Draft, design	2 m	2 m
• Depth	3 m	3 m
• Air draft	6,5 m	8,9 m
• Cargo capacity	104 TEU a' 11.3 ton or 26 trailers	100 TEU a' 11.8 ton or 24 trailers
• Displacement	2097 ton	2097 ton
• Light ship weight	780 ton	799 ton
• Design speed	18 km/h 9,7 knots	18 km/h 9,7 knots

The shallow draft version of the NOVIMAR Class Va container roro vessel has been designed with the purpose to enable navigation in shallow waters such as parts of the river Danube. Two version of this design has been developed,

1. Cargo access over a stern ramp with a retractable wheelhouse placed forward ("stern access version" concept)
2. Wheelhouse positioned at L/2 elevated above the cargo, with cargo access both over the stern and over the bow allowing drive-through possibilities or double-end loading ("double-end access version" concept)

Main dimensions - NOVIMAR Class III container roro vessel

• Length over all:	63 m
• Width:	7,0 m
• Draft, design	2,5 m
• Depth	2.8 m
• Air draft	
• Cargo capacity	28 TEU (17 ton average) or 47 trailers
• Displacement	968 ton
• Light ship weight	243 ton
• Design speed	18 km/h 9,7 knots

In order to enable waterborne transport as far out as possible in the logistic net, a smaller container roro has been developed. The dimensions of the NOVIMAR Class III container roro vessel similar to the Class III container vessel (Campine class) ((BVB), 2009)(Bureau Voorlichting Binnenvaart, 2016).

Main dimensions - NOVIMAR Sea-river container roro vessel

- Length over all: 89 m
- Width: 13,35 m
- Draft, design 3,8 m
- Depth 7.65 m
- Air draft
- Cargo capacity 140 TEU (12.7 ton average) or 47 trailers
- Displacement 3256 ton
- Light ship weight 944 ton
- Design speed 22 km/h 12 knots

The concept of the Sea-river vessel is to enable direct waterborne transport of goods from an inland port in one part of Europe to an inland port in another part including a short sea voyage. The dimensions for this particular design are chosen to allow the vessel to sail from lake Vänern in Sweden to Duisburg in Germany.

4.2.4 Structure – General

Inland waterway vessels must fulfil the European standard laying down technical requirements for inland navigation vessels (ES-TRIN). The rules provide general structural requirements that “The hull shall be sufficiently strong to withstand all of the stresses to which it is normally exposed”

The rules also state that scantling approved by a recognised classification society will be accepted.

The scantlings of the vessels have been calculated according to

- Bureau Veritas Rules for the Classification of Inland Navigation Vessels (Bureau Veritas, 2019)
- ADN Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways(UNECE, 2019)

The sea river vessel needs to comply with the classification requirements. The scantlings have been calculated according to

- DNV GL rules for classification: Ships (RU-SHIP) and
- Bureau Veritas Rules for the Classification of Steel Ships

Including the additional requirements for container and roro vessels, with a special consideration given to the wheeled cargo loadings.

The frame spacing in the cargo area is chosen to fit container stowage. The distance between each row of 40 feet containers is 24 x 510 = 12 240 mm allowing a regular pattern of reinforced locations on the deck for the container corner fitting. A web frame is fitted at every third frame

The main deck structure scantlings are governed by the loads due to containers and in particular due to wheeled cargo. These loads directly determine the main deck scantlings and, consequently, influence the steel weight. Moreover, the specific construction of the NCHV considerably affects the deck and below deck structural arrangements. From a structural viewpoint, the main feature of the NCHV is an asymmetric four-wheel arrangement that transmits the total load (from two FEU containers and vehicle weights) to the tyres and further to the deck structure, while moving. Otherwise, the deck scantlings would be determined according to the container supporting points.

An initial steel weight can be estimated with formulas based on statistical data. This estimate will be reasonably accurate for conventional vessels with main dimensions that do not deviate from typical designs. Vessel design for roro handling can be assumed to be heavier than container vessels of same size since the deck beam, stiffener and plating need to be dimensioned considering the wheel loads of the rolling cargo and the cargo handling vehicles.

Structure - NOVIMAR Class Va container roro vessel

Regular draft

The high depth of the ship and the closed cross section at midship, are in general good conditions for weight efficient global scantling of the hull beam. However, the lower deck and main deck have to be dimensioned for the container loading as well as wheel load from the handing vehicle. This increases the steel weight and the light ship weight compared to a conventional CEMT class Va container vessel.

To handle the wheel loads from the NCHV the double bottom will have a plate floor on every frame and in order to have good access to the stowing position in the lower hold it will not be possible to have any pillars to support the deck beams. This means that the deck beams need to be dimensioned to span the full width of the cargo hold´.

Steel weight of approximately 811 tis predicted based on the estimated scantlings.

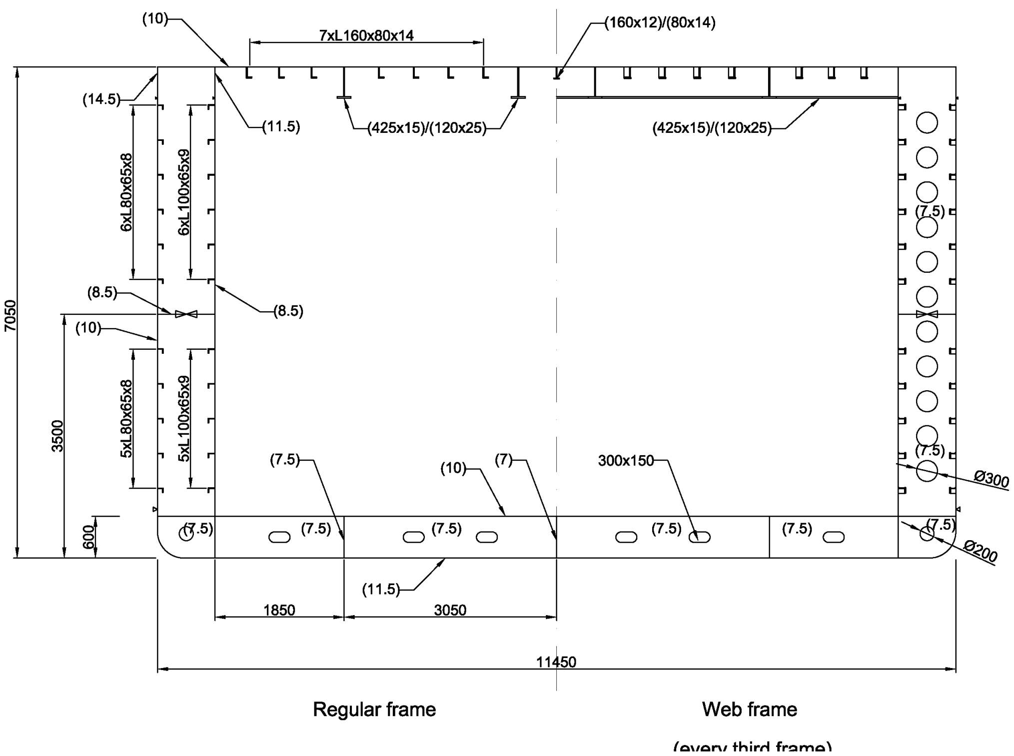


Figure 10, NOVIMAR Class Va container roro vessel, regular draft - mid ship section

Shallow draft

Since the length-to-depth ratio of the vessels (*L/D* = 34.6) is at the upper limit of the applicability of classification rules (*L/D* < 35), the vessels could be considered as unusual from the structural point of view. In such cases, the structural design implies using direct calculations. Therefore, in addition to the standard rule-based procedures, the structure of the vessels was designed following the direct longitudinal strength and buckling calculations.

Furthermore, it is reasonable to assume that the approximate formulas used for lightweight estimation of inland cargo vessels may not be applicable to hereby developed concepts. Therefore, one of the outcomes of the structural design is a more precise steel weight estimation, and consequently, a more accurate lightweight estimation.

It should be noted that the structure of both shallow draft class Va vessels is almost identical, apart from minor local differences. The vessels are longitudinally framed with web frame spacings of 1530 mm to allow alignment of the transverse elements with container corners. Longitudinal stiffeners are positioned at a distance between 465 mm and 600 mm (500 mm for majority of the elements). Both the primary and secondary members are placed in a way of supporting the concentrated loads of container stacks. The double bottom height is 600 mm in midships and 500 mm in the engine room rising some technological difficulties. The double side width is 800 mm. Normal frames and the web frames are shown in Figure 11 and Figure 12, respectively, and compared in Figure 13. The estimated steel weight of the vessels is 631 t.

The estimated steel weight was compared with the value calculated with the advanced “rule of thumb” formulas devised by Hekkenberg (2012). Using those formulas for longitudinally framed container vessels, the steel weight was estimated to 535 t. Such a considerable difference can be explained by the fact that both the double-end access vessel and stern access vessel are not the standard Lo-Lo handling container vessels, but Ro-Ro vessels intended to carry unitized cargo. Hence, these are closed deck structures with additional longitudinal bulkheads, whose scantlings are considerably influenced by the wheeled cargo loads.

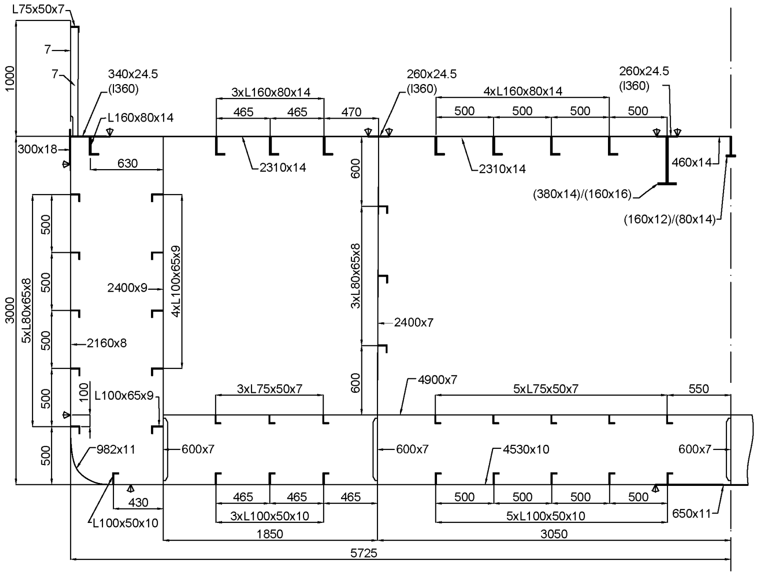


Figure 11. NOVIMAR Class Va container roro vessel, shallow draft - mid ship section Normal frame of the vessels

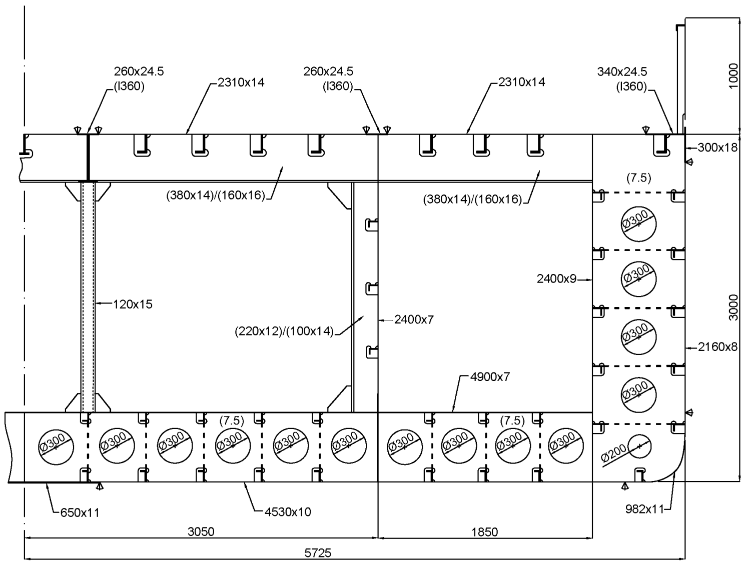


Figure 12. NOVIMAR Class Va container roro vessel, shallow draft - mid ship section Web frame of the vessels

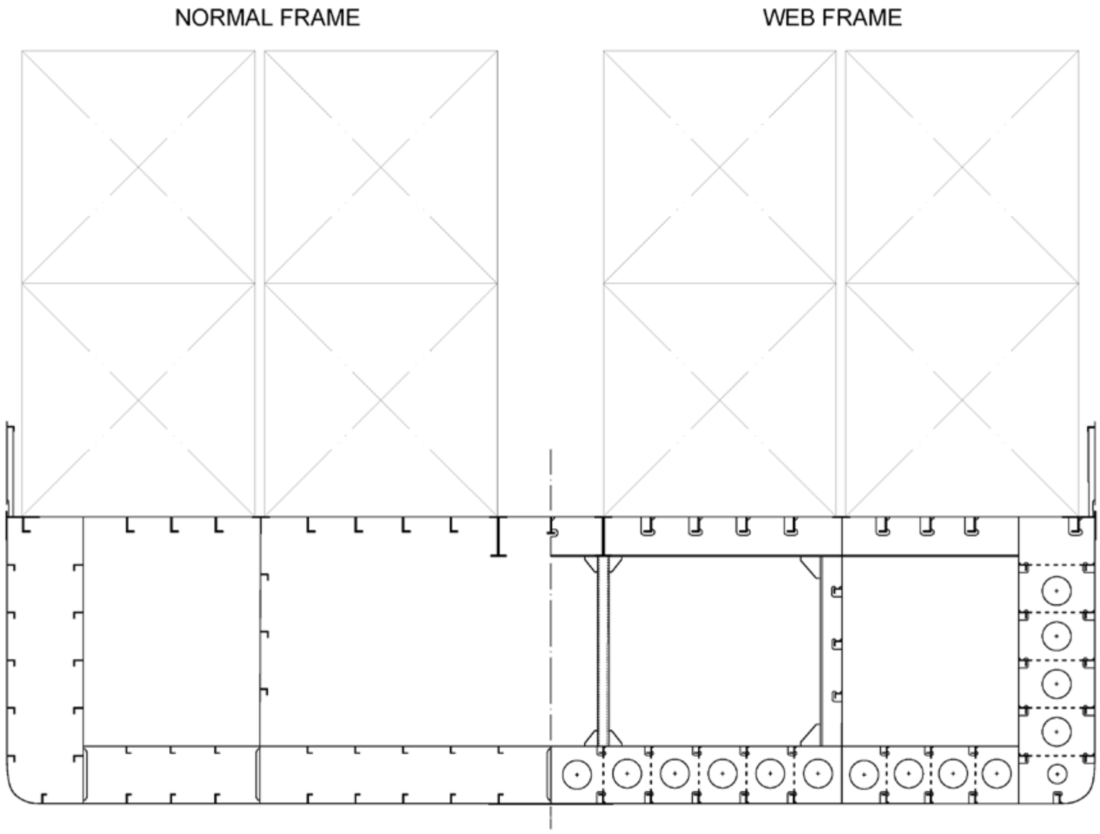


**Figure 13. NOVIMAR Class Va container roro vessel, shallow draft,
Comparison of the normal frame and the web frame of the vessels**

Given atypical features of the developed designs (asymmetric NCHV, high *L/D*), it would be advisable to perform some additional assessments using finite element method.

Structure - NOVIMAR Class III container roro vessel

The midship section of the NOVIMAR Class III container roro vessel is quite similar to a conventional container vessel of this size. The vessel has an open cargo hold with a double bottom height of 500 mm and a depth to main deck of 2800 mm. The double bottom has floor on each frame to support the container and wheel loading from the NCHV. The forward part of the cargo hold is a ramp leading to the main deck level. The ramp part has longitudinal scantling with a deck beam on every third frame.

Steel weight approx. 187 tons based on the estimated scantling.

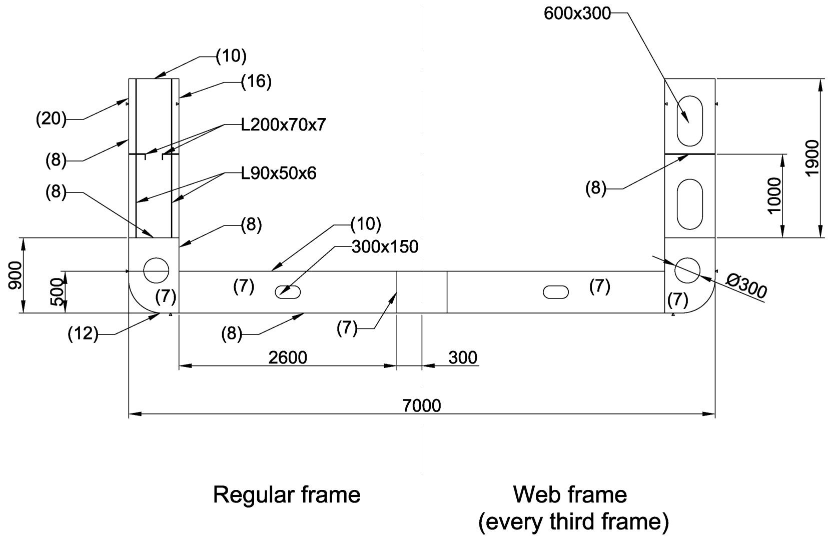


Figure 14, Figure 16. NOVIMAR Class III container roro vessel, mid ship section

Structure - NOVIMAR Sea-river container roro vessel

The structural design principles of the sea-river container roro vessel are similar to the structure of a short sea roro vessel. The sea-river vessel is much smaller than a typical short sea roro vessel.

The side tanks under the main deck are required to meet the probabilistic damage stability requirements. The crosstie between the longitudinal bulkhead and the ship side reduces the dimension in the web frames. The deck, double bottom and tank top are longitudinally stiffened with a web frame on every third frame. The ship is too short to have an internal ramp to the lower hold so the cargo space below deck will be serviced by a cargo elevator. The deck plating of the elevator deck needs to be flush with the tank top deck to transfer the vehicles between the elevator and the deck. For this reason, the double bottom needs to be high enough to fit the structure of the cargo elevator.

Steel weight approx. 756 tons based on the estimated scantling.

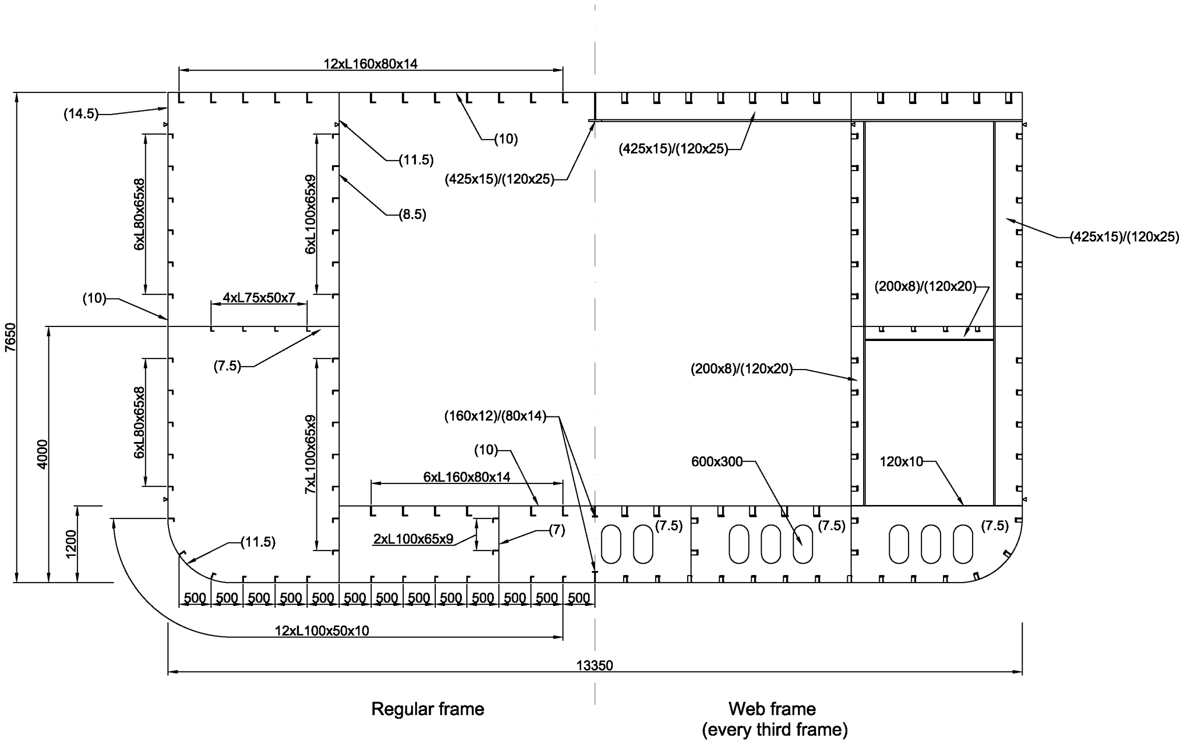


Figure 15, NOVIMAR sea-river container roro vessel, mid ship section

4.2.5 Stability - General

In course of development of vessels for the vessel train, it is necessary to verify the compliance of the concepts with intact and damage stability requirements of relevant authorities.

For the inland waterway vessel the intact stability of the vessels was calculated according to the requirements of the Chapter 27 (Special provisions applicable to vessels carrying containers) of ES-TRIN (European Standard laying down technical requirements for Inland Navigation vessels), see (CESNI, 2019). In brief, the rules stipulate that the minimal metacentric height of the vessel carrying unsecured containers should be 1 m, while the static angle of heel of the vessel due to simultaneous action of beam wind and turning, taking into account the effect of free surfaces, should not be greater than 5 degrees or the angle at which deck becomes submerged (whichever is the less).

The Sea river vessel need to comply with the IMO SOLAS rules Part 1, Chapter II-1 Part B Subdivision and stability since it is a sea going ship larger than 500 GT engaged on international voyages.

In ES-TRIN Ch- 27 Special provisions applicable to sea-going vessels it is stated that "Chapter 27:

Chapter 27 shall be deemed to have been complied with when stability complies with current IMO Resolutions, the corresponding stability-related documents have been endorsed by the competent authority and the containers are secured in the customary maritime navigation manner."

I.e. if the ship complies with IMO stability requirements it also complies with the ES-TRIN requirements.

The outcome of intact stability calculations is expressed in form of maximum allowable vertical centre of gravity of the vessel at design draft, $KG_{max.}$ The KG_{max} values for each design are presented in subsequent sections.

Since the vessels are specified to carry dangerous goods, they need also to comply with relevant rules for damage stability. For the inland waterway vessels, the damage stability calculations are performed following the requirements of the Chapter 9.1 (Rules for construction of dry cargo vessels) of ADN (European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways), see UNECE (2019).

For the sea-river vessel the damage requirements are defined in SOLAS chapter II-1.

Stability - NOVIMAR Class Va container roro vessel

The outcome of intact stability calculations is expressed in form of maximum allowable vertical centre of gravity of the vessel at design draft, KG_{max}. In Table 1, the actual values of KG attained when the vessels are fully loaded with two and three tiers of containers are compared to KG_{max}. From the shallow draft designs, the stability is verified in two hypothetical scenarios. In the first scenario, KG values of the vessels correspond to the loading cases in which containers have equal weight. It is shown that even in such cases, the attained vertical centre of gravity is far below the allowable maximum. The goal of the second scenario is to find the most unfavourable vertical distribution of (realistic) container weights in which the requirements of intact stability criteria would still be met. It is shown that KG_{max} could be attained only in loading cases in which heavy containers would be placed atop of the empty ones. It may be concluded that, as far as intact stability is concerned, there are no practical limitations in loading (at design draft).

Table 1. Intact stability assessment

Regular draft		**equal weight**					
Vessel	KG_{max}	Tiers	m_{TEU} [t]	KG [m]			
Loading 4 tiers 184 TEU	4.195	1. 2. 3. 4.	6 6 6 6	4.168			
Loading 3 tiers 126 TEU	3.965	1. 2. 3.	12.5 12.5 12.5	3.911			
Shallow draft		**equal weight**			**most unfavourable**		
Vessel	KG_{max}	Tiers	m_{TEU} [t]	KG [m]	Tiers	m_{TEU} [t]	KG [m]
Double-end access 100 TEU	5.637	1. 2.	11.8 11.8	3.975	1. 2.	2 21.6	4.548
Double-end access 146 TEU	5.517	1. 2. 3.	8.4 8.4 8.4	4.563	1. 2. 3.	2 5 20.8	5.513
Stern access 104 TEU	5.637	1. 2.	11.3 11.3	3.845	1. 2.	2 20.7	4.45
Stern access 152 TEU	5.510	1. 2. 3.	7.8 7.8 7.8	4.507	1. 2. 3.	2 3.1 19.1	5.509

To reach the maximum cargo capacity, with cargos on the deck (3rd and 4th tier), the vessel requires large amount of ballast water in the double bottom and wing tanks to reach the GM = 1 m requirement. Also, the 4th tier container positions are suitable for light or empty containers only.

The NOVIMAR cargo handling vehicle improves the stowage density compared to other roro handling alternatives i.e. less space is lost since the container can be blockstowed and the need for intermediate cargo carrying units such as cassettes and roll trailers, are eliminated. However, it still requires a full width main deck. The weight and the height of the main deck raises the vertical centre of gravity of the lightship and the cargo. This has negative effects on the stability and reduces the payload weight in the containers.

Damage stability calculations are performed following the requirements of the Chapter 9.1 (Rules for construction of dry cargo vessels) of ADN (European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways), see UNECE (2019). The regulations prescribe the extents of the side and the bottom damage and require the verification of compliance with the damage stability standards in case of flooding of two (or more) adjacent compartments. In the final stage of flooding the angle of static equilibrium should not be greater than 5 degrees, the openings which cannot be closed watertight should not be submerged, and the area under the *GZ* curve of the damaged vessel should attain a prescribed quantity. Tank arrangement plans are given in the Annex D.

The outcome of damage stability calculations is expressed in form of maximum allowable vertical centre of gravity of the vessel at design draft, KG_{max}. In Table 2, the actual values of *KG* attained when the shallow-draft vessels are fully loaded with two and three tiers of containers are compared to KG_{max}. In a scenario in which containers have equal weight, the damage stability requirements cannot be met when vessels load three container tiers. In addition, the double-end access vessel only marginally fulfils the damage stability criteria in case of uniform distribution of weight in two container tiers. In order to attain appropriate vertical centre of gravity on the double-end access vessel, containers in the third tier should be empty and care should be taken when loading the first two tiers.

Table 2. Damage stability assessment (prior to the modification of the subdivision)

Shallow draft		equal weight			most unfavourable		
Vessel	KG_{max}	Tiers	m_{TEU} [t]	*KG* [m]	Tiers	m_{TEU} [t]	*KG* [m]
Double-end access 100 TEU	3.980	1. 2.	11.8 11.8	3.975	1. 2.	11.8 11.8	3.975
Double-end access 146 TEU		1. 2. 3.	8.4 8.4 8.4	4.563	1. 2. 3.	13.3 8.7 2	3.980
Stern access 104 TEU	4.355	1. 2.	11.3 11.3	3.845	1. 2.	3.6 19.1	4.350
Stern access 152 TEU		1. 2. 3.	7.8 7.8 7.8	4.507	1. 2. 3.	9.1 8.1 6	4.353

Therefore, in order to improve the damage stability, the subdivision of the shallow-draft vessels was moderately modified by inserting two additional watertight floors in the double bottom and the double sides of the vessels. The modifications of subdivision on double-end access and stern access vessels are given in Figure 16 and Figure 17 respectively. Maximum allowable vertical centre of gravity of the modified vessels at design draft is given in Table 3. It may be noticed that the vessels still cannot meet the damage stability requirements in case of uniform vertical distribution of cargo in three tiers. Nevertheless, in such cases, it is much easier to attain the required value of *KG* with a realistic distribution of cargo. Furthermore, the stability margin of the double-end access vessel with two container tiers is now much greater.

Table 3. Damage stability assessment (after the modification of the subdivision)

Regular draft		**equal weight**			**Non-equal weight**		
Vessel	KG_{max}	Tiers	m_{TEU} [t]	KG [m]	Tiers	m_{TEU} [t]	KG [m]
Loading 4 tiers 184 TEU	3.88	1.	*4.6*	3.863	1.	*24.0*	*3.863*
		2.	*4.6*		2.	*24.0*	
		3.	*4.6*		3.	*11.8*	
		4.	*4.6*		4.	*2.0*	
Loading 3 tiers 124 TEU	3.88	1.	*13.5*	3.880	1.	*24.0*	*3.853*
		2.	*13.5*		2.	*24.0*	
		3.	*13.5*		3.	*14.8*	
Shallow draft		**equal weight**			**most unfavourable**		
Vessel	KG_{max}	Tiers	m_{TEU} [t]	KG [m]	Tiers	m_{TEU} [t]	KG [m]
Double-end access 100 TEU	4.383	1.	11.8	3.975	1.	4.9	4.378
		2.	11.8		2.	18.7	
Double-end access 146 TEU		1.	8.4	4.563	1.	10	4.378
		2.	8.4		2.	8.5	
		3.	8.4		3.	6.4	
Stern access 104 TEU	4.382	1.	11.3	3.845	1.	3.1	4.380
		2.	11.3		2.	19.6	
Stern access 152 TEU		1.	7.8	4.507	1.	8.9	4.380
		2.	7.8		2.	8	
		3.	7.8		3.	6.3	

For non-equal weight containers, the class V regular draft vessel is limited by the intact stability requirement of 1 m, instead the KG_{max} from damage stability.

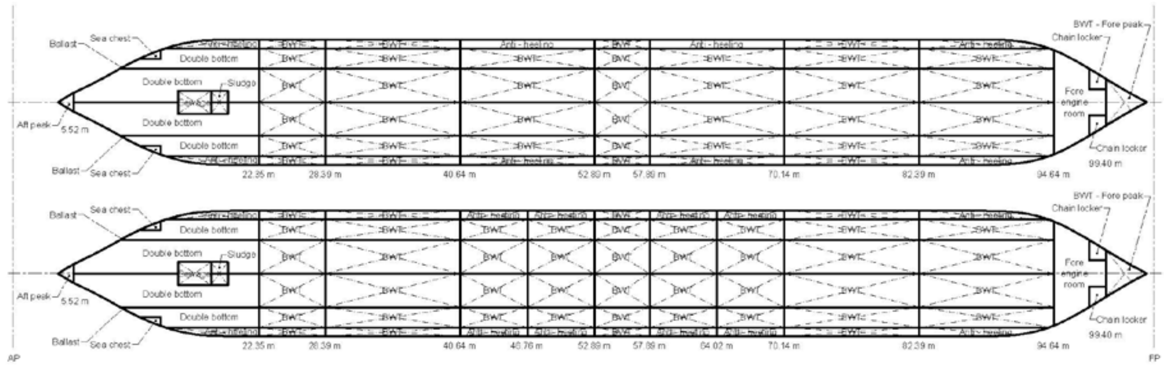


Figure 16. Original (upper image) and modified (lower image) subdivision of the shallow-draft double-end access concept

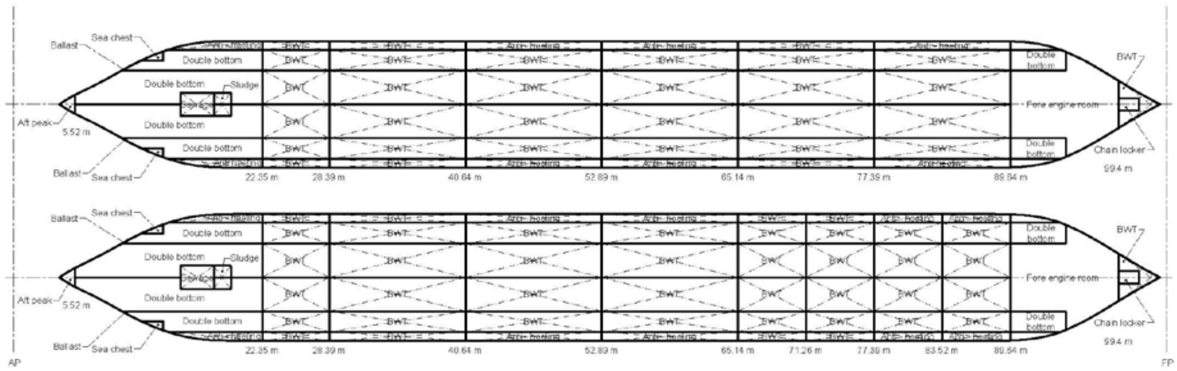


Figure 17. Original (upper image) and modified (lower image) subdivision of the shallow-draft stern access concept

Stability - NOVIMAR Class III container roro vessel

The NOVIMAR Class III container roro vessel will have a KG_{max} = 1.9 m to fulfil the intact stability requirements for stowage of unlashed containers. This will give an average weight of 17 tons per TEU.

Stability - NOVIMAR sea-river container roro vessel

Since the NOVIMAR sea-river container roro vessel will also operate a short sea leg the containers need to be lashed. The average weight of the container is then 12.7 TEU.

4.2.6 Cargo handling - General

The cargo handling concept is based on horizontal loading and unloading of cargo, i.e. roro handling. The vessels have been designed to fully accommodate the functionality of the NOVIMAR container handling vehicle (NCHV) that was developed in task 4.3 and described in NOVIMAR Deliverable 4.3 Cargo systems development (Ramne, Bengt Fagerlund, 2019b).

A roro concept is based on the commercial principle that the cargo owner has a large degree of freedom to present his cargo in a way convenient for him. This may be general cargo (unitized or not) like sawn timber bundles, logs, engine parts in wooden boxes or not, machines on wheels like tractors or entrepreneur machines and road trailers, etc. Especially for the general cargo sector, the roro possibility on inland waterways opens doors to a market segment that today almost entirely goes on rail or road from ocean port to hinterland and reverse.

By utilizing the NOVIMAR concept, a container can be rolled on and off the ship and efficiently stowed. This enables fast and cost-efficient cargo handling as well as a combination of containers and rolling cargo such as trailers, trucks and cars.

The principal concept of the NCHV is that it lifts the container directly from the ground connecting the lifting frame to the door end and the right side of the container (right hand version of the NCHV). The benefit of NCHV is that this eliminates the need for an intermediate platform (cassette or terminal trailer) for horizontal handling of the containers and it enables a compact block-stow in the ship. It is desirable that the stowage pattern onboard the ship is as symmetrical as possible to avoid heel or the need for ballast water compensation. The best way to load the vessels symmetrically is to use both right-hand versions and left-hand versions of the NCHV. This will leave an access way in the centre of the cargo space.

It is also possible to achieve symmetric loading pattern with only one type of NCHV. In this case the NCHV will go in reverse onboard the ship with 50% of the containers. However, this will require that some of the deck space is reserved for the manoeuvring of the NCHV.

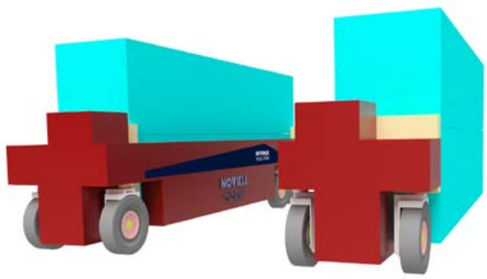


Figure 18, Right-hand and left-hand version of the NOVIMAR container handling vehicle, NCHV

Lashing

From operation point of view, it is preferred to reduce the need of lashing to a minimum. For the inland waterway vessels, the stability requirements (e.g. min GM) are higher for unlashed cargo (GM_{min} = 1.0 m) than if the cargo is lashed (GM_{min} = 0.5 m). This means that for certain services lashing of the containers will provide a higher cargo carrying capacity.

For the sea-river vessel the cargo must be lashed on the short sea leg of the voyage.There are several options to arrange the lashings for the container roro vessels. Since the height is limited to 2 tiers in each pack, the containers can be secured by means of twist locks between the tiers and also between the bottom tier and the deck. By placing the container leaving a 600 mm gap in longitudinal direction between each pack, lashing rods can be attached as an alternative to twist locks.

Cargo handling - NOVIMAR Class Va container roro vessel, regular draft

The cargo is loaded over a full width (11.2 m) bow ramp leading to the main deck. A side hinged watertight ramp cover is fitted on the forward port side of the main deck. When the ramp cover is opened, access is provided to the lower hold via a fixed 4 m wide ramp.

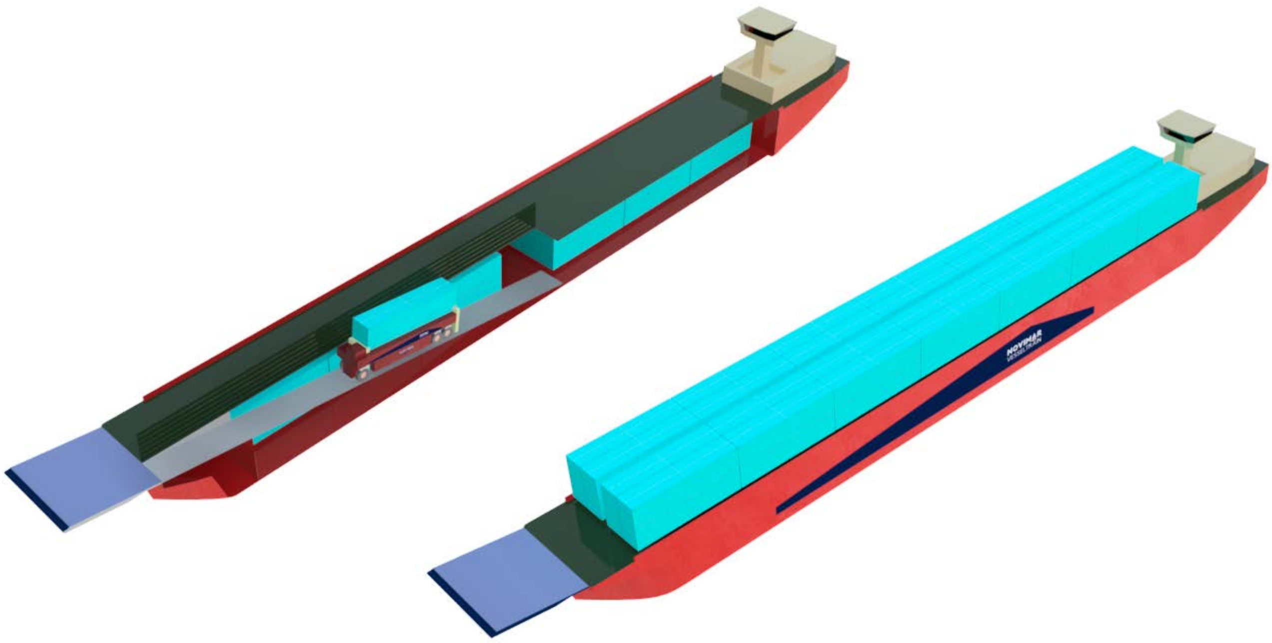


Figure 19, NOVIMAR Class Va container roro vessel, regular draft - access to the cargo space

Cargo handling - NOVIMAR Class Va container roro vessel, shallow draft

For the stern access version a 5.8 m wide stern ramp provides access to the cargo deck. For the double-end access version both a stern ramp and a bow ramp provides access to the cargo deck. If this is combined with two cross transfer platforms, CTPs a very quick turnaround of the vessel can be achieved.

The Trapist project (Bengt Ramne, 2004) showed that a roro handling vehicle needs about 4 minutes (15 cycles per hour) to make a complete loading/unloading cycle “stack-ship-stack”. This can be compared to a container crane that can make 30 cycles per hour “quay-ship-quay”. The container crane needs to be complemented by 2-3 reach stackers or straddle carriers to move the containers between the quay side and the container stacks.

Assuming that each move (cycle) of the container cranes takes one 40 feet container (2 TEU), this will give a handling capacity of 60 TEU per hour. Each move of the NOVIMAR cargo handling vehicle, NCHV will take two 40 feet containers which equals four TEU. This also adds up to a handling capacity of 60 TEU per hour. This means that one NCHV will provide the same capacity as the combination of one container crane and 2-3 reach stackers/straddle carriers. The cost of the NCHV is much lower both for CAPEX and OPEX.

An IWW vessel is too small to be serviced by more than one container crane but it is possible to operate several NCHV simultaneously in a roro operation. THis provides a potential to significantly increase the cargo handling capacity by using roro handling.

With two NCHV servicing each ramp, 100 TEUs on the stern access version can be fully unloaded and loaded in less than 2 hours and in the double-end access version in less than 1 hour, without the assistance from any other cargo handling equipment

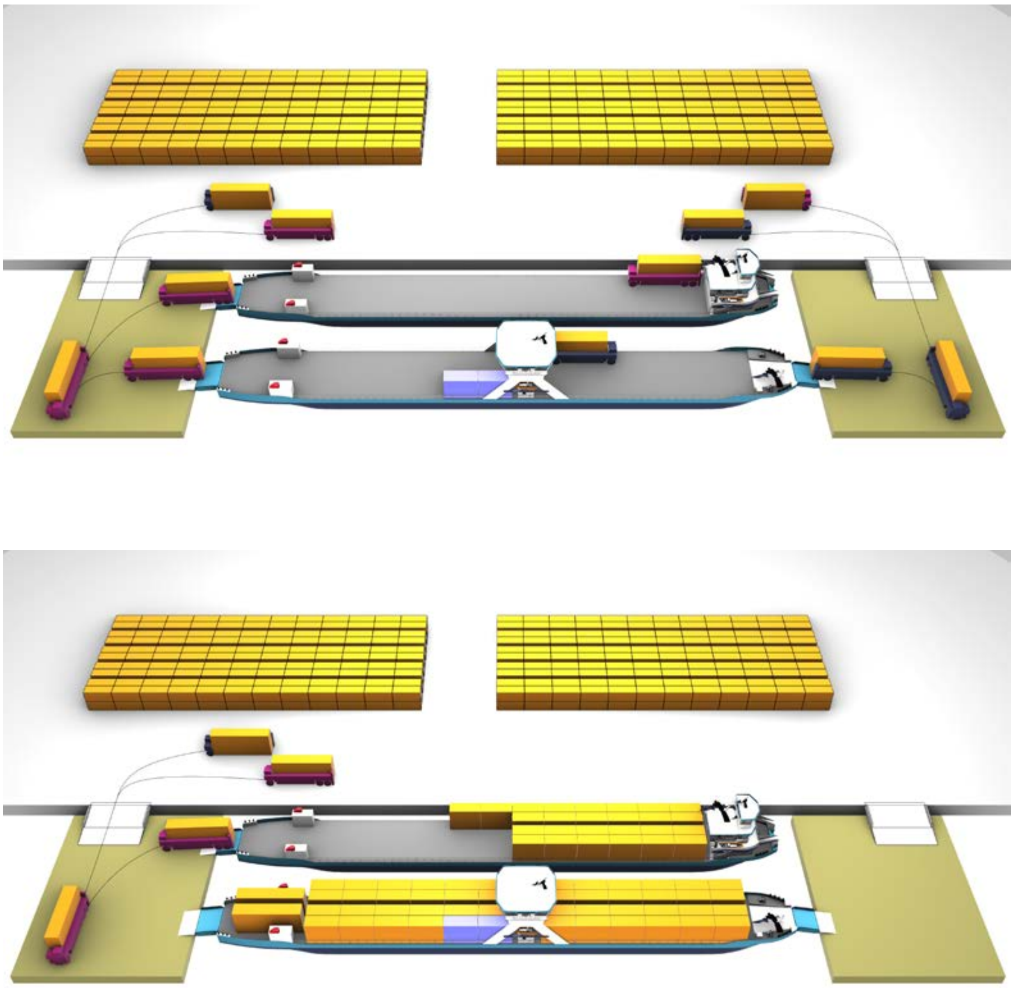


Figure 20. NOVIMAR Class Va container roro vessel, shallow draft - Loading of the vessels (click to see the supplementary video).

On both the double-end access and stern access vessel the third tier could be loaded (see Figure 21) with an appropriate means of vertical container handling (and stability check).

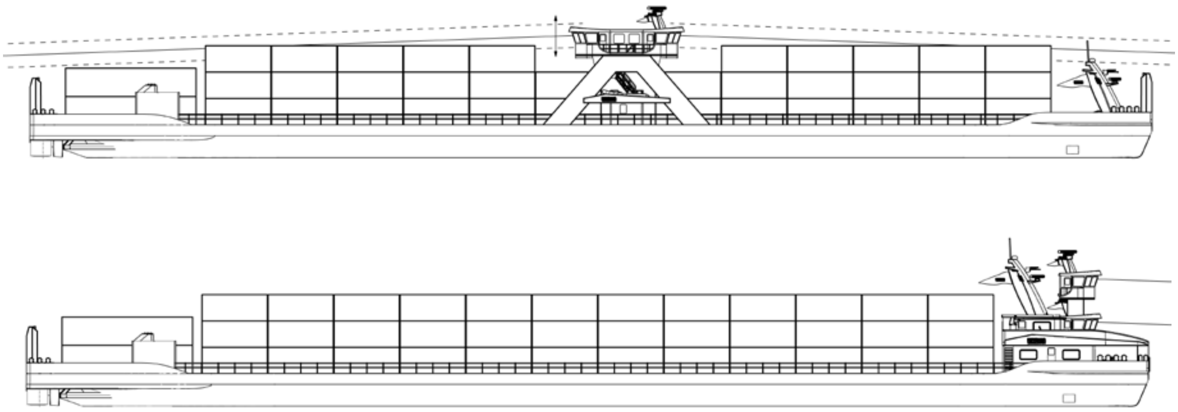


Figure 21. Side view of the developed concepts with three container tiers

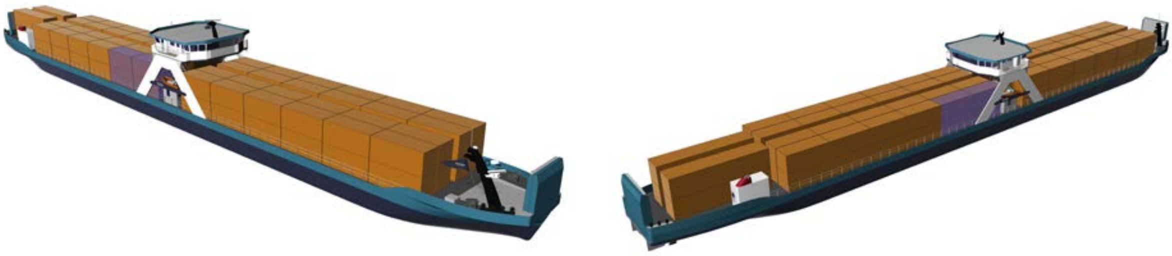


Figure 22. Bow and stern view of the “double-end access version” concept

Figure 23. Bow and stern view of the “stern access version” concept

Cargo handling - NOVIMAR Class III container roro vessel

At the most forward container position, there will only be one container layer in order to have a good bridge visibility.

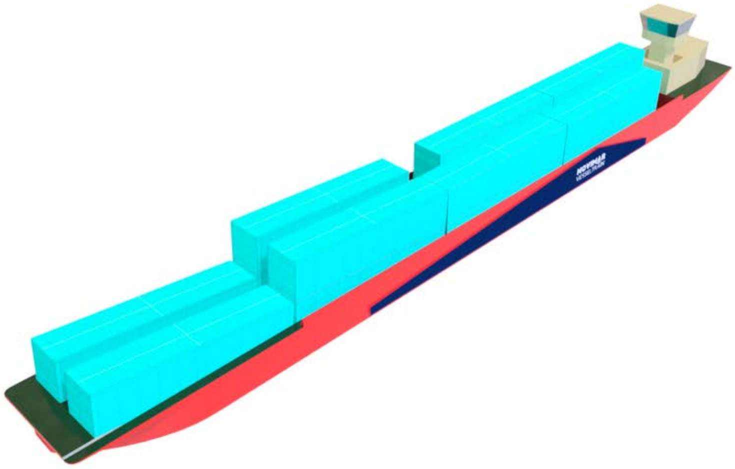


Figure 24, NOVIMAR Class III container roro vessel – container stowage

Cargo handling - NOVIMAR Sea-river container roro vessel

The NOVIMAR sea-river container roro vessel can be considered as a very small short sea roro vessel loading two tiers of containers in the lower hold and two tiers on the main deck.

The cargo access is provided via a stern ramp and a cargo elevator that transfers the cargo and the handling vehicle between the main deck and the lower hold. The vessel is too short to arrange a ramp to the lower hold which otherwise would have been preferred from cargo handling point. The deck of the lower hold is at 1200 abl. It needs to be flush with the deck of the cargo elevator deck. When the cargo hold is loaded, the watertight hinged type hatch cover on the main deck will be closed flushed.

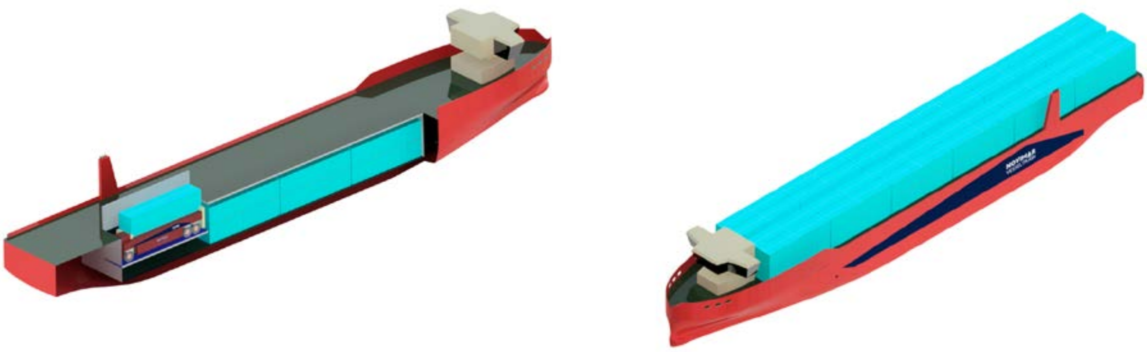


Figure 25, Cargo elevator on the NOVIAR Sea-river container roro vessel

4.2.7 Cargo capacity - General

The container roro vessels developed for the NOVIMAR concept will inevitably have lower cargo carrying capacity compared to a conventional container vessel with similar main dimensions. The ability to load over a ramp allows for fast and comparably inexpensive cargo handling operation. The challenge is to get as close to the capacity of the conventional container vessel as possible so that the benefits of the cargo handling are not off-set by the lower cargo carrying capacity.

When it comes to vessel performance in a transport system, the main feature is cargo carrying capacity. Cargo carrying capacity is not only a matter of the available cargo space, the vessels must also be able to meet the stability criteria with container weights that are relevant for the intended service. Whether the ship shall carry dangerous goods or sail with unlashed containers, affects the maximum weight and allowable maximum vertical centre of gravity.

Cargo capacity - NOVIMAR Class Va container roro vessel

A conventional Class Va container vessel can load four ties of containers on the tanktop deck, typically positioned 600 mm above baseline, ABL. With four tiers, the regular vessel has cargo space for 192 TEU in four container tiers. Since the NCHV is limited to handle one double stacked pack of containers the regular draft versions of the NOVIMAR Class Va container roro vessel have two cargo decks. The lower cargo deck is the tanktop deck, the upper deck is the watertight bulkhead deck located 7050 mm above base line. The two-deck concept will provide physical space for 184 TEU. This is a reduction by approx. 10% but the cargo carrying capacity is reduced more due to the higher VCG of the cargo.

The shallow draft versions of the NOVIMAR Class Va container roro vessel have one cargo deck. The cargo deck is located 3000 mm ABL. With two tier loading by the NCHV, the capacity is 100 - 104 TEU which is about 50% of a conventional container vessel and 45% less than the regular draft NOVIMAR class Va design, but the reduction in actual cargo carrying capacity can be much less. The NOVIMAR Class Va, shallow draft vessel has also the ability to load a third tier by means of a container crane. This will take away some of the benefits with the roro concept but increase the capacity, if needed. Furthermore, the stern access shallow-draught vessel would be able to expand cargo carrying capacity by forming a pushed convoy with a barge, when the vessel sails out of VT.

Another important factor for the actual cargo carrying capacity is whether the vessel shall be able to carry dangerous goods. For cargo vessels not designed to carry dangerous goods the stability criteria are simpler and only based on intact stability. To allow transport of dangerous goods, the vessel need also to comply with damage stability rules which might impact the cargo carrying capacity.

Which version that provides the highest overall performance will depend on a large number of factors such as average container weight, container weight distribution, ability to transport dangerous goods as well as available time in terminals and the cargo handling equipment.

Table 4, Capacities of different CEMT class Va size container vessels designed to transport dangerous goods

	CEMT Class Va size container vessel					
	NOVIMAR roro					
	Regular draft					
	Bow access		Double-end access		Stern access	
	3 tiers	4 tiers	2 tiers	3 tiers	2 tiers	3 tiers
TEU capacity	124	184	100	146	104	152
Average TEU weight	13.5	4.6	11.8	8	11.3	7.8
Total cargo weight	1674	846	1180	1139	1186	1186
Trailer capacity	46		24		26	

Table 5, Capacity of NOVIMAR Class Va, regular draft container roro vessel <u>not</u> designed to transport dangerous goods with unsecured (unlashed) containers

	NOVIMAR roro	
	Regular draft	
	4 tiers	3 tiers
TEU capacity	184	124
Average TEU weight, uniform loading	6	14.7
Total cargo weight, uniform loading	1104	1823
Trailer capacity	46	

Table 6, Capacity of NOVIMAR Class Va, regular draft container roro vessel <u>not</u> designed to transport dangerous goods, but secured (lashed) containers

	NOVIMAR roro	
	Regular draft	
	4 tiers	3 tiers
TEU capacity	184	124
Average TEU weight, uniform loading	7.9	22.3
Total cargo weight, uniform loading	1454	2765
Trailer capacity	46	

Cargo capacity - NOVIMAR Class III container roro vessel

Table 7, Capacities of NOVIMAR roro, small size inland container vessel

	NOVIMAR roro
TEU capacity	28
Average TEU weight, uniform loading	19
Total cargo weight, uniform loading	532

Cargo capacity - NOVIMAR Sea-river container roro vessel

Table 8, Capacities of NOVIMAR roro, sea-river vessel

	NOVIMAR roro
TEU capacity	140
Average TEU weight, uniform loading	12.7
Total cargo weight, uniform loading	1778

4.2.8 Machinery and propulsion – General

The propulsion system of the ships shall provide enough thrust power to reach the specified maximum speed at specified engine part load with relevant margins for added resistance. The designs have been made aiming to reduce the required thrust power by careful design of the hull form and the propulsor system while not compromising any safety aspects.

There is an ongoing development of new technology for the machinery and propulsion system. E.g electric propulsion can appear to be very attractive with low noise and no emissions onboard. The electricity can be supplied either from batteries or generated by fuel cells. The electric drive technology is today available for small cars but for heavier road transport there are still significant technology steps required to reach sufficient power density and energy storage. For waterborne transport, with even higher demand for propulsion power and energy storage capacity, the combustion engine will still be the best option for the next generation inland waterway vessels.

For waterborne transport to be a sustainable alternative to road transport, the emissions must not exceed the emissions from road transport calculated per transported unit. It is easier and more cost efficient to apply the clean propulsion technology to a ship than to a truck since the ship in general transports more units per engine installation and has more space available for exhaust gas cleaning installations and storage of alternative fuels (most alternative fuels requires larger storage volume).

With synthetic diesel oil alternatives such as HVO together with exhaust gas treatment systems for reducing NOx and particulate matter, PM a conventional diesel engine installation can provide a good environmental and climate performance. From the conventional design it will only require minor modifications to fuel storage, fire protection and detection systems to make the installation suitable for an alternative fuel such as methanol or ethanol. This is relevant since the potential for sustainable production of large volumes of alcohols is much higher than for synthetic diesel oil alternatives.

To enable implementation of new technologies and also to enable a higher degree of power optimization, a hybrid propulsion system has been considered for the NOVIMAR vessel designs. The hybrid propulsion plant has been specified with direct mechanical combustion engines complemented with a power take in (PTI). The PTI has been arranged as a direct drive permanent magnet shaft generator/motor with the propeller shaft as the rotor.

The hybrid concept has many potential benefits

1) With a limited battery capacity, it increases efficiency of the combustion engines because they can work at optimum part load condition
2) With larger battery capacity it can utilize shore power charging where available for limited zero emission operation.
3) Combined with a fuel cell it enables full zero emission operation.
4) The battery can also be used for driving the bow thruster, instead of installing and operating an additional generator.

Table 9, Summary of propulsion system data

	Class Va container roro, regular draft	Class Va container roro, shallow draft	Class III container roro	Sea river container roro
Engine type	Multi fuel	Diesel or multi fuel	Multi fuel	Multi fuel
Installed power	1350 kW	1125 kW	450 kW	1350 kW
Engine rpm,	1800	1600	1800	1800
Number of ME	2	2	1	2
Aux engine power	450 kW	450 kW	150 kW	450 kW
No of aux engines	1	1	1	1
Shaft generator/motor	PTI/PTO	PTO	PTI/PTO	PTI/PTO
Number of propellers	2	2	1	2
Number of rudders	2	2	1	2
Propeller diam	1550 mm	1550 mm	1550 mm	1550 mm
Type of propeller	Ducted, CPP	Ducted, CPP	Ducted, CPP	Ducted, CPP
Vessel sped	18 km/h 9,7 knots	18 km/h 9,7 knots	18 km/h 9,7 knots	22 km/h 12 knots

The conventional propulsion system option, as adopted for the class 5 shallow draft version, will have the two main engines in separate engines room compartments separate by a longitudinal watertight and fireproof (A category) bulkhead. Each engine is mechanically coupled via a gearbox to the controllable pitch propeller. A shaft generator is connected to each of the gearboxes, providing electric power supplied to the main switchboard. An auxiliary engine is positioned in the forward part close to the bow thruster.

The hybrid propulsion system will have, for the larger vessels (Class Va regular draft and the sea-river vessel) two main engines in the engine room with each engine mechanically coupled via a gearbox to a controllable pitch propeller. The auxiliary engine will also be fitted in the engine room. There will be no longitudinal bulkhead in the CL between the main engines, but the auxiliary engine will be fitted in a separate compartment to increase redundancy.

In the bow section, three units of li-iron batteries are installed to supply the Veth-jet. In absence of the generator and related fuel system the bow machinery space can be minimized. The li-ion batteries have a high energy output rate and do not have to “start” in advance like diesel engines. This characteristic matches very well the manoeuvring operation.

The Class III container roro vessel has the same hybrid concept but only one main engine with single propeller and a smaller auxiliary engine which also fitted in a separate compartment, for increased redundancy, in the engine room and with a smaller battery capacity in the bow section

Engine system redundancy

To ensure the redundancy of the propulsive system, the main engine room can be divided in two parts by longitudinal watertight and fireproof (A category) bulkhead. Separated engine rooms will increase the redundancy but will have negative impact on the damage stability.

4.2.9 Manoeuvring - General

The vessels require a high level of manoeuvrability to get to and from berths as well as in and out of locks without assistance or delays. The manoeuvring system to be arranged considering the option of remote operation from a lead vessel

A water jet thruster arranged in the bow section provides excellent manoeuvrability. The jet can also act as an emergency propulsion and manoeuvring would thus fulfil the requirements for secondary means of propulsion and secondary means of steering as prescribed by the safety assessment of the VT.

Table 10, Summary of bow thruster data

	Class V, regular	Class V, shallow	Class III	Sea river
Bow thruster type	4-channel -jet	4-channel -jet	Steering grid	4-channel -jet
Bow thruster power	400 kW	400 kW	191 kW	400 kW

4.2.10 Mooring

Mooring systems should be arranged for minimum manning requirement and with an option to be remotly or fully automatically operated. The spud pole concept provides these features and will be applied for the inland waterway vessels. Conventional electric mooring winches are provided in addition to the spud poles to be used were for different reasons the spud pole cannot be used e.g. risk of damage to river bed, cables etc.

The sea-river vessels will be equipped with a conventional mooring system with one anchor on each side of the bow section.

4.2.11 Deck house positions, Wheelhouse and air draft

The different vessel designs show three different locations of the deck house aft, midship and forward. There are pros and cons with all the alternatives and the conditions of an actual transport mission will have to be carefully considered to decide the best position.

For all designs it is valid that the deckhouse should be large with good visibility and sufficient space to accommodate additional VT operators, which are important when the vessel leads the VT.

With cargo access over a bow ramp the deckhouse and wheelhouse will be positioned aft. This means that the distances between the engine room, wheelhouse and accommodation space are short with the benefit of easy access, communication and less routing of cables. It will also mean that the funnel casing will not interfere with the cargo space. This comes with some disadvantages such as more noise from engine space in the accommodation and the wheelhouse. The view forward will be more obstructed than for other locations of the deckhouse and the wheelhouse.

The stern access version with the deckhouse and wheelhouse forward will provide a better ahead visibility from the wheelhouse. According to the CCNR, allisions with bridges and other types of infrastructure on the waterway account for around 40% of all accidents. The data given in NOVIMAR Deliverable 5.1, see (Gerbert, G., Corrignan, Ph., 2018), show that as much as 86 allisions of the wheelhouse with a road/railroad bridge crossing took place in Western European inland waterways over 73 months period, from January 2011 to March 2017. It is obvious that the loss of wheelhouse would imply the interruption of the VT operations and a possible onset of a range of hazards. IVR findings indicate that the number of hull/bridge and wheelhouse/bridge allisions increased over the last couple of years, even though neither ships nor waterway infrastructure were changed. Instead, the increase could be attributed to "alarm fatigue", over-reliance on alarm systems and the information overload in the wheelhouse (Arntz, 2019). Therefore, in context of navigation in the VT, a better visibility achieved by design might prove to be more useful than another alarm system, as the VT operators would already have to cope with a lot of information.

The double-end access concept features a large wheelhouse with all-round lookout. This concept would have a more restrictive air draft than other vessels and the mechanism for moving the wheelhouse may be more complex (and, possibly, more expensive). In order to provide an unobstructed cargo flow along the vessel, the accommodation spaces have to be positioned in such way so as not to impede the movement of the vehicles. Therefore, upon drawing inspiration from Dutch and German architects[1] the accommodation on the double-end access vessel is foreseen to be consisted of modular, containerized units (see purple containers on Figure 22 and Figure 26).

For the forward and midship bridge position a lower level of noise and vibrations could be expected both in the wheelhouse and in the accommodation spaces as these would not be located directly above the main engine room. As a result, the level of physical stress, contributing to human fatigue, should be lower as well. This would be particularly important when the vessels lead the VT, as the fatigue is one of main contributors to human errors.

[1] See Barneveld Noord train station design by NL Architects and Wertheim micro apartments by Containerwerk

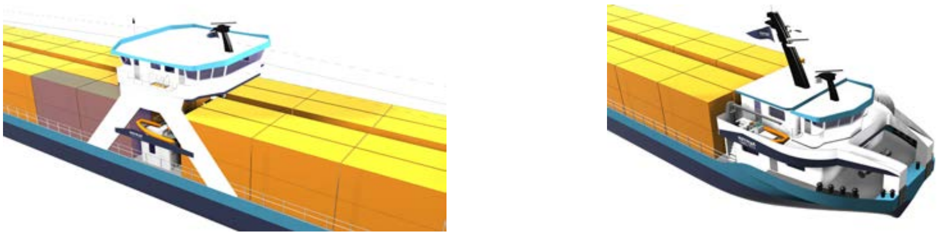
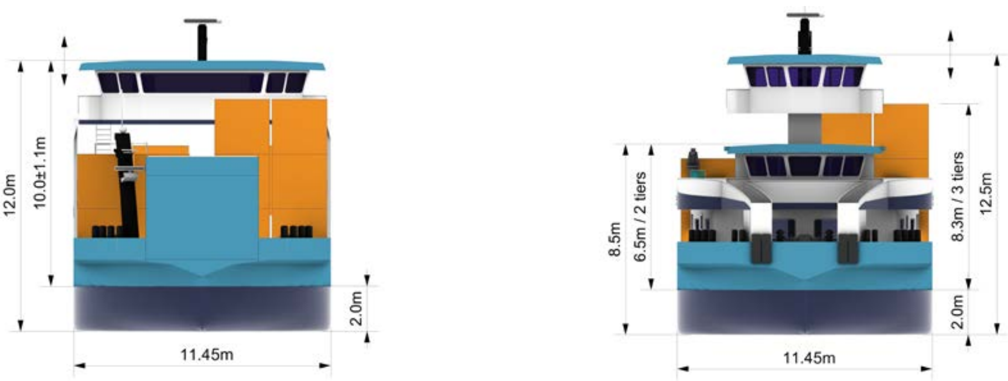


Figure 26. Position of the lifeboats on the developed concepts

All vessels feature a single passageway on the main deck, along the centreline of the vessel. It should be verified that this will not inflict any major problems for the actual operation.The lifeboat would be positioned in the vicinity of the accommodation / wheelhouse, see Figure 26. From the point of view of evacuation in case of emergency, it may be considered that the vessels comply with appropriate ADN regulations. The double-end access vessel would have two escape routes inside the protected area[2] leading in opposite directions and one lifeboat, while the stern and bow access vessels would have one escape route inside the protected area and one lifeboat at the opposite end, see UNECE (2019).

All vessels feature retractable, hydraulically driven wheelhouses.

For the NOVIMAR Class Va container roro vessel, the air draft of the double-end access version, corresponding to the lowest position of the wheelhouse (d_A = 8.9 m), should enable unrestricted navigation on the Rhine downstream of Strasbourg, see Figure 27(a).[3] The air draft of the stern access vessel with two container tiers is determined by the lowest position of the wheelhouse (d_A = 6.5 m) and should enable unrestricted navigation downstream of Basel, see Figure 27(b).[4] If three container tiers are loaded (d_A = 8.3 m), the stern access vessel should be able to sail downstream of Strasbourg without restrictions. The main dimensions of the developed concepts are given in section 4.2.3. The vessels are presented in Figure 22 and Figure 23.



(a) (b)

Figure 27. Front view of the developed concepts: (a) double-end access and (b) stern access vessel

[2] "Protected area" is a virtual space which includes cargo holds (and adjacent spaces above the deck) on dry cargo inland vessels intended for carrying dangerous cargo. For the precise definition of "protected area" see ADN regulations (UNECE, 2019).

[3] However, the height of the bridge Josef-Kardinal-Frings-Brücke in Düsseldorf at HNWL is 8.61 m, the height of the bridge Kniebrücke in Düsseldorf at HNWL is 8.82 m, and the height of the bridge Rheinhausen – Duisburg-Hochfeld at HNWL is 8.88 m.

[4] However, the height of the bridge Europabrücke in Strasbourg at HNWL is 6.79 m.

4.2.12 Considerations extracted from the Vessel Train (VT) safety assessment

From the safety assessment point of view, both the LV and the FV should fulfil the specific technical requirements (for more details see (Bačkalov, 2019)). The LV should have the following features.

- Redundancy of propulsive system comprising implementation of secondary means of propulsion and secondary means of steering.
- The vessel should be equipped with fire alarm systems (fire detectors, fire indicators, control panel with at least two electric power sources) and fire extinction systems (permanent firefighting systems).
- The vessel should comply with the damage stability requirements for dry cargo vessels carrying dangerous cargo.
- The vessel should be equipped with an emergency power supply of VT control system.
- The vessel should be equipped with tools for stability management and cargo loss prevention.
- The space intended for placement of the VT control system should be designed so as to take ergonomics and habitability appropriately into account.

Technical requirements specific for FV are intended to enable early detection of hazards and automatic or remote execution of safety functions. Thus, the FV should have the following technical features.

- The vessel should be equipped with means for cargo shift monitoring and water ingress detection.
- The vessel compartments should be protected with fire detection and fire extinction systems.
- The vessel should be equipped with tools for stability management and cargo loss prevention.
- The vessel should be equipped with automatic draining systems.
- The vessel should be equipped with means for remote / automatic anchoring.
- The vessel should be equipped with the secondary means of steering.
- The vessel should comply with the damage stability requirements for dry cargo vessels carrying dangerous cargo.

The requirements for lead vessels, LV and follower vessel, FV given above follow from the findings of the first safety assessment carried out within the framework of the NOVIMAR WP5, see (Gerbert, 2018). In the moment of the preparation of this Deliverable, the report on the VT operation safety and cybersecurity, performed during the second WP5 safety assessment workshop in March 2020, was still in progress. Therefore, the compliance of the vessels developed within WP4 with the VT safety requirements should be reassessed once the WP5 report is finalized.

4.2.13 Decreasing the crew size due to automated navigation

The task T4.5: "Guidelines for design of vessels with reduced crewing levels" have just started. Some early results are presented here, while more comprehensive results will be provided in the deliverable D4.5 "Design guidelines" in project month 45.

To assess the possible decrease of the crew size on board of a ship when specific tasks are automated, a purpose build crew analysis algorithm is used. This algorithm uses a task list to determine the required crew as well as the monthly cost of this crew. The details of the algorithm can be found in (Kooij and Hekkenberg, 2019). An assessment has been performed on a 130 meter long short sea container vessel. The method applied for the short sea vessel can also be used to analyse sea-river and inland vessels.

The typical crew on a short sea container ship of this size consists of approximately 10 to 12 crew members, dependent on the cargo type, route and ship operator. In this case, the original ship has a crew that consist of 11 crew members: a bridge crew of 3, an engine room crew of 2, a deck crew of 5 and a cook.

When a ship is sailing in the vessel train, the navigational tasks are performed by the lead vessel. To simulate this, these tasks are removed from the task list. This results in a decrease in the required number of crew members in the normal sailing phase.

In the first assessment, it is assumed that the crew members do not perform tasks from other departments, even if they do have the required skill for it. This results in only a small reduction in the required crew, even though a significant part of the workload for some of the crew members has been removed.

In a second analysis, it is assumed that if a crew member has the skill to perform a task, they can be assigned to perform it, even if it does not belong to their department. This allows for a better occupation rate for the crew members, which results in a lower required number of crew members.

Table 11 shows that in this case the number of crew members that are required decreases by two in the normal sailing phase compared to the traditional task assignment.

Table 11 Required crew members for each scenario

Scenario	Normal sailing
Conventional situation	11
Navigation automated – traditional task distribution	10
Navigation automated – relaxed task distribution	8

Decrease in cost

With the decrease in the required crew, it is also possible to estimate the crew cost for each scenario. This is shown in Table 12. It shows that the crew cost drop by about 15% between the conventional situation and the relaxed task distribution. By automating the navigational tasks on a ship by having it sail in the vessel train, the yearly savings are approximately €50 000 – €84 000 a year.

Table 12 Estimated monthly crew cost for each scenario

Scenario	Normal sailing
Conventional situation	€48 900
Navigation automated – traditional task distribution	€44 700
Navigation automated – relaxed task distribution	€41 900

The lowering of the crew cost influences the viability of the vessel train concept. In (Colling, Kooij and Hekkenberg, 2020), the viability of the vessel train concept with reduced crew is investigated. For the vessel train concept to be viable, a number of crew members on board of the follower vessels needs to be removed. If more crew is removed, the minimum length of the vessel train, at which the concept is viable, is reduced.

Sea river and inland vessels

At this point in time, the method has not been applied to the vessels investigated for this project. However, the following hypotheses have been formulated for these vessels. On a sea river vessel, the reduction of crew is assumed to be between one and two crew members. This is based on the estimated workload reduction from sailing in a vessel train. For inland ships, the benefits are slightly different. Here the ships can sail in one of three operating regimes;

- A1 – operating 14 hours a day
- A2 – operating 18 hours a day
- B - Operating continuously (24/7)

For the regimes that do not sail continuously, the benefit of the vessel train can be an increase in operating time. While the ship is in the vessel train, the crew can rest, increasing their potential operating time to 24/7. In these cases, the number of crew members would not change, but their productivity would. This also means that ships that operate on a 24/7 operating regime, might be able to reduce their crew to an A1 or A2 regime, without losing operating time.

4.3 Model for assessment of performance of the vessels within the transport mission

In the NOVIMAR deliverable D4.2 Cargo systems analysis WP4(Ramne, Bengt Fagerlund, 2019a), a model to calculate the total transportation cost door-to-door was presented.

Back t	Cargo handling				Lolo	RoRo	Sea River roro	Truck
Consignor (Sender)		A	- Load truck	1	FLT	FLT	FLT	FLT
		B	Truck	2	Truck	Truck	Truck	
Small inland waterway terminal	Load ship	C	- Unload truck (Gate to stack)	3	RS	RS	RS	
			- Stack to quay	4	RS	NCHV	NCHV	
			- Quay to ship	5	QC			
		D	IWV - CEMT III	6	IWV - CEMT III	CEMT III - Roro	CEMT III - Roro	Truck
Large inland waterway terminal		E	- Unload truck (Gate to stack)	7				
	Unload ship		- Ship to quay	8	QC	NCHV	NCHV	
			- Quay to stack	9	RS			
	Load ship		- Stack to quay	10	RS	NCHV	NCHV	
			- Quay to ship	11	QC			
		F	IWV - CEMT V	12	IWV - CEMT V	IWV - Roro		
Sea port terminal	Unload truck	G	- Unload truck	13				RS
			- Gate to stack	14				SC
	Unload ship		- Ship to quay	15	QC	NCHV		
			- Quay to stack	16	SC			
	Load ship		- Stack to quay	17	SC	NCHV		SC
			- Quay to ship	18	QC			QC/WS
		H	SS container vessel	19	SS container vessel	SS Roro vessel	SR vessel	SS container vessel
Sea port terminal	Unload ship	I	- Ship to quay	20	QC	NCHV		QC
			- Quay to stack	21	SC			SC
	Load ship		- Stack to quay	22	SC	NCHV		
			- Quay to ship	23	QC			
	Load truck		- Stack to gate	24				SC
			- Load truck	25				RS
		J	IWV - CEMT V	26	IWV - CEMT V	IWV - Roro		
Large inland waterway terminal	Unload ship	K	- Ship to quay	27	QC	NCHV	NCHV	
			- Quay to stack	28	RS			
	Load ship		- Stack to quay	29	RS	NCHV	NCHV	
			- Quay to ship	30	QC			
		L	IWV - CEMT III	31	IWV - CEMT III	CEMT III - Roro	CEMT III - Roro	Truck
Small inland waterway terminal	Unload ship	M	- Ship to quay	32	QC	NCHV	NCHV	
			- Quay to stack	33	RS			
			- Load truck (Stack to gate)	34	RS	RS	RS	
		N	Truck	35	Truck	Truck	Truck	
Consignee (receiver)		O	- Unload truck	36	FLT	FLT	FLT	FLT

Figure 28, Principle model for multi modal door-to-door transport chain with different transport concepts

The model can be used to compare different alternatives of ship and cargo handling concepts. Each numbered line represents a transport or cargo handling activity. For a given transport mission the cost for the activity will differ depending on the transport system (Lolo, Roro, sea-river or truck). By summing up the costs for the activities for the different transport systems respectively, a total cost can be calculated, and the concepts can be compared. For comparison of a particular transport mission, several of the listed activities might not be relevant and can then of course be removed from the model.

The costs for the handling activities are calculated as cost per move. Regardless if it is a 20', 40' or 45' container that is moved the cost is in principle the same. The cost per move will however very much depend on the terminal size, throughput and handling equipment used in the terminal. This means that the cost per move will differ between deep-sea, short-sea and inland terminals and of course differ from the cost for a move made by the NOVIMAR container handling vehicle, where the units are rolled instead of lifted on and off the vessel.

The costs for the actual transport of the cargo unit will depend on the size of the unit (the cost will be different depending on if it is a 20, 40 or 45 feet container) as well as on the transport distance and infrastructural constrains (What size of vessel that can be used).

In addition to the ship design activity that has been performed for the NOVIMAR container roro vessels, the costs to operate the vessels have been estimated and compared to the cost to operate conventional vessels. The total operational cost is then related to the cargo transport capacity and a cost per unit can be derived and used in the transport cost model (see section 4.3.1).

The costs for cargo handling in different terminals have also been estimated (see section 4.3.2) to provide sufficient data for the model.

The cost estimates are generalised and rough, but the objective has been to highlight the principal differences between transport chain alternatives, to see how and where the transport cost accumulates and if and where an alternative concept can provide added value.

Note that only the physical handling and transport costs have been addressed. Costs related to documentation or administration have been left out of the comparison.

4.3.1 Performance of the NOVIMAR vessels

The NOVMAR vessels are designed for roro handling capability. It is unavoidable that vessels designed for roro handling will have less container carrying capacity, for given dimensions, than a vessel where the cargo is lifted on and off the ship. The driving idea is that the roro handling concept will have significant benefits when it comes to flexibility, scalability and speed.

When comparing different ships that can provide the same service the required freight rate, RFR can be used as the key performance indicator, KPI.

The RFR is the total operating cost of a transport service divided by the number of nominal cargo units that are transported or the minimum income per cargo unit that is needed to reach breakeven.(Watson, 1998)

The operating cost are normally divided in

- Running costs
- Voyage costs
- Capital costs

$$RFR = \frac{Annual\ captial\ cost +\ Annual\ running\ cost + Annual\ voyage\ cost}{Annual\ no\ of\ TEUs}$$

Capital cost

The capital cost is made up of

- Capital charges
- Capital amortisation
- Profit and taxes
- Depreciation

In our comparison we will consider the new building cost and calculate an annuity cost (i.e. an equal cost every year for the commercial lifetime of the ship)

- Annuity cost, AC
- Interest, i
- Commercial lifetime, n
- Present value of the ship (Contract price), CP

There are two ways to calculate the annuity "ordinary annuity" or "annuity due".

At ordinary annuity, the periodical cost is paid at the end of the period for "annuity due" the periodical payment is paid at the beginning of the period. In our case we will assume "annuity due".

The periodical payment can then be calculated as (Investopieia, no date)

$$AC = CP\ x\ \frac{i}{1-(1+i)^{-n}}\ x\ \frac{1}{(1+i)}$$

An example

- Contract price € 5 000 000
- Interest 5%
- Commercial lifetime, 20 years

The annuity formula gives an annual cost of approx. € 380 000, monthly cost of approx. €32 000 and daily cost of approx. € 1 050

Running cost

The running cost is made up of

- crew costs
- provisions and stores
- maintenance and repairs
- insurance
- administration and general charges

Voyage cost

The voyage cost is made up of

- bunkers
- port and canal dues
- tugs, pilotage
- miscellaneous port expenses
- terminal handling charges, THC (this cost will be further discussed in following sections)

If the terminal handling charges are excluded from the operating cost the terms are defined as FIOS. FIOS (Free In Out and Stowed), the freight rate only covers the actual transport. Neither the costs for loading, unloading or stowing of the goods onboard the ship are included in the freight rate. These costs are payable separately.

The freight rate is the price a vessel operator manged to charge a client for the service to transport the cargo. If the freight rate is higher than the required freight rate, the operator will make a profit.

The operating cost and the required freight rates have been estimated for the NOVIMAR vessel designs as well as for some reference vessels. A summary is presented in Table 13. A more extensive table can be found in annex 0.

Table 13, Required freight rate estimation

		Short Sea container vessel	Short Sea RoRo	Sea-River	CEMT V reference	Class Va container roro vessel	container roro vessel shallow draft	CEMT III reference	Class III container roro vessel
Capital cost									
Investment (New builiding cost)	€	40 000 000	60 000 000	6 351 093	4 533 701	4 521 606	3 962 135	1 440 829	1 467 079
Ecomomic lifetime	y	25	25	20	20	20	20	20	20
Interest		5%	5%	5%	5%	5%	5%	5%	5%
Calculated annuity	€/y	2 702 951	4 054 426	485 360	346 472	345 548	302 792	110 110	112 116
Total capital cost per year		2 702 951	4 054 426	194 949	346 472	345 548	302 792	110 110	112 116
Running cost									
Daily running cost									
- crew costs	€/y	523 454	523 454	450 000	377 475	377 475	377 475	265 366	265 366
- maintenance and repairs, variabl	€/y	893 890	893 890	23 763	30 142	24 560	11 908	5 513	5 513
- insurance	€/y	600 000	900 000	95 266	68 006	67 824	59 432	21 612	22 006
Total running cost pe year		2 017 344	2 317 344	228 556	527 470	539 770	534 339	292 491	292 885
Voyage cost									
- bunkers	€/y	3 627 596	6 216 912	575 803	487 899	514 966	568 165	100 270	119 742
Totall voyage cost		3 627 596	6 216 912	575 803	487 899	514 966	568 165	100 270	119 742
					0	0	0		
Total cost per year		**8 347 891**	**12 588 682**	**999 308**	**1 361 841**	**1 400 284**	**1 405 297**	**502 871**	**524 743**
Transported untis per year	TEU	66442	87919	7725	48985	40087	7725	6240	6090
Reqiured freight rate	€/TEU	126	143	129	67	65	78	81	86
Reqiured freight rate	€/FEU	251	286	259	133	131	157	161	172
Route distance one way	km	1 019	1 019	1 019	560	560	560	200	200
	€/(FEU x km)	0.25	0.28	0.25	0.26	0.32	0.34	0.81	0.86

4.3.2 Terminal cargo handling

The handling to/from and inside the terminal are done by the terminal operator and is charged as a terminal handling charge THC. It can either be included in the transport charge that the liner company is charging the cargo owner, or paid directly by the cargo owner if the transport is carried out FIOS (Free In Out and Stowed)

The terminal handling charge includes the cost for the terminal operation i.e. capital and operational costs as well as the profit of the terminal operator. Similar to the required freight rate the required handling charge can be calculated as the actual cost per unit or more accurate per move.

The global container transport system has become extremely efficient. By the growth of vessels and cranes the “economy of scale” has drastically reduced the cost per transported unit. On the global scale, for large cargo flows and where there are no geometric constrains, it is very difficult to find a better concept than large ships with box shaped cargo holds were containers are loaded and unloaded with a container crane. This concept provides the best combination of cargo space utilization cargo handling speed and cost.

The cargo handing concepts that are efficient for the major cargo flows are sometimes less efficient when the cargo flow is divided into smaller streams.

The handling equipment in the terminals is dimensioned for the largest vessels. The larger vessels will always have priority at the quay which means that the smaller vessels in general and the inland waterway vessels in particular, will have to wait until resources becomes available. When the smaller vessels eventually are loaded/unloaded it is done by unnecessary large and expensive equipment.

The intention of the NOVIMAR cargo handling concept is to provide a system where smaller vessels for short-sea and inland waterway operation do not occupy or must depend on the expensive equipment that is required for the larger ships. The benefit of the NOVIMAR cargo handling concept is twofold

1) The capacity of the terminal to service the deep seas vessels can be increased without increasing crane capacity and
2) The waiting time for the smaller vessels can be reduced, thus allowing more tie for transport work.

The NOVIMAR container handling vehicle, NCHV developed in task 4.3. and described in section 4.2.4 of this report provides a fast and cost-efficient alternative for conventional cargo handling. The NCHV can provide full service for roro vessels i.e. loading and unloading of double stacked containers, terminal handling and gate-in-gate-out service without interfering with or occupying any of the capacity of the quay-cranes, straddle carriers or reach stackers in the terminal. The NCHV is cheaper and more versatile than the other terminal equipment used for container handling and provides a quick, inexpensive fast track service for smaller feeder and inland waterway vessels in the deep-sea and short-sea terminals.

For inland terminals, the NCHV can replace the need for traditional container cranes and other handling equipment. Any hard surface terminal with a roro berth can be utilized for container service with minimum investment. For a multimodal door-to-door transport chain the NCHV provides new possibilities.

In the Tarpits project(Bengt Ramne, 2004) the cargo handling speed of loading and unloading containers with container cranes and roro handling vehicles were studied and compared.

The study showed that a normal handling speed for a ship-to -shore crane in a short sea terminal is 20-25 moves per hour, i.e. 20-25 cargo units per hour. The crane needs to be serviced by 3-4 straddle carriers which are shuttling the containers between the stack and the quay. The same study showed that a roro handling vehicle needs about 4 minutes (15 cycles per hour) to make a complete loading/unloading cycle "stack-ship-stack" without the help from any other equipment. Each cycle brings two cargo units which equals two moves of the ship-to-shore container crane. I.e. one roro handling vehicle will single-handed load/unload 30 FEUs per hour and outperform a combination of one ship-to shore crane and three straddle carriers that can load/unload 20-25 FUEs per hour and this to a much lower cost.

An inland waterway vessel is too small to utilize more than one ship-to-shore crane simultaneously but for each ship-to-shore ramp connection at least two roro handling vehicles can be used without creating a risk of waiting time at the ramp. With one ramp access the loading/unloading capacity using roro handling vehicles is estimated to at least 120 TEUS per hour. By providing double-end access as proposed for one of shallow draft NOVIMAR Class Va container roro vessels a loading/unloading speed of 240 TEUS per hour can be achieved meaning that the vessel can be unloaded and loaded in less than one hour. (See Figure 20)

Terminal operating cost

For a seaport the terminal handling charges, THC, are typically €180-190 per container regardless if it is a 20-, 40- or 45-feet container. In this charge both the handling from the deep-sea vessel to the shore is included as well as the movements at the terminal and the loading to another mode of the transport (barge, rail, truck) or vice versa.

The THC includes the profit for the terminal. The Terminal Operating Cost, TOC, is the actual cost for the terminal to do the handling and for this purpose a more relevant number.

Terminal operating cost for a seaport container terminal

Table 14, Terminal operating cost, container handling seaport container terminal, ship in truck out

Sea port terminal	Unload ship	- Ship to quay	Ship to shore crane	€	45
		- Quay to stack	Straddle carrier	€	40
	Load truck	- Stack to gate	Straddle carrier	€	40
		- Load truck	Reach stacker	€	20
			Terminal Operating Cost per container move	**€**	**145**

Table 15, Terminal operating cost, container handling seaport container terminal, ship in barge out

Sea port terminal	Unload ship	- Ship to quay	Ship to shore crane	€	45
		- Quay to stack	Straddle carrier	€	40
	Load large barge	- Stack to quay	Straddle carrier	€	40
		- Quay to ship	Ship to shore crane	€	45
			Terminal Operating Cost per container move	**€**	**170**

Terminal operating cost for a larger inland container terminal

The THC for a short sea terminal can be about 35-40% lower with a correlating TOC

Table 16, Terminal operating cost, container handling large inland container terminal, ship in barge out

Large inland terminal	Unload large barge	- Ship to quay	Ship to shore crane	€	35
		- Quay to stack	Reach stacker	€	20
	Load small barge	- Stack to quay	Reach stacker	€	20
		- Quay to ship	Ship to shore crane	€	35
			Terminal Operating Cost per container move	**€**	**110**

Terminal operating cost for a small inland container terminal

Table 17, Terminal operating cost, container handling large inland container terminal, barge in truck out

Small inland waterway terminal	Unload small barge	- Ship to quay	Ship to shore crane	€	35
		- Quay to stack	Reach stacker	€	20
	Load truck	- Load truck	Reach stacker	€	20
			Terminal Operating Cost per container move	**€**	**75**

Terminal operating cost for handling with NOVIMAR container handling vehicle, NCHV

No detailed estimate of the operating cost of the NCHV has been done but a rough, reasonable estimate is that the cost per handled unit will be between the smaller ship-to-shore crane and a reach stacker.

One of the great benefits of the NCHV is that it will take a container from the stow onboard the ship to the quay and then all the way to the container stack in the terminal, in one move. That reduces the number of operations compared to the conventional container handling where one vehicle will take it to and from the quay and then a crane will do the lifting on and off the ship.

Table 18, Terminal operating cost, NOVIMAR container handling vehicle, NCHV, ship in barge out

NOVIMAR container handling vehicle, NCHV	Unload large barge	- Ship to quay - Quay to stack	NCHV	€	25
	Load small barge	- Stack to quay - Quay to ship	NCHV	€	25
			Terminal Operating Cost per container move	**€**	**50**

The costs in the tables are rough estimates but deemed to be representative. Data for the cost estimate has been gathered from following sources

- Discussion with Dr. Ir. Edwin van Hassel, University of Antwerp
- Annual report APM terminals Gothenburg AB
- Annual report Yilport Gavle Container Terminal AB
- Posted port tariffs from the Containerships group('Containerships' port tariffs, 2017', no date)

- Deliverable 8.6 Cargo Handling Performance from the EU project TRAPIST(Bengt Ramne, 2004)

4.3.3 Door to door handling and transport cost

By inserting the values for required freight rate derived in section 4.3.1 and cargo handling cost derived in 4.3.2 in the model for multi modal door-to-door transport chain (Figure 28), the total cost for handling and transport door-to-door can be compared.

A sample mission of transporting one 40 feet container from Karlstad, Sweden to Stuttgart, Germany was studied (see Figure 29). The cost for required freight rate and for cargo handling was calculated according to the principles described earlier and inserted in the multi modal door-to-door transport chain model. The result is presented in Table 19.

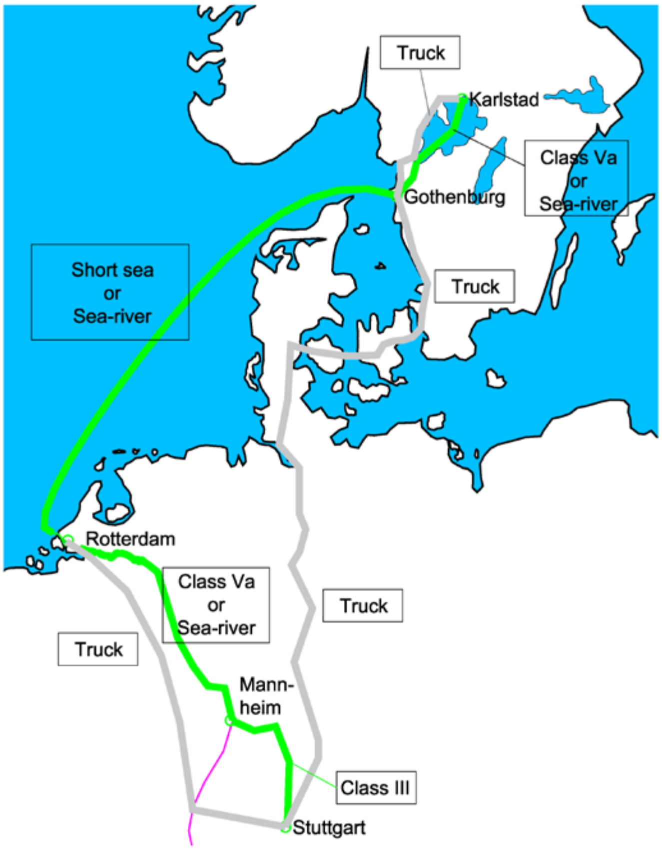


Figure 29, Transport options from Karlstad, Sweden to Stuttgart, Germany

Different alternatives for inland waterway transport were compared to each other and to other alternatives i.e. truck plus short sea service and pure truck door-to-door service.

The cost for the truck transport has been estimated to €1 per km except for the first and last mile pick-up and drop-off were a flat rate of €200 has been assumed.

Again, these are general and rough estimates, but they show the potential of different waterborne transport options in particular when considering that €1 per km for truck transport is not a sustainable cost level considering climate and environmental impact

Table 19, Comparable door to door handling and transport cost for a 40 feet container Karlstad, Sweden to Stuttgart, Germany

				Short sea and inland waterway lolo con		Short sea and inland waterway roro co		Sea River roro operation	Truck and Short sea lolo operation		Truck door-to-door	
					Cost €/FEU		Cost €/FEU			Cost €/FEU		Cost €/FEU
Karlstad		A	- Load truck	FLT	€ 20	FLT	€ 20	FLT	FLT	€ 20	FLT	€ 20
		B		Truck 20 km	€ 100	Truck 20 km	€ 100	Truck 20 km	Truck 230 km	€ 230	Truck Dist 1700 km 2 days	€ 1 700
Karlstad inland waterway terminal			- Unload truck (Gate to stack)	RS	€ 20	RS	€ 20	RS				
	Load ship		- Stack to quay	RS	€ 20	NCHV	€ 25	NCHV				
			- Quay to ship	QC	€ 35							
		F		IWV - CEMT V 230 km	€ 66	IWV - Roro 230 km	€ 62	SR vessel Karlstad - Goth 230 km				
Gothenburg Sea port terminal	Unload truck	G	- Unload truck						RS	€ 20		
			- Gate to stack						SC	€ 40		
	Unload ship		- Ship to quay	QC	€ 45	NCHV	€ 25	Got - Rot 1018.6 km				
			- Quay to stack	SC	€ 40							
	Load ship		- Stack to quay	SC	€ 40	NCHV	€ 25		SC	€ 40		
			- Quay to ship	QC	€ 45				QC	€ 45		
		H		SS container vessel 1018.6 km	€ 251	SS Roro vessel 1018.6 km	€ 286		SS container vessel 1018.6 km 2 days	€ 251		
Rottrerdam Sea port terminal	Unload ship	I	- Ship to quay	QC	€ 45	NCHV	€ 25		QC	€ 50		
			- Quay to stack	SC	€ 40				SC	€ 50		
	Load ship		- Stack to quay	SC	€ 40	NCHV	€ 25	Rot - Mannheim 560 km				
			- Quay to ship	QC	€ 45							
	Load truck		- Stack to gate						SC	€ 50		
			- Load truck						RS	€ 20		
		J		IWV - CEMT V 560 km	€ 139	IWV - Roro 560 km	€ 136					
Mannheim inland waterway terminal	Unload ship	K	- Ship to quay	QC	€ 35	NCHV	€ 25	NCHV	Truck 640 km	€ 640		
			- Quay to stack	RS	€ 20							
	Load ship		- Stack to quay	RS	€ 20	NCHV	€ 25	NCHV				
			- Quay to ship	QC	€ 35							
		L		IWV - CEMT III 200 km	€ 174	CEMT III - Roro 200 km	€ 182	CEMT III - Roro 200 km				
Stuttgart inland waterway terminal	Unload ship	M	- Ship to quay	QC	€ 35	NCHV	€ 25	NCHV				
			- Quay to stack	RS	€ 20							
			- Load truck (Stack to gate)	RS	€ 20	RS	€ 20	RS				
		N		Truck 20 km	€ 100	Truck 20 km	€ 100	Truck 20 km				
Stuttgart		O	- Unload truck	FLT	€ 20	FLT	€ 20	FLT	FLT	€ 20	FLT	€ 20

Cargo flow

Short sea and inland waterway lolo container operation	Cost €		Cost €			Cost €		Cost €
In transport	830	In transport	867	In transport	In transport	1 121	In transport	1 700
In terminal	640	In terminal	280	In terminal	In terminal	**355**	In terminal	**40**
Total	**1 470**		**1 147**			1 476		1 740
Relative cost to truck	84%	Relative cost to truck	66%	Relative cost to truck	Relative cost to truck	85%	Relative cost to truck	100%
Relative cost to lolo	100%	Relative cost to lolo	78%	Relative cost to lolo	Relative cost to lolo	100%	Relative cost to lolo	118%

Table 20, Summary of results, handling and transport cost for a 40 feet container Karlstad to Stuttgart

Short sea and inland waterway lolo container operation				
	Cost		**Fuel cons.**	**time**
	€	kg/FEU	kg/(FEU x km)	h
In transport	820	368.3	0.22	132
In terminal	640	45.0	x	157
Total	**1 460**	**413.3**		**289**
				12.0 days
Relative to truck	84%	69%		
Relative to lolo	100%	100%		

Short sea and inland waterway roro container operation				
	Cost		**Fuel cons.**	**time**
	€	kg/FEU	kg/(FEU x km)	h
In transport	861	434.4	0.26	100
In terminal	280	36.6	x	79
	1 141	**471.0**		**179**
				7.5 days
Relative to truck	66%	78%		
Relative to lolo	78%	114%		

Sea River roro operation				
	Cost		**Fuel cons.**	**time**
	€	kg/FEU	kg/(FEU x km)	h
In transport	911	453.7	0.27	137
In terminal	180	25.3	x	31
	1 091	**479.0**		**168**
				7.0 days
Relative to truck	63%	80%		
Relative to lolo	75%	116%		

Truck and Short sea lolo operation				
	Cost		**Fuel cons.**	**time**
	€	kg/FEU	kg/(FEU x km)	h
In transport	1 121	486.5	0.29	55
In terminal	355	30.0	x	97
	1 476	**516.5**		**152**
				7.0 days
Relative to truck	85%	86%		
Relative to lolo	101%	125%		

Truck door-to-door				
	Cost		**Fuel cons.**	**time**
	€	kg/FEU	kg/(FEU x km)	h
In transport	1 700	595.0	0.35	49
In terminal	40	7.5	x	1
	1 740	**602.5**		**50**
				2.1 days
Relative to truck	100%	100%		
Relative to lolo	119%	146%		

It can be seen from the table that the cost for the roro alternatives are cheaper than for the lolo alternatives but the fuel consumption per transported unit is higher. The cost savings for the handling are larger than the increase cost due to higher fuel consumption i.e. the potential environmental and climate impact for the roro handling might be larger as well unless clean burning renewable fuel is used.

5 RESULTS

5.1 General

Inland waterway transport is fundamental for the transport of goods in Europe. For low value goods such as bulk and liquid cargo, the waterborne service on inland waterways is the preferred mode of transportation due to its low cost and high capacity. In addition to bulk and liquid cargo, a significant number of containers are transported as well. Rolling cargo such as trucks, trailers and new built vehicles are utilizing the waterborne inland transportation to limited extent.

The cargo volumes will grow, and to avoid that the negative environmental footprint and road congestion problem are escalated beyond control, a large part of the increased cargo volumes need to be accumulated by the waterborne transportation.

Inland waterway operations need to attract cargo from the road. To compete with road transport, the services must be frequent, regular, dependable and cost-efficient. Speed can in some cases be a critical parameter but for a lot of cargo, a longer transport time can often be accepted if the client can depend on that a given delivery time always will be met.

In task 4.4. is has been shown that intermodal transport chains utilizing efficient waterborne transport to the largest possible extent can be a competitor to road transport when it comes to cost

5.2 Results for task 4.4.1 Identify vessel categories and the corresponding design requirements and constraints for the transport mission(s)

Three vessel categories were identified as necessary to provide cost-efficient waterborne transportation solutions for service to and from inland ports.

- CEMT Class Va vessel
- CEMT Class III vessel
- Sea-river vessel

5.3 Results for task 4.4.2 Develop vessel concepts for the identified vessel categories: main dimensions, power estimate, cargo equipment, accommodation, an outline General Arrangement and CAPEX/OPEX estimates.

Five vessel concepts have been developed to provide relevant portfolio for the transport missions. All vessels can be equipped to act as lead vessels or follower vessels in a vessel train or operate as individual units.

Following vessels concepts have been developed

- NOVIMAR Class Va container roro vessel
- NOVIMAR Class Va container roro vessel, shallow draft
    - o Stern access version
    - o Double-end access version
- NOVIMAR Class III container roro vessel
- NOVIMAR Sea-river container roro vessel

In task 4.4.2 reference vessels, statistical data and general design parameter were used to get a first rough estimate of light ship weight, propulsion power and cargo capacity considering preliminary stability assessment.

5.4 Results for task 4.4.3 Prepare vessel concepts for assessment of performance within the transport mission(s).

An essential part of the work in WP4 was to evaluate a roro handling concept vs a regular handling concepts for unitised cargo in inland waterborne service. The container roro vessel will in general have lower cargo carrying capacity but potential benefits when it comes to cost and speed for cargo handling in the terminal. Applying the results from the cargo systems development in task 4.3, the vessels and the cargo handling were prepared to enable the assessment of the performance for a specific transport mission. The performance of the vessels and the cargo handling was first estimated separately

a) For the vessels, the required freight rate was calculated assuming a typical route. This gave the transport cost per cargo unit, see section 4.3.1
b) For the cargo handling, the terminal operating cost was estimated for the different terminals and the different handling concepts. From this a handling cost per unit was derived, see section 4.3.2.

The transport cost for the different vessels from a) and the handling cost for the different terminals and handling concepts from b) can then be used for comparison of different transport concept involving one or several waterborne transport links in a multi modal door-to-door transport chain. A sample route Karlstad, Sweden to Stuttgart, Germany was analysed, see section 4.3.3.

5.5 Results for task 4.4.4 Detail at least three vessel concepts including sea-river and inland RORO options: hull geometry, compartments, propulsion, cargo system (ramps, doors, lashing details), outline specification.

The design of the five vessels concepts was advanced from the initial estimates in task 4.2 to a more detailed concept level. The hull structure scantlings were calculated according to the rules of the classification society providing a more accurate steel and lightship weight. Speed – power estimates were refined considering the specific displacement, hull shapes and propulsive efficiency, resistance and propeller selection. Stability analyses were made for different criteria and load cases.

6 ANALYSIS OF RESULTS

6.1 Summary of results

In task 4.4. it has been shown that a roro handling concept can be an attractive alternative to conventional handling of unitized cargo for inland waterway service. When comparing vessels of similar size, the container roro vessel will in general have lower cargo capacity than the conventional vessel but the possibility to use less expensive and quicker cargo handling concepts can compensate for the loss in cargo capacity to a large extent.

The container roro vessel will have a higher flexibility so that all types of rolling cargo can be combined with container cargo. Such combined service will lower the threshold to get trailers off the road and onto the water.

The container roro vessels should have significantly shorter waiting time in the short-sea and deep-sea container terminals since they do not utilize the same cargo handling equipment as the larger prioritized vessels. This leads to a better utilization of the container roro vessel with more round trips per year compared to a conventional vessel.

Additionally, the container roro vessels would be able to serve smaller inland ports with less developed port infrastructure, considering that container cranes would not be necessary and that vessels could always carry an NCHV onboard.

6.2 NOVIMAR container roro vessels

Both the roro handling concept and the sea-river concept have the potential to improve the competitiveness of waterborne transport for inland transportation.

When comparing vessels of similar size, it is clear that a vessel designed for horizontal loading and unloading over a ramp (roro handling) will have lower cargo carrying capacity than a conventional vessel. However, the reduced cargo carrying capacity may be compensated by the lower transport costs per unit, which is achieved by the following.

1. Lower cost for the cargo handling operation since less expensive, and higher capacity cargo handling equipment can be used.
2. Reduced wating time at the short-sea and deep-sea terminals for the inland waterway vessels. By using roro handling equipment, the IWW will not have to wait for the larger ships that always are given priority. Reduced wating time means more round trips per year and higher vessel utilization.

The sea-river vessel might be less efficient on the individual short-sea and inland waterway sections compared to purpose-built short-sea and inland waterway vessels. This is because the sea-river vessel has to combine a large number of requirements, but by eliminating the need for cargo transfer in the sea-ports, cost and time are saved which can make the overall efficiency of the sea-river vessel higher than other alternatives.

Table 21, Summary pros and cons container roro vessel vs conventional container vessel

	Container roro vessel	Conventional container vessel
Type of cargo	+ (Container and rolling cargo)	- (Only containers)
Cargo capacity	- (lower)	+ (higher)
Cargo handling speed	+ (higher)	- (lower)
Cargo handling cost	+ (lower)	- (higher)
Waiting time at terminals	+ (shorter)	- (longer)
Round trips per year	+ (more)	- (less)
Vessel cost	- (higher)	+ (lower)

The table gives a qualitative comparison. A detailed evaluation for a specific transport mission will have to be done in order to see if the container roro vessel can provide a more competitive operation.

6.2.1 NOVIMAR Class III container roro vessel

The smallest container roro vessel that was designed, the class III size vessel, is the design that loses least cargo capacity compared to a regular container vessel of similar size. The vessel can load 28 TEU compared to the 32 TEU capacity. The additional light ship weight is quite small, the centre of gravity of the cargo is slightly higher which reduces the average container weight.

Table 22, Capacities of Conventional and NOVIMAR roro, small size inland container vessel

	NOVIMAR roro
TEU capacity	28
Average TEU weight, uniform loading	19
Total cargo weight, uniform loading	532

6.2.2 NOVIMAR Class Va container roro vessel

Two concepts were developed one with regular draft and one with shallow draft. For the shallow draft concept one stern access and one double-end access version have been developed. The objective was to provide the best performing design option for a specific service based on operational and physical requirements.

When it comes to vessel performance in a transport system the main feature is cargo carrying capacity. Cargo carrying capacity is not only a matter of the available physical cargo space, it also involves to very high degree the ability to meet the different stability criteria. In principle, the different stability criteria will provide the limits for the combination of maximum weight and maximum vertical centre of gravity, VCG, of the cargo that can be transported.

A conventional Class Va container vessel can load four tiers of containers on the tanktop deck (inner bottom), typically positioned 600 mm above baseline. With four tiers, the regular draft vessel has cargo space for 192 TEUs. Since the NCHV is limited to handle one double stacked pack of containers the regular draft versions of the NOVIMAR Class Va container roro vessel have two cargo decks. The lower cargo deck is the tanktop deck, the upper deck is the watertight bulkhead deck located 6950 mm above base line. The two-deck concept will provide physical space for 184 TEU. This is a reduction by approx. 10% but the cargo carrying capacity is reduced even more due to the higher VCG of the cargo. The benefits of the container roro vessel over the conventional container vessel will very much depend on the weight of the containers for the actual service, if it has to carry dangerous goods and if the possibility to combine roro and container cargo provides additional earning potential.

The shallow draft versions of the NOVIMAR Class Va container roro vessel have one cargo deck located 3000 mm ABL. With two tier loading by the NCHV, the capacity is 100 - 104 TEU which is about 50% of a conventional container vessel and 45% less than the regular draft NOVIMAR class Va design. However, the reduction in actual cargo carrying capacity can be much less. The NOVIMAR Class Va, shallow draft vessel has also the ability to load a third tier by means of a container crane. This will take away some of the benefits of the roro concept but will increase the capacity, if needed. Furthermore, the stern access shallow-draft vessel would be able to expand cargo carrying capacity by forming a pushed convoy with a barge, when the vessel sails out of VT.

Another important factor for the actual cargo carrying capacity is whether or not the vessel shall be able to carry dangerous goods. For cargo vessels not designed to carry dangerous goods the stability criteria are simpler and based only on intact stability. To allow transport of dangerous goods the vessel needs also to comply with damage stability rules.

Which version that would provide the highest overall performance will depend on a large number of factors such as average container weight, container weight distribution, ability to transport dangerous goods as well as available time in terminals and the cargo handling equipment.

The regular draft vessel is optimized for carrying secured containers, without dangerous goods. In such case, the regular draft vessel will have the best cargo carrying capacity of all class Va container roro vessels. On the other hand, the shallow-draft vessels are optimized to carry unsecured containers with dangerous goods. Therefore, their cargo carrying capacity would not change in case that the containers are secured, or in case that the cargo does not contain dangerous goods. However, there would be greater flexibility with respect to the vertical distribution of cargo which could enable faster loading.

Table 23, Capacities of different CEMT class Va size container vessels designed to transport dangerous goods

<table>
<tr><th></th><th colspan="6">CEMT Class Va size container vessel</th></tr>
<tr><th></th><th colspan="6">NOVIMAR roro</th></tr>
<tr><th></th><th colspan="2">Regular draft</th><th colspan="4"></th></tr>
<tr><th></th><th colspan="2">Bow access</th><th colspan="2">Double-end access</th><th colspan="2">Stern access</th></tr>
<tr><th></th><th>4 tiers</th><th>3 tiers</th><th>2 tiers</th><th>3 tiers</th><th>2 tiers</th><th>3 tiers</th></tr>
<tr><td>TEU capacity</td><td>184</td><td>124</td><td>100</td><td>146</td><td>104</td><td>152</td></tr>
<tr><td>Average TEU weight, uniform loading</td><td>4.6</td><td>13.5</td><td>11.8</td><td>8</td><td>11.3</td><td>7.8</td></tr>
<tr><td>Total cargo weight, uniform loading</td><td>846</td><td>1674</td><td>1180</td><td>1139</td><td>1186</td><td>1186</td></tr>
<tr><td>Trailer capacity</td><td colspan="2">46</td><td colspan="2">24</td><td colspan="2">26</td></tr>
</table>

Table 24, Capacities of NOVIMAR Class Va, regular draft container roro vessel not designed to transport dangerous goods

	NOVIMAR roro	
	Regular draft	
	4 tiers	3 tiers
TEU capacity	184	124
Average TEU weight, uniform loading	6	14.7
Total cargo weight, uniform loading	1104	1823
Trailer capacity	46	

Table 25, Capacity of NOVIMAR Class Va, regular draft container roro vessel not designed to transport dangerous goods, but secured (lashed) containers

	NOVIMAR roro	
	Regular draft	
	4 tiers	3 tiers
TEU capacity	184	124
Average TEU weight, uniform loading	7.9	22.3
Total cargo weight, uniform loading	1454	2765
Trailer capacity	46	

6.2.3 NOVIMAR Sea-river container roro vessel

The dimensions of the Sea-river container roro vessel were chosen so the ship can operate from lake Vänern, Sweden to the major inland ports along river Rhine. The container space capacity is 140 TEU which is about 10% less than what can be achieved for a similar sized conventional vessel designed for vertical container handling.

Depending on the actual water level and destination, the possibility to carry a second tier on the main deck will be affected. The vessel has large ballast capacity to enable adjustment to the depth of the fairway and air draft.

Table 26, Capacities of Conventional and NOVIMAR roro, sea-river vessel

	NOVIMAR roro
TEU capacity	140
Average TEU weight, uniform loading	12.7
Total cargo weight, uniform loading	1778

6.3 Vessel concepts performance within a transport mission

To assess the different vessel concepts, the interaction with the shore (loading, unloading and terminal handling) need to be considered. For the assessment, a limited transport and handling cost model was developed. The model does not consider the total cost of transport but is limited to the parts that significantly differs between the concepts.

In the model, the required freight rate (RFR) for each vessel is calculated. The capital costs, operation costs and voyages cost are summarized to the get the total operating cost. The RFR is then given by the ratio between the total operating cost and the number of units that are expected to be transported.

The ship design work done in the task 4.4 has been the foundation for the RFR calculation

The other relevant part for the vessel concept comparison, is the cargo handling cost which differs between the vessel concepts and terminals.

The benefits of using NOVIMAR container roro vessels are supported with a sample calculation of the door-to-door transport and handling costs on the route from Karlstad, Sweden to Stuttgart Germany. The model indicates that there are considerable benefits with both the roro handling as well as the sea-river concepts, with potential to improve the competitiveness and attractiveness of inland waterway shipping.

Table 27, Comparison of different transport concepts for door-to-door transport of one 40 feet container from Karlstad Sweden to Stuttgart, Germany

Short sea and inland waterway lolo container operation				
	Cost		**Fuel cons.**	**time**
	€	kg/FEU	kg/(FEU x km)	h
In transport	820	368.3	0.22	132
In terminal	640	45.0	x	157
Total	**1 460**	**413.3**		**289**
				12.0 days
Relative to truck	84%	69%		
Relative to lolo	100%	100%		

Short sea and inland waterway roro container operation				
	Cost		**Fuel cons.**	**time**
	€	kg/FEU	kg/(FEU x km)	h
In transport	861	434.4	0.26	100
In terminal	280	36.6	x	79
	1 141	**471.0**		**179**
				7.5 days
Relative to truck	66%	78%		
Relative to lolo	78%	114%		

Sea River roro operation				
	Cost		**Fuel cons.**	**time**
	€	kg/FEU	kg/(FEU x km)	h
In transport	911	453.7	0.27	137
In terminal	180	25.3	x	31
	1 091	**479.0**		**168**
				7.0 days
Relative to truck	63%	80%		
Relative to lolo	75%	116%		

Truck and Short sea lolo operation				
	Cost		**Fuel cons.**	**time**
	€	kg/FEU	kg/(FEU x km)	h
In transport	1 121	486.5	0.29	55
In terminal	355	30.0	x	97
	1 476	**516.5**		**152**
				7.0 days
Relative to truck	85%	86%		
Relative to lolo	101%	125%		

Truck door-to-door				
	Cost		**Fuel cons.**	**time**
	€	kg/FEU	kg/(FEU x km)	h
In transport	1 700	595.0	0.35	49
In terminal	40	7.5	x	1
	1 740	**602.5**		**50**
				2.1 days
Relative to truck	100%	100%		
Relative to lolo	119%	146%		

A more extensive table and more detailed data can be found in section 4.3.3

The calculations are based on estimates and assumptions so the resulting numbers should only be considered as indications.

However, for the multimodal transportation of a 40 feet container from Karlstad, Sweden to Stuttgart, Germany the model indicates the following.

- An operation combining inland waterway vessels and short sea vessels designed for roro handling and stowage of containers with novel roro handling technology, can reduce the door-to-door cost by 22% compared to conventional short sea and inland waterway operations, however the fuel consumption per transported unit is 14% higher compared to conventional operation.
- A sea-river vessel designed for roro handling and stowage of containers with novel roro handling technology, can reduce the door-to-door cost by 25% compared to conventional short sea and inland waterway operations but the fuel consumption per transported unit will be 2% higher .
- The door-to-door transport time is expected to be shorter for roro concept. This is based on the assumption that the dwell time in the terminals will be shorter since the roro handling of containers will involve fewer steps and less interaction and coordination for utilization of the expensive equipment that prioritizes the larger vessels.
- When it comes to speed, there is nothing that can compete with a direct truck transport, however a well-designed and organized waterborne service will be cheaper and maybe more significant, it will be more energy efficient. Compared to a direct door-to-door truck service the sea river concept will be 37% cheaper and 20% more energy efficient for transporting a 40 feet container from Karlstad, Sweden to Stuttgart, Germany

A regular and frequent service that can transport containers at a competitive cost and at the same time bring along rolling cargo such as road trailers, wheeled construction equipment, new vehicles etc should have a great potential to move significant volumes of cargo from the roads to the waterways.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

7.1.1 Ship design

Ship design has been performed for a total of five vessels for inland waterway operation. The vessels are suitable for operation in a vessel train or as individual units. The design work includes a Class III container vessel, a sea-river container vessel and three versions of CEMT class Va sized container vessels. The vessels are designed to accommodate efficient cargo handling and stowage utilizing the NOVIMAR container handling vehicle, NCHV. The designs are presented in section 4.2.

NOVIMAR Class III container roro vessel

The smallest container roro vessel that was designed, the class III size vessel, is the design that loses least cargo capacity compared to a regular conventional container vessel of similar size. The limited draft should make the design quite versatile and applicable in a wide range of potential services to improve the penetration of waterborne transport further out in the logistic network. Due to limited cargo capacity, the cost and fuel consumption it is less favourable compared to the larger vessels but still the fuel consumption per transported unit per km is 20-25% lower than for truck transport

NOVIMAR Class Va container roro vessel

CEMT Class Va is the standard size vessel for inland container transport. The roro handling concepts affects the onboard stowage arrangement to a high degree, compared to conventional design.

Three different designs were developed. Which design that will provide the best performance will depend on the specific route and the intended service. “One design” will not fit all possible routes, services and navigation conditions. In unrestricted navigation conditions, the regular draft vessel (d = 3.15 m) would be a more suitable choice. However, the shallow-draft vessels (d = 2 m) could offer an uninterrupted service throughout the year, i.e. even during the low-water periods which seem to become more extreme in recent years. The double-end access shallow-draft vessel could prove to be a good option especially in situations when the cargo handling speed is more important. The three designs can be considered as a menu of options where the best combination will have to selected based on factors like.

- Fairway depth limitation, including current navigation conditions
- Distance
- Vessel train lead vessel, follower vessel or individual operation
- Requirement to transport dangerous good
- Container weights
    - Average weight
    - Weight distribution

The right specified vessel for the right operation will have the potential to provide an efficient service, more flexible than conventional operation and to a lower cost than road transport.

NOVIMAR sea-river container roro vessel

The objective of the Sea-river vessel is to enable direct waterborne transport of goods from an inland port in one part of Europe to an inland port in another part including a short sea voyage. Such direct transport eliminates the cost and damage-risk related to the transhipment operation in the intermediate seaport. The dimensions of the sea river vessel are constrained by the physical limitations in both ends of the route as well as the requirements to perform well on the short sea route. This will reduce the cargo capacity. However, the elimination of coast, time and risk of cargo handling int the seaports can compensate for the lower cargo capacity.

A sea-river vessel designed for roro handling and stowage of containers with novel roro handling technology, can considerably reduce the door-to-door transport cost and time compared to conventional short sea and inland waterway operations.

7.1.2 Vessel concepts performance

Both the roro handling concept and the sea-river concept have potential to improve the competitiveness of waterborne transport for inland transportation.

The benefits of the NOVIMAR container roro were demonstrated with a sample calculation of the door-to-door transport and handling costs on the route from Karlstad, Sweden to Stuttgart Germany. The door—to-door transport and handling costs were calculated for comparison. The results indicate that there are considerable benefits with both the roro handling as well as the sea-river concepts, with potential to improve the competitiveness and attractiveness of inland waterway shipping. More specifically, the model for the multimodal transportation of a 40 feet container from Karlstad, Sweden to Stuttgart, Germany indicates the following (See also Table 19);

- An operation combining Inland waterway vessels and short sea vessels designed for roro handling and stowage of containers with novel roro handling technology, can reduce the door-to-door cost by 22% compared to conventional short sea and inland waterway operations, however the fuel consumption per transported unit is 14% higher.
- A sea-river vessel designed for roro handling and stowage of containers with novel roro handling technology, can reduce the door-to-door cost by 25% compared to conventional short sea and inland waterway operations but the fuel consumption per transported unit will be 2% higher .
- The door-to-door transport time is expected to be shorter for roro concept. This is based on the assumption that the dwell time in the terminals will be shorter since the roro handling of containers will involve fewer steps and less interaction and coordination for utilization of the expensive equipment that prioritizes the larger vessels.
- When it comes to speed, there is nothing that can compete with a direct truck transport, however a well-designed and organized waterborne service will be cheaper and maybe more significant, it will be more energy efficient. Compared to a direct door-to-door truck service the sea river concept will be 38% cheaper and 21% more energy efficient for transporting a 40 feet container from Karlstad, Sweden to Stuttgart, Germany

A regular and frequent service that can transport containers at a competitive cost and at the same time bring along rolling cargo such as road trailers, wheeled construction equipment, new vehicles etc should have a great potential to move significant volumes of cargo from the roads to the waterways. Furthermore, a careful selection of design parameters could make inland vessels less dependent on the climate change effects, such are low water levels.

7.2 Recommendations

Based on the work and conclusions in NOVIMAR task 4.4 following recommendations are made

- The NOVIMAR roro handling concept should be further developed in order to identify how the potential of the concept, to move cargo from road to water, can be maximized in context of greening and climate change-resilience of inland navigation.
- For the sea-river concept, more design versions should be developed were the main dimensions are adopted so that the concept is made available to other short-sea/inland route combinations. (Similar to the work done for the CEMT class Va size vessels)
- The clear benefit of the lower energy consumption (higher energy efficiency) when transporting unitized cargo on water instead of on land should be better communicated, but for this to be relevant the waterborne alternative also need to implement renewable fuel and reduce emissions to show that they are the best overall alternative from environment and climate perspective.

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9 ANNEXES

Annex A: Public summary

Deliverable 4.4 Vessel concepts presents the design of **five container roro vessels** that can provide an efficient and compatible inland waterway service both in a vessel train and as independent vessels. The deliverable also presents a model to compare transport and handling cost for different multi-modal door-to-door transport alternatives

Three vessel categories were identified as relevant to provide cost efficient waterborne transportation solutions for service to and from inland ports.

- CEMT Class Va vessel
- CEMT Class III vessel
- Sea-river vessel

Based on the three categorise, five vessel concepts were developed.

- NOVIMAR Class Va container roro vessel
- NOVIMAR Class Va container roro vessel, shallow draft
  - Stern access version
  - Double-end access version
- NOVIMAR Class III container roro vessel
- NOVIMAR Sea-river container roro vessel

The vessels are designed to fully utilize the potential benefits of roro handling in general and the use of the NOVIMAR cargo handling concept in particular.

The benefits of the NOVIMAR container roro were demonstrated with a sample calculation of the door-to-door transport and handling costs on the route from Karlstad, Sweden to Stuttgart Germany was chosen and the door—to-door transport and handling cost was calculated for comparison. The results indicate that there are considerable benefits with both the roro handling as well as the sea-river concepts, with potential to improve the competitiveness and attractiveness of inland waterway shipping.

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Annex B: HAZID recommendations assigned to WP4

Table 28. HAZID recommendations assigned to WP4

No.	Recommendation	Affects	
1	Secondary means of propulsion	LV	
7	Minimum safe manning	LV	
8	Necessary equipment for emergency procedures	LV	FV
10	Monitoring of essential systems or operational characteristics		FV
11	Remote / automatic anchoring		FV
12, 14	Secondary means of steering	LV	FV
30	Support tools necessary to avoid / handle loss of stability / cargo		FV
33	Automatic draining systems	LV*	FV
36	Monitoring of cargo shift	LV*	FV
49	Handling the anchoring equipment failure on a following vessel	VT	
51, 56	Fire safety of VT control system (Location of the control system)	LV	FV
52	Fire safety of VT control system (Fire extinction)	LV	FV
53	Fire safety of VT control system (Fire detection)	LV	
54	Fire safety of ship compartments (Fire detection)	LV	
55	Handling the fire on a following vessel	VT	
57, 58	Fire safety of ship compartments (Fire detection and extinction)		FV
59, 60	Flooding protection of VT control system	LV	FV
61	Water ingress detection	LV*	FV
62	Damage stability calculations	LV*	FV
67	Emergency power supply of VT control system	LV	

* Originally designated to apply to FV (Follower vessel) only but may apply to LV (Lead vessel) as well for the sake of attaining the same safety level.

Annex C: Required freight rate calculation

Assumptions for required freight rate calculation			
Economic lifetime	25	years	for short sea RoRO, short sea container vessel
	20	years	for sea-river vessel, IWV
Interest rate	5.0%		
Insurance cost per year	1.5%		
Average cargo load	60%		for short sea container vessel
	75%		for other vessels
Average time in lock	45	minutes / lock	
Average time in major ports	6	hours	for sea-river vessel, CEMT Va RoRo
	12	hours	for CEMT Va ref
	8	hours	for short sea RoRo vessel
	24	hours	for short sea container vessel
Average time in small ports	2	hours	for sea-river vessel, CEMT Va RoRo
	5	hours	for CEMT Va ref
	1	hours	for CEMT II RoRo
	3	hours	for CEMT II ref
Number of terminal calls per round trip in small ports	3		
Vessel fuel cost	600	Euro / ton	
Truck freight rate	1	Euro / (FEU x km)	
Truck fuel consumption	0.35	kg / km	

			Short Sea container vessel	**Short Sea RoRo**	**Sea-River**	**CEMT V reference**	**Class Va container roro vessel**	**Class Va container roro vessel shallow draft**	**CEMT III reference**	**Class III container roro vessel**
Ship data	Length	m	140.0		89.0	110.0	110.0	104.0	63.0	63.0
	Beam	m	21.8		13.4	11.5	11.5	11.5	7.0	7.0
	Depth	m	17.5		7.7	6.8	7.1	3.0	2.8	2.8
	Draft	m			3.8	3.9	3.9	2.0	2.5	2.5
	Design speed	km/h	29.6	35.2	22.2	18.0	18.0	18.0	18.0	18.0
		knots	16.0	19.0	12.0	9.7	9.7	9.7	9.7	9.7
	Block coefficient				0.74	0.89	0.89	0.89	0.84	0.84
	Hull weight	ton			756	1 000	811	631	187	187
	No. of propellers		1	1	2	1	2	2	1	1
	Installed propulsion power per propeller	kW	7500	10000	675	1 492	675	562	450	450
	Installed electric installed	kW			450	450	450	450	150	150
	Specific fuel oil consumption SFOC	g/kWh	180	180	200	200	200	200	200	200
	No. of bow thruster		2	2	1	1	1	1	1	1
	Installed power per bow thruster	kW			400	400	400	400	191	191

Operation data		Short Sea container vessel	Short Sea RoRo	Sea-River	CEMT V reference	Class Va container roro vessel	Class Va container roro vessel shallow draft	CEMT III reference	Class III container roro vessel
		Gothenburg - Rotterdam			Rotterdam - Mannheim			Mannheim - Stuttgart	
Distance per RT	km	2037			1120			400	
Distance perl leg		1019			560			200	
	NM	1100							
Average sailing speed	km/h	25.9	31.5	21.3	12	12	12	12	12
	knots	14	17	12					
Speed-power coefficient		2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Average engine part load	%	72%	76%	90%	34%	34%	36%	34%	34%
Average engine power	kW	5 371	7 572	1 214	504	456	490	152	152
Sailing time RT	hr	79	65	96	93	93	93	33	33
Sailing time per leg									
Average number of locks per round trip		0	0	0	2	2	2	16	16
Average time in lock					0.75	0.75	0.75	0.75	0.75
Total time in lock	hr				1.50	1.50	1.50	12.00	12.00
Number of terminal calls per RT in major ports		2	2	0	2	2	2	0	0
Average time per terminal call in major ports		24	8	8	12	6	4.5	3	1
Number of teminal calls pre RT in small ports		0	0	0	3	3	3	3	3
Average time per terminal call in smaller ports		0	0	0	5.0	2.0	1.0	3.0	1.0
Total time in terminal	hr	48	16	0	39	18	12	9	3
Average electric consumption	kW	500	500	150	113	113	113	25	38
Total time per round trip	hr	127	81	96	134	113	107	54	48
	days	5.27	3.36	3.99	5.58	4.70	4.45	2.26	2.01
Voyage section persentage				40%					
RT per year		69	109	37	65	78	82	130	145
Sailing hours per year		5438	7023	7877	6109	7246	7653	4333	4833
Maximum cargo capacity	TEU	800	540	140	208	184	146	32	28
Average cargo load		60%	75%	75%	75%	75%	75%	75%	75%
Average number of TEU per one way trip		480	405	105	156	138	110	24	21
Transported TEU per year per one way trip		66442	87919	7725	20422	21428	17957	6240	6090
Transported TEU per year per RT		132883	175838	15450	40844	42855	35915	12480	12180
Fuel price	€/ton	600	600	600	600	600	600	600	600
Fuel consumption ship	ton/year	6046	10362	960	813	858	947	167	200
Check		0.089	0.116	0.122	0.071	0.072	0.094	0.134	0.164

			Short Sea container vessel	Short Sea RoRo	Sea-River	CEMT V reference	Class Va container roro vessel	container roro vessel shallow draft	CEMT III reference	Class III container roro vessel
Capital cost										
Investment (New builiding cost)		€	40 000 000	60 000 000	6 351 093	4 533 701	4 521 606	3 962 135	1 440 829	1 467 079
Ecomomic lifetime	n	y	25	25	20	20	20	20	20	20
Interest	i		5%	5%	5%	5%	5%	5%	5%	5%
Calculated annuity		€/y	2 702 951	4 054 426	485 360	346 472	345 548	302 792	110 110	112 116
					0	-	-	-		
Total capital cost per year			2 702 951	4 054 426	194 949	346 472	345 548	302 792	110 110	112 116
Running cost										
Daily running cost										
- crew costs		€/y	523 454	523 454	450 000	377 475	377 475	377 475	265 366	265 366
- provisions and stores										
- maintenance and repairs, fixed		€/y			23 763	30 142	24 560	11 908	5 513	5 513
- maintenance and repairs, variable		€/y	893 890	893 890	127 610				21 450	26 100
						-	-	-		
- insurance	1.50%	€/y	600 000	900 000	95 266	68 006	67 824	59 432	21 612	22 006
Total running cost pe year			2 017 344	2 317 344	279 812	557 613	564 330	546 247	313 941	318 985
Voyage cost										
- bunkers			3 627 596	6 216 912	575 803	487 899	514 966	568 165	100 270	119 742
						0	0	0		
Totall voyage cost			3 627 596	6 216 912	575 803	487 899	514 966	568 165	100 270	119 742
						0	0	0		
Total cost per year			**8 347 891**	**12 588 682**	**1 050 564**	**1 391 983**	**1 424 845**	**1 417 205**	**524 321**	**550 843**
Transported untis per year		TEU	66442	87919	7725	48985	40087	7725	6240	6090
Reqiured freight rate		€/TEU	126	143	136	68	66	79	84	90
						0	0	0		
Reqiured freight rate		€/FEU	251	286	272	136	133	158	168	181

Annex D: Tank arrangements NOVIMAR Class Va container roro vessel, shallow draft

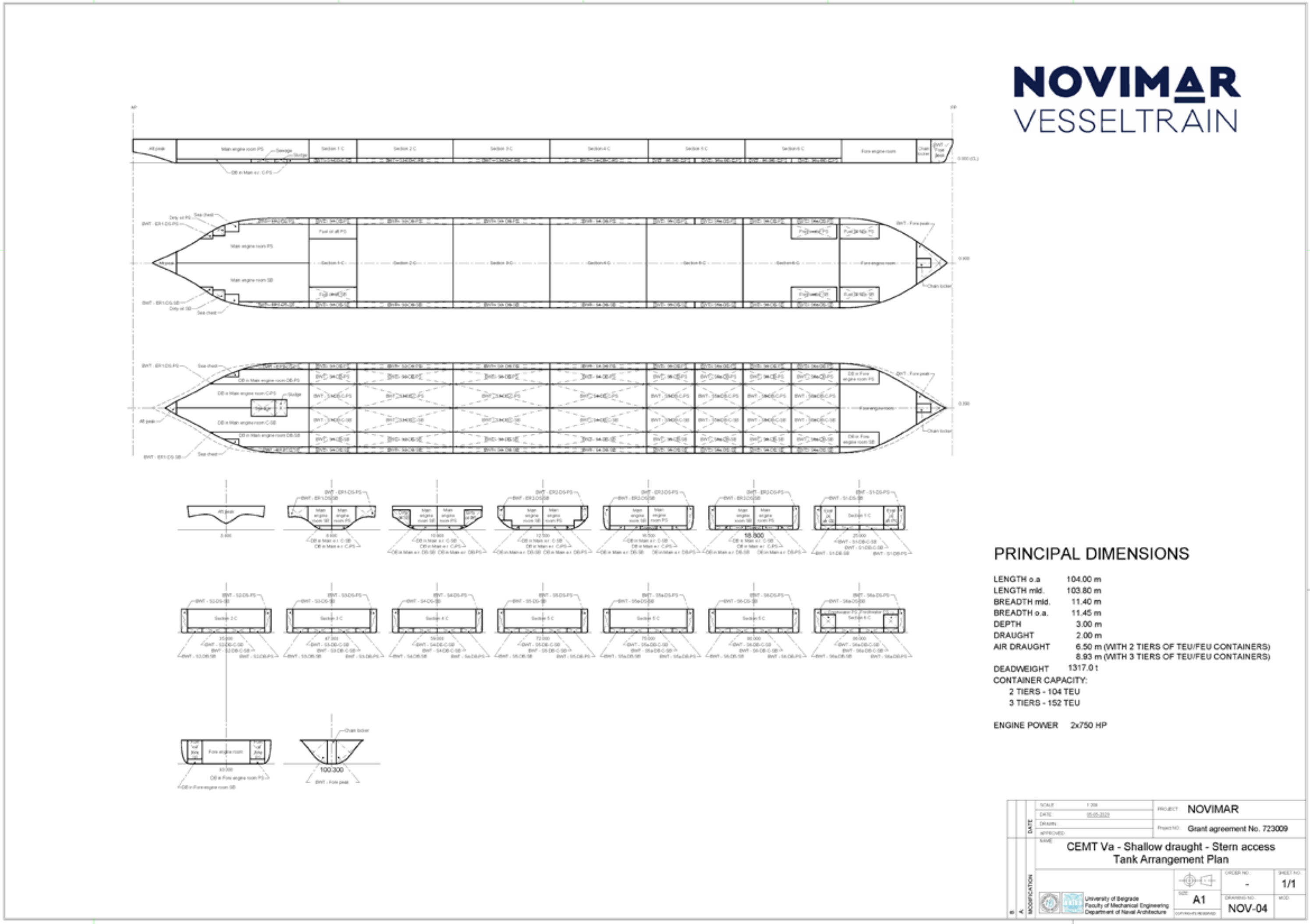

Figure 30, Tank arrangement, stern access version

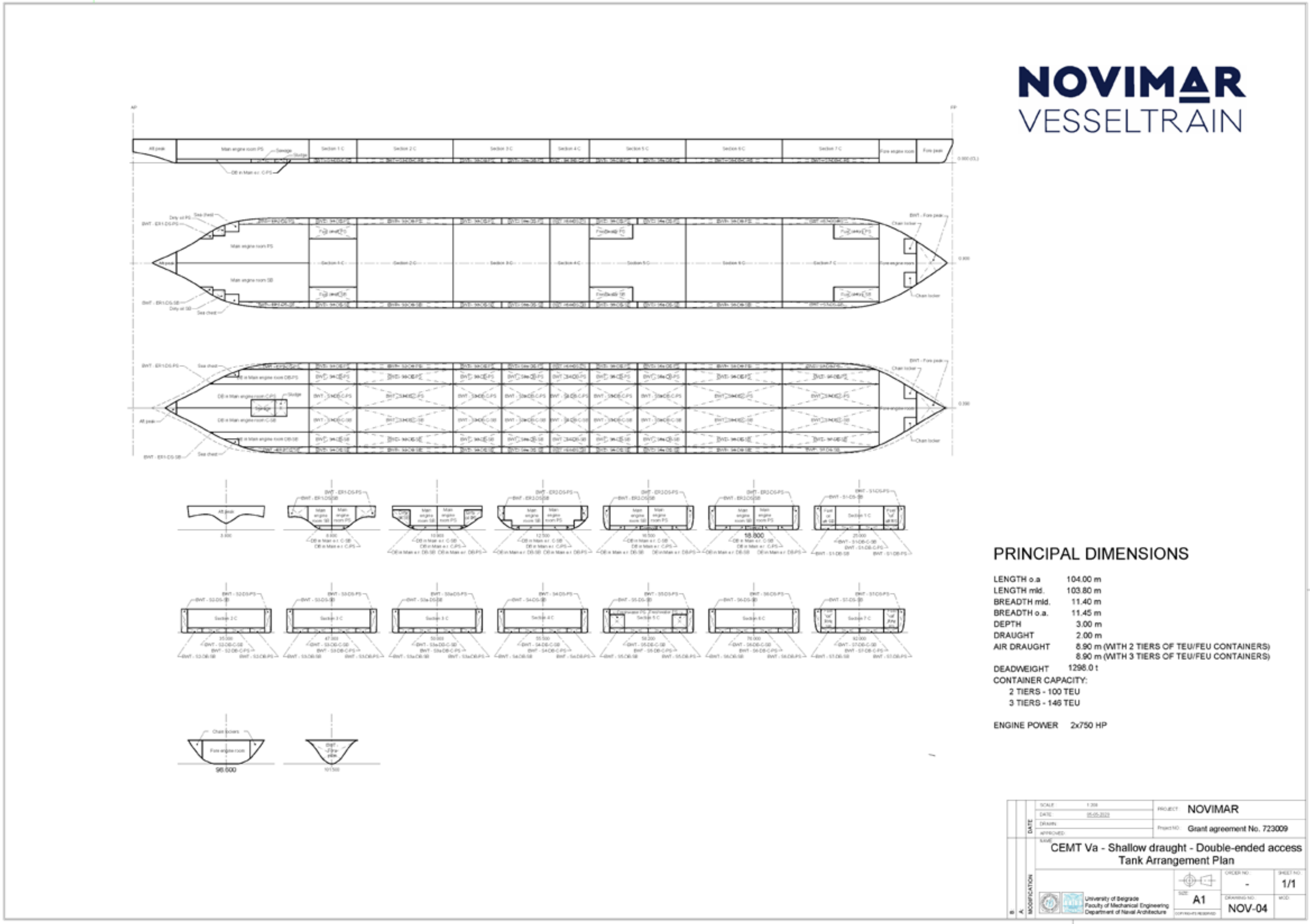

Figure 31, Tank arrangement, double-end access version