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New Design Options for Container Barges with Improved Navigability on the Danube

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Abstract: One of the measures set forth by the European Green Deal to decarbonize the freight transport sector is the promotion of inland waterway transport (IWT), and particularly intermodal transport in Europe. To facilitate intermodal transport on the Danube, we developed six new barge designs for the transport of 45′ pallet-wide high-cube containers using a four-step approach. Our approach consisted of detailed desk research, followed by the design and further analysis of the identified barge types, considering, for example, sightlines and stability. Their container carrying capacity reaches up to 90 containers in three layers, which is double the capacity of existing standard barges on the Danube. Nevertheless, three-layer transport is hardly feasible in several cases, due to restrictions regarding sightlines and stability. We conclude that each loading condition must be evaluated separately to determine the best barge design option for each case. This study is limited by its geographical scope and the type of container used to develop the new barge designs. A possible direction for further research could be using other container types and/or extending the geographical scope to extend the usability of our container barge designs.

Keywords: barge design; navigability; low water level; container transport; naval architecture; CAD; Danube

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1. Introduction

The European Green Deal has set ambitious targets: climate neutrality by 2050 and a reduction of transport-related greenhouse gas emissions by 90% by 2050. The Sustainable and Intelligent Mobility Strategy lays the foundations for achieving the green and digital transformation of the EU's transport system. One measure which has been identified to reduce transport emissions is a shift to inland waterway transport (IWT). IWT can reduce the negative impacts of road transport, such as greenhouse gases, emissions, noise, and congestion costs [1,2]. For several years now, the European Commission has been promoting shifts from road freight transport to more sustainable modes. Nonetheless, these alternative modes currently account for only a limited share of transport activities across most European regions [3]. IWT has a limited network density and is dependent on multimodal transport, with pre-carriage and on-carriage often carried out by road due to the high-density road network for collection and delivery [4,5]. As containers are mostly standardized and usually utilized as equipment for intermodal transports, it is essential to enable and facilitate their transport on inland waterways. While the transport of containers is already common on rivers, such as the Rhine, there are hardly any container transports carried out on the Danube [6]. Thus, enabling container transports on the Danube could, on the one hand, promote intermodal transport and, on the other hand, increase the usage of the Danube significantly by attracting new customers [7].

To enable efficient intermodal transport, a continuous and resilient infrastructure for the involved transport modes is required [8,9]. For IWT, this means that there are minimum

fairway parameters, such a minimum fairway depth and width, which are required to ensure economic, viable transport and a resilient infrastructure [10]. The IWT infrastructure faces two main challenges, which hamper the deployment of these minimum fairway parameters. Firstly, as a natural resource, inland waterways have uneven riverbeds, which means that the fairway depth of the river can vary throughout the course of the river and throughout a year. This could be a cause for the development of bottlenecks on inland waterways [11]. To maintain a water depth of 2.5 m throughout the year, maintenance works, such as continuous dredging works to remove the surplus sediment in inland waterways, are essential. Secondly, there have been increasingly frequent periods of low water in recent years. Low water means that a river does not carry enough water due to metrological conditions, e.g., droughts. Periods of low water often last for several months and massively impede IWT, as the resulting shallower fairway depth means that the cargo-carrying capacity of inland vessels decreases significantly. This may lead to delayed, unreliable and uneconomical transport [10].

One possibility to improve the navigability of inland waterways in low-water periods is to adapt the current available vessel designs to the increasingly frequent low water conditions. Few studies have already addressed this issue, because the modernization of inland vessels in Europe primarily focuses on innovative solutions aimed at enhancing propulsive efficiency, utilizing alternative fuels, adopting telematics and other operational assistance tools, and exploring the potential for autonomous shipping on inland waterways [12].

A study from Obidike [13] investigates the possibility for the improvement of cargo transport within European inland waterways by exploring the design and optimization of a pushed barge capable of coping with the events of shallow water while also remaining a plausible solution in normal water conditions. The proposed vessel is optimized with the aim of minimizing its overall lightship weight through structural weight reduction via a careful assessment of the vessel's main dimensions and hull structure, while conforming to structural, economic and production constraints [13]. Sha et al. [14] present a new design for a 3000 tonne dead weight barge. Alternate stern shapes are examined using the CFD software SHIPFLOW. The hull form is model-tested. The propeller geometry is optimized for the given engine and a suitable gear box. The proposed design was then investigated for its manoeuvring ability in shallow waters. The hydrodynamic sway forces, yaw moments and nominal wake distribution of the port and starboard propellers during manoeuvring motions are estimated by CFD software SHIPFLOW. The barge's directional stability performance is investigated for twin-propeller twin-rudder configurations [14]. Radojčić et al. [15] address the key aspects for the design of contemporary, shallow-draught IW vessels for the transport of dry cargo (containers and bulk cargo). Most of the logic that they presented is applicable to the design of river vessels for any river, but the material that they presented is focused on vessels for the Danube and its tributaries. Backalov et al. [16] investigate the possibilities for the improvement of container transport on the Danube by means of an innovative and unconventional container vessel design. The proposed design differs from standard European inland ships of the same capacity due to its shallow draught and increased breadth [17].

Our paper pursues the aim of identifying new barge options for optimized container transport on the Danube. As containers have a lower density than, e.g., bulk goods, their navigability on fluctuating and low water is cost-effective. The research questions which guide this paper are the following:

(RQ1): Which design options effectively enhance navigability for container barges on the Danube?
(RQ2): How do these improvements compare in terms of stability and sightline assessments?

This paper is structured as follows: Section 2 focuses on the methodology. Section 3, which presents the new barge designs in detail, followed by an in-depth analysis of the barge designs, includes the analysis of the sightlines and a stability analysis. In Section 4, the results are discussed, and further research needs are identified.

2. Materials and Methods

Our approach to developing and evaluating new barge design options for the fluctuating water conditions on the Rhine–Main–Danube corridor is based on naval engineering knowledge and involved a systematic four-step process, which is visualized in Figure 1.

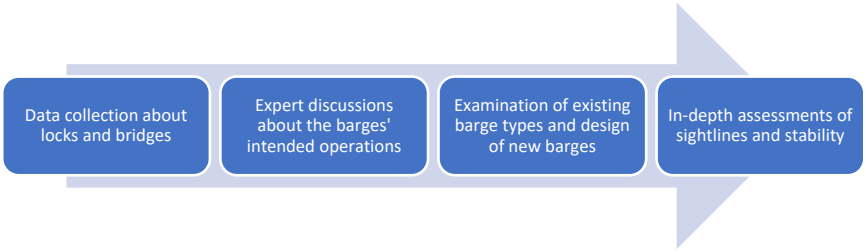


Figure 1. Four-step approach to new barge designs.

First, we embarked on a comprehensive data collection phase, meticulously gathering information on the infrastructure along the corridor. This included detailed data on locks, bridges and ports, which were essential to understand the operational constraints and navigational challenges faced by barges. Through extensive desktop research and a literature review, we synthesized these data to gain insight into the specific requirements and constraints of the waterway.

As a second step, we engaged in detailed discussions to establish the precise parameters of the barge's intended operation. This crucial step involved defining the specific waterways the barge would navigate and identifying the types of goods it would carry. With a view to seamlessly integrate IWT into existing logistics chains, it is essential for the barges to be able to carry 45′ pallet-wide high-cube units (dimensions: 13.716 m × 2.55 m × 2.896 m), as this is the predominant type used for intermodal transport in mainland Europe. By aligning our design objectives with the unique requirements of the waterway and cargo, we ensured that the resulting barge designs would be optimally suited to their intended purpose.

With a clear understanding of the operational context and design objectives, we proceeded to analyse the existing barge options for container transport on the Danube. This comparative analysis provided valuable insights into the strengths and limitations of current designs and laid the groundwork for the development of innovative solutions. Based on this analysis, we conceptualized and designed a series of new barge prototypes equipped to navigate safely and economically through fluctuating water levels. For the determination of their lightship weight, all barge types have been modelled using the structural 3D CAD software SOLIDWORKS, version 2022, according to the dimensions derived from the longitudinal strength assessment. As for building material, conventional grade A shipbuilding steel has been assumed, with the following material properties [18]: relative density, 7.8 t/m^3; yield strength, 235 N/mm^2. All hydrostatic calculations (floating position under different loading conditions, stability, bending moments) have been performed with the naval architecture software Delftship, version 14.30 [19].

To achieve acceptably comparable results, the preliminary dimensioning for all barge versions was carried out using the software GLRulesND (Version 2.950, Edition 2014). Based on the preliminary results for the thickness of the bottom, bilge and side plating, as well as the dimensions of the bottom and side girders, the main sections for all barge versions have been drawn up. This structural design has been further refined by assessing the individual moments of inertia and the section moduli of the cross-sections of the different barge versions against the bending moments resulting from a standardised load distribution at a draught of 2.70 m. This structural design testing has been carried out for all barge versions for grade A shipbuilding steel. To achieve directly comparable results for lightship weights and draughts, with different loading conditions for the various barge versions, we endeavoured to keep the safety factor between the maximum permissible bending moment and the actually given bending moment in a range between 2.15 and 2.3.

In the final stage of our approach, we carried out an in-depth assessment of the identified design options, examining their stability, line of sight requirements and the suitability of their construction materials. We also carefully evaluated key nautical factors such as draught and air draft to ensure their compatibility with the dynamic water conditions of the Danube. This rigorous evaluation process enabled us to refine and prioritise the design options based on their feasibility, performance and potential to improve navigational efficiency and safety.

By rigorously following this systematic approach, we not only developed a diverse range of innovative barge designs, but also laid the foundation for informed decision-making regarding their implementation and deployment in real-world scenarios. It has to be noted that the barge designs have not been optimized from a hydrodynamic perspective, as the focus was placed on the optimization of their cargo capacity.

3. Results

Generally, there is minimal room for enhancing or refining barge dimensions to efficiently utilize the current infrastructure of the Danube. Regrettably, the existing infrastructure lacks a coherent size framework. For instance, locks that are 24 m wide can accommodate two vessels that are 11.75 m wide each, whereas, to accommodate three barges in the larger 34-m-wide locks on the Danube, the maximum width of such barges would be capped at 11.16 m. Therefore, for all further considerations during barge design, the following limits have been applied as these dimensions are considered to be an acceptable compromise between lock utilization and sufficient flexibility, with a view to the accommodation of 45′ high-cube containers.

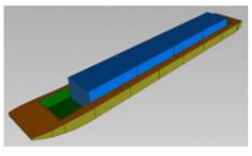
Maximum length: 97.50 m
Maximum breadth: 11.45 m

The sections below describe the new barge designs one by one, addressing various characteristics such as the sight lines, stability and capacity of each barge.

3.1. Design Options

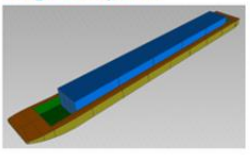
Based on the Europe 2b and Europe 3a barges, which are both visualized in Figure 2, six new barge designs were developed. The Europa 2b barge can be regarded as a prototypical example of a multifunctional vessel within the realm of European inland navigation. For the analysis of design options for new barges, it serves as a benchmark for comparison purposes. Many barges of this type or with slightly varied main dimensions can be found in operation on European inland waterways with a wide range of different cargoes (e.g., bulk, containers, high and heavy, etc.). The Europa 3a is a larger version of the Europa 2b barge and also serves as a benchmark, for comparison purposes, for the new barge designs. Figure 2 shows the CAD models and details of the Europa 2a and Europa 2b barge designs.

Barge Europa 2b



Project ID		001	
Length	[m]	76.5	
Breadth	[m]	11.5	
Lightship displacement	[t]	368.1	
No. of containers (45′ pallet-wide)		2 layers	3 layers
		24	36

Barge Europa 3a

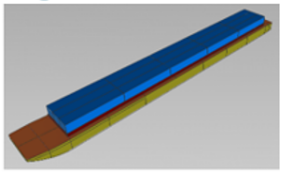


Project ID		002	
Length	[m]	90.0	
Breadth	[m]	11.5	
Lightship displacement	[t]	433.4	
No. of containers (45′ pallet-wide)		2 layers	3 layers
		30	45

Figure 2. CAD models and details of Europa 2b and Europa 3a barges.

The general idea behind the design of the "IW-NET—3 units abreast" barge is to tightly fit the principal geometry of the Europa 2b and Europa 3a barges around a container stack of three by five by two 45′ high-cube containers; i.e., to reduce the width of the barge to the width necessary for the cargo hold and two side decks, in accordance with the applicable statutory technical requirements, and to fit a bow and a stern section similar to the Europa barges to the cargo hold lengthwise. Figure 3 shows the IW-NET—3 units abreast barge design.

Barge IW-NET – 3 units abreast

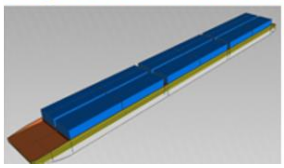


Project ID		003	
Length	[m]	81.0	
Breadth	[m]	9.5	
Lightship displacement	[t]	334.4	
No. of containers (45′ pallet-wide)		2 layers	3 layers
		30	45

Figure 3. CAD model and details of "IW-NET—3 units abreast" barge design.

The general idea of the 004 IW-NET NEWS Evolution barge design, which is presented in Figure 4, is to optimise the Europa 2b and Europa 3a barge designs for container transport by replacing the two side decks with a central walkway to create container bays in order to fit four rows of containers abreast. The need to accommodate 45′ pallet-wide high-cube containers in order to facilitate the integration of inland navigation into the logistics chains in mainland Europe (i.e., in particular, pre- and on-carriage by road or rail) is also taken account.

Barge IW-NET – NEWS Evolution v2

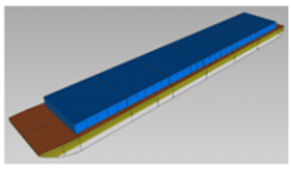


Project ID		004_v2	
Length	[m]	85.9	
Breadth	[m]	11.5	
Lightship displacement	[t]	465.6	
No. of containers (45′ pallet-wide)		2 layers	3 layers
		40	60

Figure 4. CAD model and details of 004 IW-NET NEWS Evolution barge design.

The 005 IW-NET containers transverse design (see Figure 5) is the result of an attempt to "think outside the box". Instead of the usual lengthwise placement of the containers, in this design option, the containers are arranged transverse to the longitudinal centre plane. Naturally, this results in a much broader barge, which does not fit into the usual convoy patterns, etc. However, it was considered worthwhile to include this option in the analysis. With a view to the breadth of the barge, it would not be possible to pass the locks on the upper Danube (upstream of Regensburg) and on the Main–Danube Canal. Considering the low grade of the compatibility of this barge for convoy formations, this basic design might be converted into a self-propelled motor cargo vessel.

Barge IW-NET – Containers transverse v2

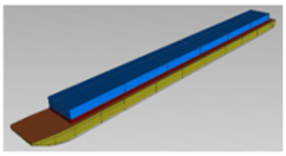


Project ID		005_v2	
Length	[m]	89.8	
Breadth	[m]	16.3	
Lightship displacement	[t]	611.9	
No. of containers (45′ pallet-wide)		2 layers	3 layers
		60	90

Figure 5. CAD model and details of 005 IW-NET containers transverse barge design.

The 006 IW-NET 3 units abreast long, which is shown in Figure 6, is a variation of the IW-NET 3 units abreast barge, lengthened to accommodate an additional stack of containers.

Barge IW-NET – 3 units abreast long

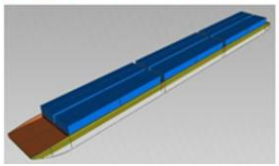


Project ID		006	
Length	[m]	94.8	
Breadth	[m]	9.5	
Lightship displacement	[t]	389.6	
No. of containers (45′ pallet-wide)		2 layers	3 layers
		36	54

Figure 6. CAD model and details of 006 IW-NET 3 units abreast long barge design.

The 007 IW-Net NEWS Evolution long version of the IW-NET NEWS Evolution barge has been designed with six instead of ten container bays; however, the individual container bays can accommodate two lengths of 45′ high cube containers instead of just one. This variation therefore provides higher flexibility for other container types, for example it is capable of carrying three lengths of 30′ containers or four lengths of 20′ containers in its container bays. The CAD model, with details, is presented in Figure 7.

Barge IW-NET – NEWS Evolution long

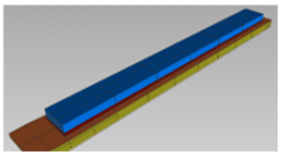


Project ID		007	
Length	[m]	97.3	
Breadth	[m]	11.5	
Lightship displacement	[t]	501.4	
No. of containers (45′ pallet-wide)		2 layers	3 layers
		48	72

Figure 7. CAD model and details of 007 IW-Net NEWS Evolution long barge design.

The 008 IW-NET 3 units abreast long/shallow (see Figure 8) is a further variation of the IW-NET 3 units abreast barge, which keeps the container hold of the "long" variation while at the same time increasing the breadth to 11.45 m (instead of 9.50 m). The changes provide additional buoyancy, thus improving its shallow water capabilities, and it had more favourable stability characteristics than the other two variations.

Barge IW-NET – 3 units abreast long/shallow



Project ID		008	
Length	[m]	94.8	
Breadth	[m]	11.5	
Lightship displacement	[t]	448.7	
No. of containers (45′ pallet-wide)		2 layers	3 layers
		36	54

Figure 8. CAD model and details of 008 IW-NET 3 units abreast long/shallow barge design.

In the following sub-sections, the modelled barge designs will be further evaluated and assessed regarding their stability and their given sightlines.

3.2. Analysis of Sightlines

A sufficiently unobstructed view from the wheelhouse, i.e., the helmsman's position, is essential for safety during navigation on inland waterways. For non-motorized barges, the provisions of the European Standard for Technical Requirements for Inland Waterway Vessels (ES-TRIN) are not applicable as they are not equipped with a wheelhouse; however, operational limits as defined in navigational police regulations have to be taken into account. Most navigational police regulations for the European inland waterway network are at least based on the European Code for Inland Waterways (CEVNI) of the UNECE Inland Water Transport Committee [20]. Therefore, this set of rules has been used as a benchmark for the assessment of sightlines. Article 1.07 of the CEVNI requires that the "load [. . .] of the vessel shall not restrict the direct view at a distance of more than 350 m in front of the vessel". This means that a direct sightline from the helmsman's position to a point not farther than 350 m in front of the bow of the vessel or convoy on the surface of the water must be present.

To cover a realistic range of possible pusher vessels, two different types which are typical for Danube navigation have been taken into consideration for the assessment of sightlines—the main difference between the two versions is that type 1 (Figure 9) has a fixed wheelhouse while type 2 (Figure 10) is equipped with an elevating wheelhouse which can be lifted to provide more favourable visibility for high cargoes.

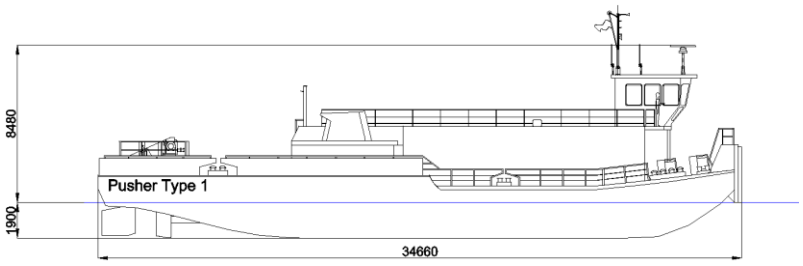


Figure 9. Pusher type 1—fixed wheelhouse.

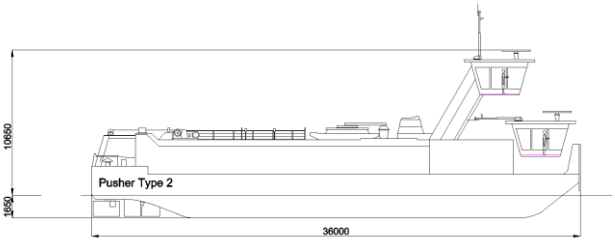


Figure 10. Pusher type 2—elevating wheelhouse.

The analysis is based on the assumption that the barges are sailing on level trim for all loading conditions considered and in convoy formations with only one barge length. In line with our initial thoughts on barge designs, it has been assumed that the load consists of 45′ pallet-wide high-cube containers, which certainly have a considerable impact on sightlines.

For all combinations of pushers and barges, three different loading conditions for the containers have been considered: (1) all containers empty, (2) all containers loaded to 70% of the permissible maximum load and (3) all containers loaded to the maximum permissible load. The sightlines have been assessed geometrically, assuming an eye height of 1.65 m above the wheelhouse floor at the steering position [21]. The assessment shows that pushers with a fixed wheelhouse will mostly not be suitable to be used for the transport of 45′ pallet-wide high-cube containers. In general, sightlines in compliance with the applicable rules can only be demonstrated for one layer of containers. For two layers of containers, compliance with the applicable rules can mainly be demonstrated for the maximum load only. The detailed analysis is presented in Figure 11.

Pusher Type 1 (fixed wheelhouse)					pushed convoy one barge length					
					loading condition					
					2 layers			3 layers		
Vessel type	Project ID	length	breadth	side height	empty	70 % full	100 % full	empty	70 % full	100 % full
Europa 2b	001	76.5	11.45	3.20						
Europa 3a	002	90.00	11.45	3.25						
IW-NET 3 units abreast	003	81.00	9.50	3.20						
IW-NET NEWS Evolution v2	004_v2	85.92	11.45	4.10						
IW-NET Containers transverse v2 (Solidworks)	005_v2	89.80	16.28	4.00						
IW-NET 3 units abreast long	006	94.77	9.50	3.20						
IW-NET NEWS Evolution long	007	97.32	11.45	4.10						
IW-NET 3 units abreast long/shallow	008	94.77	11.45	3.20						

Figure 11. Analysis of sightlines for pusher type 1 (fixed wheelhouse).

As Figure 12 reveals, the situation is much more favourable for pushers with elevating wheelhouses as two layers of containers can be carried within the applicable legal framework in all standard loading conditions assessed in this study. For three-layer transport,

in most pusher/barge combinations, compliance can be demonstrated for containers with 70% of their maximum load.



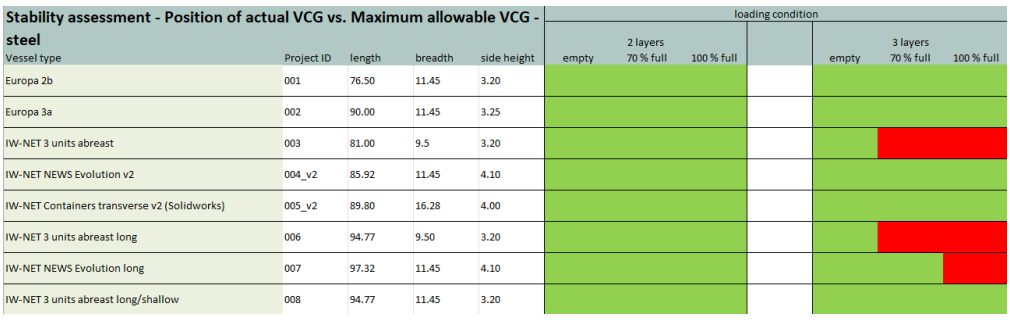
Pusher Type 2 (elevating wheelhouse)					pushed convoy one barge length						
					loading condition						
					2 layers				3 layers		
Vessel type	Project ID	length	breadth	side height	empty	70 % full	100 % full		empty	70 % full	100 % full
Europa 2b	001	76.5	11.45	3.20							
Europa 3a	002	90.00	11.45	3.25							
IW-NET 3 units abreast	003	81.00	9.50	3.20							
IW-NET NEWS Evolution v2	004_v2	85.92	11.45	4.10							
IW-NET Containers transverse v2 (Solidworks)	005_v2	89.80	16.28	4.10							
IW-NET 3 units abreast long	006	94.77	9.50	3.20							
IW-NET NEWS Evolution long	007	97.32	11.45	4.10							
IW-NET 3 units abreast long/shallow	008	94.77	11.45	3.20							

Figure 12. Analysis of sightlines for pusher type 2 (elevating wheelhouse).

3.3. Stability Analysis

Both technical requirements (ES-TRIN) and navigational police regulations (CEVNI) address the issue of the stability of inland navigation vessels carrying containers. The provisions of Article 1.07 No. 5 of CEVNI focus on individual operational situations and require a stability check prior to loading and unloading, as well as prior to departure. The responsibility for such stability checks lies with the boat master. Exemptions from performing stability checks apply to certain loading configurations which are always deemed inherently stable. Regarding the technical characteristics of an inland navigation vessel, the ES-TRIN sets out a range of provisions in Chapter 27 concerning limit conditions and methods of calculation for the transport of non-secured and secured containers, considering the hydrostatic characteristics of the hull (mainly depending on the shape of the hull and the weight distribution), the loading situation and the heeling moments to be considered. For the purpose of this study, we decided to assess the stability of the different barge designs under the conditions set out in Article 27.02 of the ES-TRIN (non-secured containers) and for six standard loading conditions (Figure 13):

1. Two layers of 45′ high-cube containers empty.
2. Two layers of 45′ high-cube containers 70% full.
3. Two layers of 45′ high-cube containers 100% full.
4. Three layers of 45′ high-cube containers empty.
5. Three layers of 45′ high-cube containers 70% full.
6. Three layers of 45′ high-cube containers 100% full.



Stability assessment - Position of actual VCG vs. Maximum allowable VCG - steel					loading condition						
					2 layers				3 layers		
Vessel type	Project ID	length	breadth	side height	empty	70 % full	100 % full		empty	70 % full	100 % full
Europa 2b	001	76.50	11.45	3.20							
Europa 3a	002	90.00	11.45	3.25							
IW-NET 3 units abreast	003	81.00	9.5	3.20							
IW-NET NEWS Evolution v2	004_v2	85.92	11.45	4.10							
IW-NET Containers transverse v2 (Solidworks)	005_v2	89.80	16.28	4.00							
IW-NET 3 units abreast long	006	94.77	9.50	3.20							
IW-NET NEWS Evolution long	007	97.32	11.45	4.10							
IW-NET 3 units abreast long/shallow	008	94.77	11.45	3.20							

Figure 13. Stability assessment of different barge designs under six loading conditions.

For each loading condition, the calculation delivers a maximum allowable vertical centre of gravity (VCG) that must be met to ensure compliance with the requirements of Article 27.02 of the ES-TRIN. The actual VCG of each loading condition is assessed against the maximum allowable VCG. It can be shown that most of the loading conditions comply with the statutory requirements, the only exceptions being the 9.50 m wide barge, in its short and long variants, for three layers of loaded containers (70% and 100%) and the long version of the NEWS Evolution barge for three layers of fully loaded containers.

When comparing loading scenarios, it is essential to note that the results discussed are based on standardized loading conditions. Optimizing the loading situation for individual cases may give better results, especially when considering the transport of three layers of containers. Only high-cube containers were considered for these standardized loading conditions. However, by using standard-height containers, the total load height for three layers could be reduced by approximately 1.20 m, which would improve visibility and the vertical centre of gravity of the load, thereby increasing stability. In addition, the use of a pusher with a longer operating range for the lifting wheelhouse could further improve sightlines compared to the pusher type analysed in this study.

In summary, we developed, in total, six new barge designs with the aim to optimize container transport on the Danube, particularly for 45′ high-cube containers operating between Enns, Austria, and Giurgiu, Romania. Both the stability and sightline assessments revealed that the transport of three container layers is difficult in most cases but needs to be separately evaluated for each loading scenario.

4. Discussion and Conclusions

One goal of our study was to identify design options which enhance the navigability of container barges on the Danube. We identified, in total, six new barge designs which fit into the boundaries we decided on (i.e., the barges should serve the Danube stretch between Enns, Austria, and Giurgiu, Romania; they should be optimized to carry 45′ pallet-wide high-cube containers used for intermodal transport; and the barges should not exceed the dimensions of 97.50 m × 11.45 m). The new barge designs are able to carry up to 90 45′ pallet-wide high-cube containers in three layers, compared to a traditional Europa 2a barge, which is able to carry up to 45 containers in three layers. Nevertheless, after assessing the stability and sightlines of each barge design, we observed that three-layer transport is not feasible in each case. Two-layer transport is, in most cases, possible. There is not a general answer which can be given regarding the best suitable barge design for transporting 45′ pallet-wide high-cube containers. For this reason, each transport situation needs to be evaluated separately to determine the best suitable barge design for this specific transport situation. Nevertheless, there is considerable room for improvement compared to current barge types (001 Europa 2b and 002 Europa 3a), especially when it comes to accommodating the 45′ pallet-wide high-cube containers commonly used in European road and rail transport. It is estimated that a minimum of 30 45′ containers per barge is required to achieve competitive freight rates on the Danube corridor. Standard Europe 2b barges fall short of this capacity, while Europe 3a barges barely meet it. Conversely, all new design options meet or exceed this threshold.

With low water resistance as the primary consideration, the 005 IW-NET Containers transverse barge appears to be the most favourable design. However, this design has operational drawbacks that need to be carefully considered. Considering other factors such as stability, traffic safety and unobstructed views from the wheelhouse, the best design choice can only be made on an individual basis, considering specific transport routes, port facilities and available pusher tugs.

This study contributes to theoretical knowledge by identifying six new barge designs tailored for enhanced navigability on the Danube, specifically optimized for transporting 45′ pallet-wide high-cube containers within defined boundaries. Our study provides practical contributions by offering the stakeholders involved in container transport along the Danube viable barge designs optimized for specific operational requirements. The identification of feasible designs, along with considerations of stability and sightlines, further enables practical enhancements in barge design aimed at improving efficiency and safety in container transport operations on the Danube. Therefore, this study's practical significance lies in improved container capacity. However, for companies to invest in new ships, they require access to financing and capital; clear regulations and policies that support technological advancements; incentives or tax breaks; adequate infrastructure, such as modern ports, loading facilities and navigational aids; and there needs to be sufficient

demand for goods' transportation via inland navigation to justify investments in new technologies or ships.

A limitation of our study is its geographical scope, which limits the generalizability of the results to other inland waterways, as other rivers present other boundaries and preconditions. Another limitation concerns the container type. This study focused solely on 45′ pallet-wide high cube containers, omitting other possible container types. Further research on this topic could include broadening the geographical scope and the utilization of other possible container types. This study underscores the need for barge designs to be optimized for specific applications and tailored to the requirements of their future operators. This implies that there is no one-size-fits-all solution, and design optimization should consider factors such as cargo type, navigation area and available infrastructure.

Other areas for further research would be investigating the operational feasibility of the six new barge designs developed or utilizing dynamic simulation modelling techniques to simulate various loading scenarios.

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