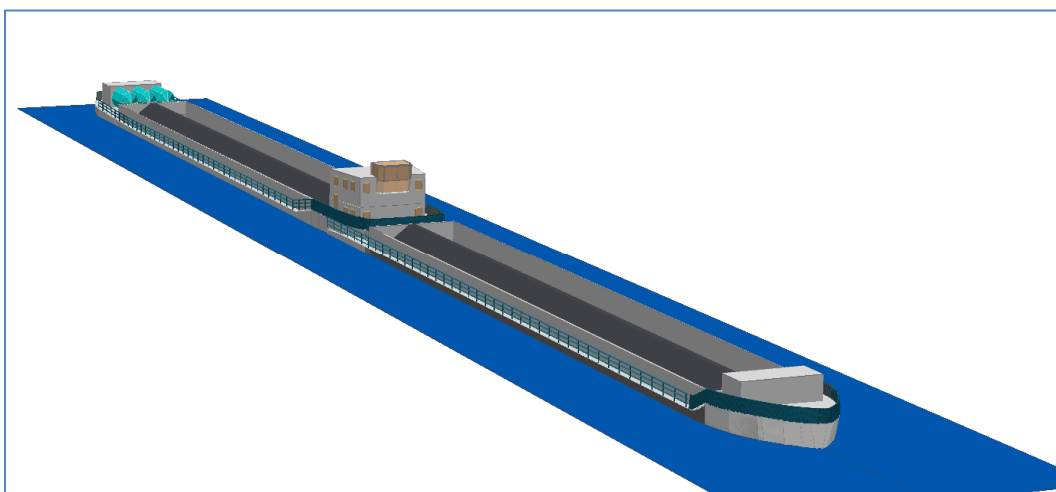


INNOVATIVE DANUBE VESSEL

Main Project Results



SCHIFFBAUTECHNISCHE VERSUCHSANSTALT IN WIEN GMBH
VIENNA MODEL BASIN LTD



УНИВЕРЗИТЕТ
У БЕОГРАДУ
МАШИНСКИ
ФАКУЛТЕТ

UNIVERZITET
U BEOGRADU
MAŠINSKI
FAKULTET

UNIVERSITY OF
BELGRADE
FACULTY OF
MECHANICAL ENGINEERING



Content:

1.	Abstract	4
2.	Background of innovative Danube vessels	5
2.1	Navigation conditions of the waterway	5
2.2	Current cargo flows and future market developments	9
2.3	Logistic chains	11
2.4	Danube ports	12
2.5	Danube fleet	14
2.6	Prerequisites for investments	17
3.	Main dimensions and innovative technical solutions	18
3.1	Selection of optimum vessel dimensions	18
3.2	Best equipment and innovative devices	26
4.	Comparison of different vessel concepts	29
4.1	Cost and performance calculation	29
4.2	Calculation setup	32
4.3	Calculation results	33
4.4	Conclusions	38
5.	Concepts for the innovative Danube vessel	39
5.1	Common requirements and technical design concepts	39
5.2	Vessel concepts	48
5.3	Cost and performance of the innovative Danube vessels	60
6.	Recommendations	62

Background information on the research project INNOVATIVE DANUBE VESSEL

After a public call for tender, this research project was contracted by viadonau to a European consortium of 5 partners with DST as coordinator:



Development Centre for Ship Technology and Transport Systems
Duisburg, Germany

Project coordinator and editor of concluding reports. Ship performance and ship concepts, cost performance calculations, assessment of technical solutions



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Ship concepts, ship efficiency, assessment of technical solutions



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Ship concepts, ship efficiency, assessment of technical solutions



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Ship concepts, plans and calculations

As subcontractor to the consortium, the association "Pro Danube International" provided valorous data input and experience from the ship operator's point of view.

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1. Abstract

The project INNOVATIVE DANUBE VESSEL has the objective to give recommendations for the modernisation of the Danube fleet, considering

- Requirements of the transport market in the Danube region,
- Specific fairway and navigation conditions of the Danube river,
- The state of the art in inland vessel technology,
- Innovative technical solutions derived from published research projects.

For the project, “innovation” is not an end in itself, but understood to be “better than the existing fleet”, in terms of ENERGY EFFICIENCY, COST EFFICIENCY and REDUCED ENVIRONMENTAL IMPACT.

In the short project duration of 16 month, the research work developed with consecutive steps: The background of inland waterway transport (IWT) on the Danube in geographical, commercial and technical aspects was described as first step. This was of high interest as the IWT industry on the Danube is confronted with particular restrictions and challenges.

Considering these aspects, the discussion turned to technical aspects: What is the performance that can be expected from novel ship designs? What are appropriate vessel concepts and dimensions and are there innovative devices to improve the ships? In order to establish reliable criteria for comparison of vessel concepts with respect to energy and cost efficiency, several different methods for assessment of energy efficiency of pushed convoys and self-propelled vessels were examined. As a result, the report contains some original and novel conclusions related to the energy efficiency of self-propelled vessels and pushed barge convoys, to enable optimisation of not only new designs but also of existing inland fleet, which can be considered as an additional value of the research carried out within this project.

A comprehensive cost-performance study allowed then to obtain realistic exploitation figures for a set of basic ship types. Now the situation became much clearer as one vessel concept could outperform the other ship types. For reasons that are closely related to the specific Danube conditions, it could be shown that investment in a new type of Danube push boat would bring the best result in terms of energy and cost efficiency, together with a reduced environmental impact. On second place, the innovative version of a self-propelled vessel is also an interesting option.

Both innovative concepts were worked out and specified in more detail and the expected performance was determined. This can be considered as successful result of the study, but it also appeared very clearly and based on exploitation figures that the specific navigation conditions of the Danube are an obstacle to effective inland waterway transport as long as the maintenance to the agreed minimum standard is not assured.

2. Background of innovative Danube vessels

The objective of this chapter is the collection and evaluation of data on conditions for ship operation on the Danube as an essential basis for future R&D activities on technological development. The report gives a comprehensive overview on the substantial aspects of inland navigation on river Danube and encompasses references to Rhine navigation:

- Navigation conditions: the waterway conditions relevant for the choice of the vessel main dimensions, including information on bottlenecks, locks and bridges
- Current and future market developments and cargo flows in the Danube region (transport flows, commodities and competing modes)
- Main logistic chains existing on river Danube
- Technical state of the Danube Fleet (composition, technical state)
- Good-practice benchmarks in Danube Navigation regarding ship design
- Information on ports (available infrastructure regarding handling of goods, hinterland connections, transshipment volumes).



Figure 1: Regional scope of the study

Source: via donau. (http://www.donauschiffahrt.info/fileadmin/group_upload/7/Daten_und_Fakten/Wasserstrassenkarten/Donaukarte_de_2010.jpg; 30.10.2012).

2.1 Navigation conditions of the waterway

General

The **dimensions of the fairway**, its bending, the dimensions of locks and bridges restrict the size of the vessel and thus have essential impacts on the ships' ecologic and economic performance:

- The **maximum vessel loading** is directly related to the vessel's draught and thus limited by the fairway depth. The efficiency of the vessels (energy consumption per tkm and operational costs per tkm) is dramatically reduced with lower vessel loading (hence, also an ecological issue).
- The impact of the shallow water bottlenecks is engraved for **long average transport distances** (~1000 km on the Austrian Danube in 2010) and the low predictability of navigable

conditions for long-distance-transport. Already slightly critical water levels compel the shippers to limit the load to be on the safe side.

- A reduced fairway depth has always two negative consequences: The payload of the vessel is reduced by the limited draught and the voyage speed is reduced by an increased ship resistance.

Characteristics of river Danube

The Danube is a **free flowing river over long distances**. Whereas 18 dams with locks provide stable and favourable conditions for navigation (with the exception of a few days of ice in some years), the free flowing stretches, which account for roughly 75% of the waterway, result in instable and often unfavourable conditions for navigation. The Upper Danube has 16 locks, but also fast flowing stretches, which eventuates in severe bottlenecks for navigation. On the Mid Danube there are 2 locks and on the Lower Danube there is no lock. The Danube waterway is classified according to its fairway conditions by **waterway classes** as shown in the following figure (a higher waterway class is navigable for larger ships and larger convoys).

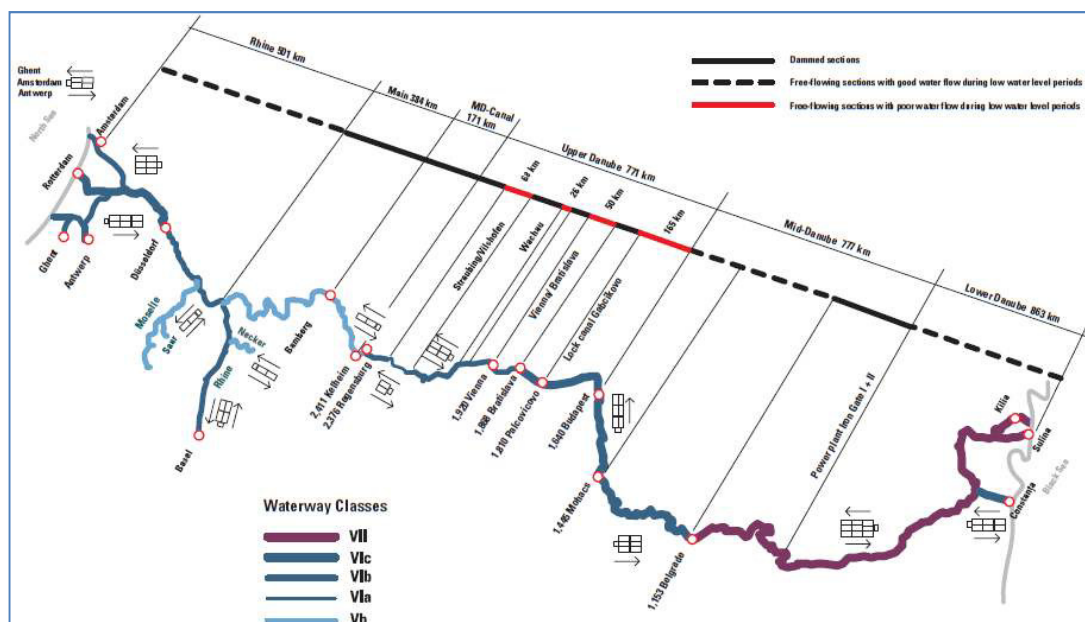


Figure 2: Map of the river Danube including waterway classes, bottlenecks and configuration of convoys
(Source: via donau (2007): Manual on Danube Navigation)

Technical constraints for Danube navigation arise also from the **lock dimensions**, as they limit the size of convoys, i.e. the number and size of the barges per convoy. If sufficient transport volume is available, large convoys may reduce considerably the cost of operation.

From the Black Sea to the Iron Gate lock convoys can transport nine barges or more. Between the Iron Gate and Budapest convoys may operate with up to six barges, from Budapest to Straubing–Vilshofen four barges can use the waterway and from Straubing–Vilshofen to Kelheim and in the Rhine–Main–Danube canal the convoys are limited to two barges.

The **height of bridges** impacts the air clearance. It thus mainly limits container transportation, i.e. the number of layers transported. The air clearance at high water level is between 4.7 m (Deggendorf) and 6.36 m (Passau) at the upper sections, about 6 m for the RMD canal bridge. Bridges upstream from Budapest have at least 7.66 m and downstream Budapest 7.5 m (after the renewal of the bridge at Novi Sad).

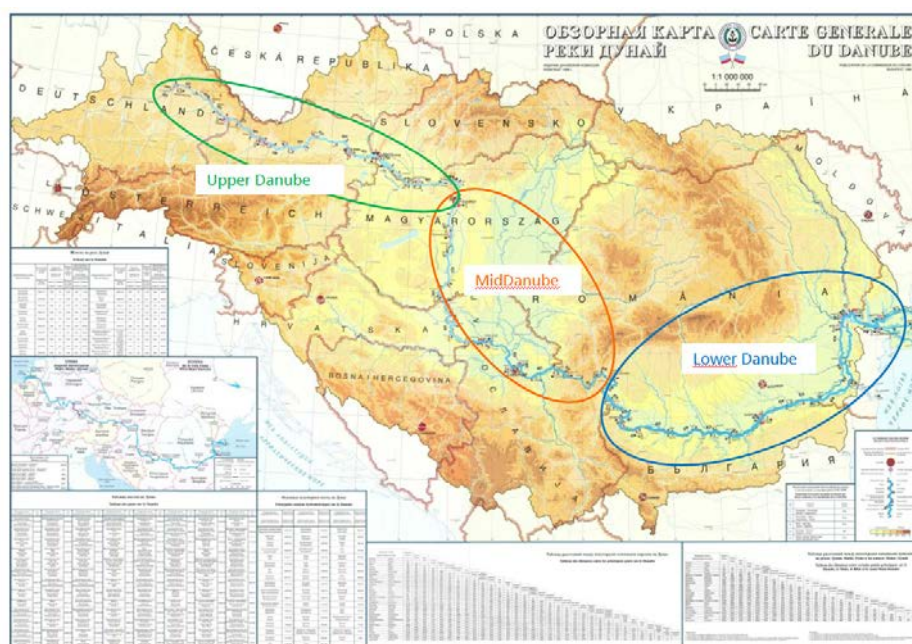


Figure 3: Sections of the Danube (Source of map: Danube Commission and OIR)

International standards

The Danube riparian countries agreed on **international standards** for the fairway parameters, to ensure the navigability. In order to be navigable during the whole year and thus to ensure the reliability of the services Danube vessels should be able to safely operate during occasional low water periods, with a draught of 2.0 m.

For economic and more ecologic operation of inland navigation more draught is required. The European Agreement on Main Inland Waterways of International Importance (AGN) defines the minimum requirements for navigation on the Danube. For a river with fluctuating water levels, a draught of 2.5 m shall be guaranteed during 300 days of the year. The Danube Commission¹ goes further and **recommends maintaining a draught of 2.5 m on the Danube during 94% of a year (343 days)**.

¹ Danube Commission (2011): "DK/TAG 77/11. Recommendations on minimum requirements for standard fairway parameters, hydro-technical and other improvements on the Danube".

The bottlenecks

These targets are presently not met on long stretches. Currently, the main bottlenecks are

- Straubing–Vilshofen (Bavaria): fairway depth of 2 m at LNRL, occasionally 1.7 to 1.8 m in shallow water periods. The targets of the upgrading project currently discussed vary between 2.2 m (Var. A) to 2.65 m (Var. C) at LNRL.
- the Austrian Section “Wachau”, with current fairway depth of 2.3 m at LNRL. The target is to enhance navigation conditions up to 2.5 – 2.7 m at LNRL.
- the section from Vienna to the Austrian/Slovakian border, where the Danube is fast flowing and the fairway depth is at 2.2 m at LNRL. Currently a pilot project examines the effects of new hydro-engineering methods in order to upgrade the fairway to 2.7 or 2.8 m at LNRL including ecological evaluations.
- the Hungarian section along the Slovakian/Hungarian border and near Dunaföldvár
- the stretch along the Romanian–Bulgarian border with the main bottleneck around km 630 and the shallow water stretch from Bala Arm (Calarasi) to Cernavoda. A memorandum of understanding between Romania and Bulgaria was signed in October 2012 on setting up an Interministerial Committee for sustainable development of inland waterway transport. The tasks comprise an action plan for common projects for improving navigation conditions and an analysis of the legal framework regarding maintenance and upgrading works.

Maintenance

Existing bottlenecks shall be eliminated through the realisation of upgrading projects and **regular maintenance measures**, as laid down in the AGN and the Declaration of transport ministers of the EU Member states in June 2012.

Due to the lack of financial and human resources, many of the Danube countries require international funding for financing general projects for river navigation, water management, flood prevention and environmental protection.

Support

Since the waterway axis Rhine/Meuse–Main–Danube is part of the **Trans-European Transport Network** (TEN-T, project 18), EU-funding for projects in the Danube Corridor is available (studies usually get 50% EU-funding, operative measures 20%). The measures are supported by the **EU Strategy for the Danube Region** (EUSDR), which focuses on enhancing cooperation within the Danube Region in order to achieve one of the main EUSDR targets: increasing cargo transport on the river by 20% by 2020 compared with 2010.

Improving the navigability of each single bottleneck is thus a crucial factor for the economic performance of inland navigation and for the desired shift from road transport.

2.2 Current cargo flows and future market developments

Transport volume

In year 2010 a **total of 49.5 million tons** was transported on the river Danube, of which 29.6 mn tons in international transport relations and 19.9 mn tons in national (domestic) transport relations². The core business of Danube transportation is international transport. Long distance transports enable inland navigation to make use of its strength of cost efficient and comparably ecological transportation.

Regional distribution: 18.6 mn tons are transported on Upper Danube relations and 30.9 mn tons on Middle and Lower Danube relations, adding up to 49.5 mn tons on the Danube River. Compared to the Rhine's transport market, these figures are somewhat disappointing as Rhine relations made up for 209 mn tons in 2010.

Despite the advantages of long-distance IWT transport, astonishing 63% of the overall transport volume on the river Danube can be considered as short and medium distance transports of up to 700 km³. Since travel times are shorter, loading of such transports can be more easily adapted to varying water levels and the capacity of the ships can be used more efficiently. On the contrary, **long distance transports make up for only 37% of the overall transport volume, a consequence of being confronted by more bottlenecks and lower water level predictability.**

Whereas transport volumes of IWT on Upper, Middle and Lower Danube are not too different in size, the prevailing inequalities of trade exchange (both in volumes and commodity structure) result in **asymmetric transport flows** on river Danube (64% transported upstream, 36% transported downstream; Austrian Danube Corridor, 2011). The low share of IWT in downstream relations has unfavourable consequences on the efficiency of IWT, leading to lower capacity utilization. This again decreases economic performance of IWT.

Modal split

Whereas transport volumes of IWT on Upper, Middle and Lower Danube are not too different in size, the prevailing inequalities of trade exchange (both in volumes and commodity structure) result in asymmetric transport flows on river Danube (64% transported upstream, 36% transported downstream; Austrian Danube Corridor, 2011). The low share of IWT in downstream relations has unfavourable consequences on the efficiency of IWT, leading to lower capacity utilization. This again decreases economic performance of IWT.

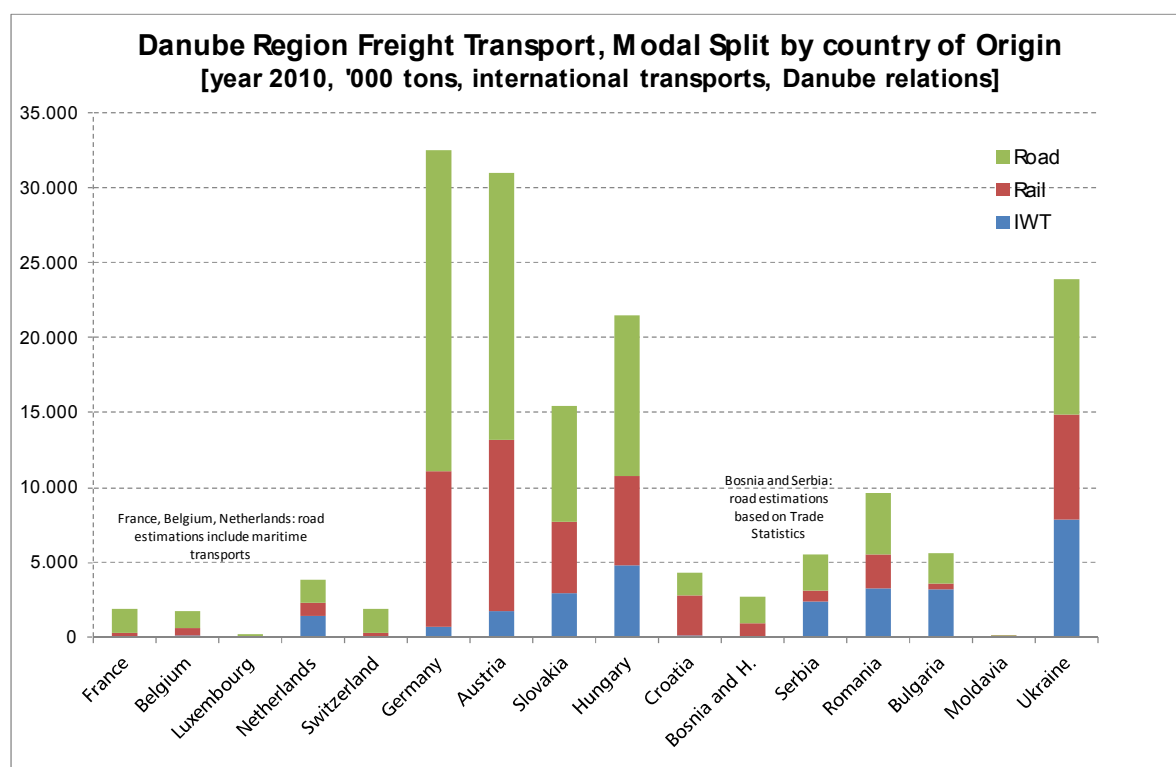
While inland navigation transport volume is higher in the Middle and Lower Danube countries, the inverse situation is observed for road and rail transport. Land transports are considerably

² OIR based on Eurostat Freight Statistics Database. The figures contain all inland navigation transports between the countries given, thus reflect all transport volume moved on the Danube between the German-Austrian Border and the Black Sea. Bavarian O/D transports from/to the West and Bavarian domestic transports accounted in 2011 for another 3.5 mn tons.

³ Calculated by OIR at a country-to-country basis including Bavaria

higher in the Upper Danube countries: Germany, Austria, Slovakia and Hungary contribute for 106.7 mn tons, the other Danube Region countries for 37.5 mn tons, the Ukraine and Moldova for 5.4 mn tons and Western Europe for 12.1 mn tons to the total of 161.8 mn tons of transport in the Danube Region.

Figure 4: Modal Share in Danube Region, 2010 [mn tons]

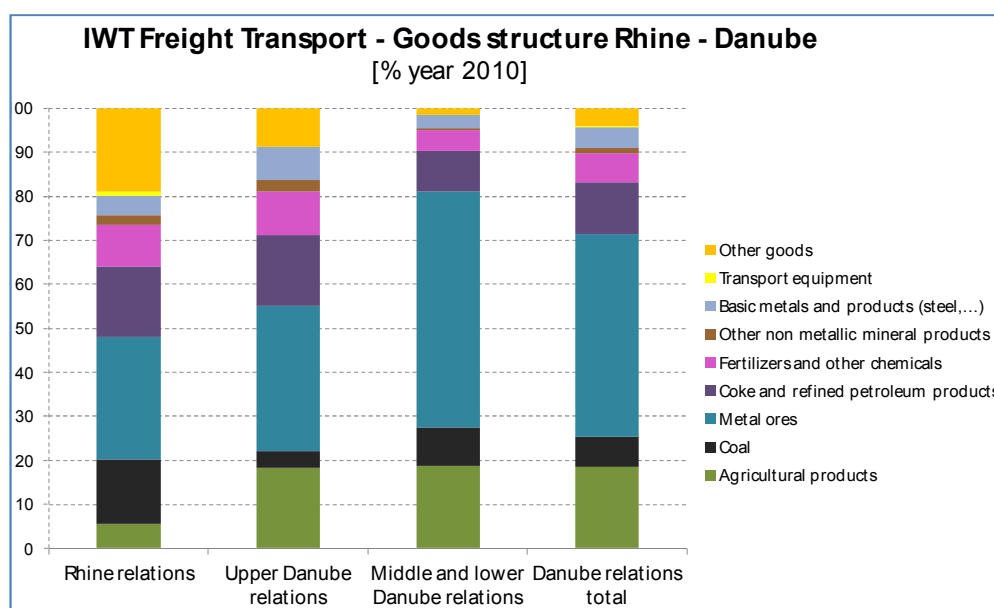


Source: ÖIR based on Eurostat Freight and Trade Statistics

Goods structure

Inland navigation on river Danube is largely **dominated by bulk goods**. The predominant transport commodity is metal ore with 22.7 mn tons, above all iron ore used in the steel industry. Agricultural products are the second largest commodity (9.2 mn tons), followed by refined petroleum products (5.9 mn tons), coal (3.4 mn tons) and fertilizers including chemical products (3.3 mn tons) as well as (basic) metals (2.3 mn tons). The category 'other goods' comprises 2.0 mn tons, a category which includes high valued finished goods and containers.

Figure 5: IWT Freight Transport – goods structure Rhine – Danube 2010 ['000 t]



Source: ÖIR based on Eurostat IWT Statistics, 2012

Inland navigation on river Danube has not succeeded to gain relevant share of **high valued goods**, such as inland navigation on river Rhine has. High valued goods (categories 'other goods' and 'basic metals and products') have a share of 24% on Rhine relations, 17% on Upper Danube, 9% on the Danube altogether and 5% on Middle and Lower Danube (Figure 5).

2.3 Logistic chains

Inland navigation faces strong competition from road and rail transport which complicates the integration of IWT into the logistic chains. Transshipment of goods is related to costs and expenditure of time for pre- and post-haulage. Thus IWT is preferably used when the transport distance is long (from 700 to 2000 km⁴) and the number of transshipments low, i.e. the producer or the consumer is located near the river Danube. In contrary to the Rhine, industrial production in the Danube region is in most cases not located next to the river which severely hampers the utilization of Danube navigation.

Existing logistic chains are either of rather simple structure, e.g. grain transports by truck from the producer to the next port or the transshipment of petroleum products between refineries located in the vicinity of the river Danube. Other logistic chains are attracted by the favourable cost structure when transporting large quantities of mass goods (iron ore, scrap or chemicals). Furthermore Danube navigation benefited from regulated markets and border regimes (Ro-Ro to Vidin, Austrian road transit quota). The liberalisation of such policies has – finally – led to the abandonment of the services.

Alternative 'high quality' logistic chains (liner services) were of low economic performance up to now. It has not been possible to enter the full container market transporting high value

goods and existing liner services as HELO1 have been abandoned. Projects for new services are difficult to realize.

Chances are seen in logistic chains for LNG or bio fuels. For example the raw material supply of the bio-ethanol plant in Pischelsdorf is served by Danube navigation to a large extent. Additionally LNG is discussed as fuel for Danube vessels themselves, which would increase the transport volumes of LNG in the Danube Corridor additionally. A master plan for the implementation of LNG on the Danube is currently elaborated.

In the Danube Region the logistic providers determine decisions on modal choice to a large extent. Their interest to establish logistic chains including the waterway is low, since they often dispose of an own trucking fleet or are strongly linked to rail transport companies.

Future development

The future development of IWT will depend on the general economic development in the region as well as on the performance of the quality of the three modes. Trends observed encompass:

- In the beginning of 2013 an end of the financial and economic crisis may be stated. A growth perspective of around +2% in trade volumes may be realistic due to the latest economic forecasts (WIIW).
- The growth will concern both high and low value goods. Growth, above all in South East European countries, might stem from intensified agricultural production, along with new agricultural products ('green' energy, bio fuels), in addition with investments in wood production, in the chemical industry, metal industry and as well in construction industry.
- Growth expectations of the Black Sea economies are somewhat higher than the Danube countries perspectives, but the process of integration towards the European Union still leaves questions unanswered.
- The investment policy and the location of new industries next to Danube ports will strongly influence the ability of inland navigation to serve its transport function well.

More than 70 ports and transshipment sites are located on the navigable Danube between Kelheim and the Black Sea. Thereof 40 ports are considered inland ports of international significance ("E-ports") according to the AGN (European Agreement on Main Inland Waterways of International Importance – ECE/Trans/120). Given an average distance of 60 km between the ports on the Danube (2,400 km with 40 E-ports), the density of ports and internationally important industry settlements is considerably lower than on the Rhine with 20 km between its 150 E-ports.

2.4 Danube ports

Ports and cargo specialisation

On the Danube most ports are **well equipped for the transshipment and storage of general cargo respectively bulk cargo**, being the main commodities of IWT in the Danube region. In some cases the ports provide further services like container transshipment or RoRo ramps. Additionally there are ports for liquid cargo (mostly mineral oil ports).

The ports can be classified by the main commodities transhipped, as shown in the following figure. The main specializations of ports regarding the commodities handled are:

- **Steel, steel products, iron ore and coal** are transhipped in the ports next to steel industry sites. The most important ports are Linz–Voestalpine, Dunaújváros Dunafer, Smederovo Feranex and Galati Mittal.
- **Mineral oil:** With the construction of pipelines the importance of oil ports declined. Nowadays, they are important as backup systems and storage facilities and are used in case of price differences between countries. The most important ports with oil tank storages are Regensburg, Deggendorf, Linz tank port, Vienna Lobau and Vukovar.

A new prospective lies in the handling and storage of LNG in ports. Currently a study examines the potential of LNG as fuel for Danube vessels as well as cargo for the Danube fleet.

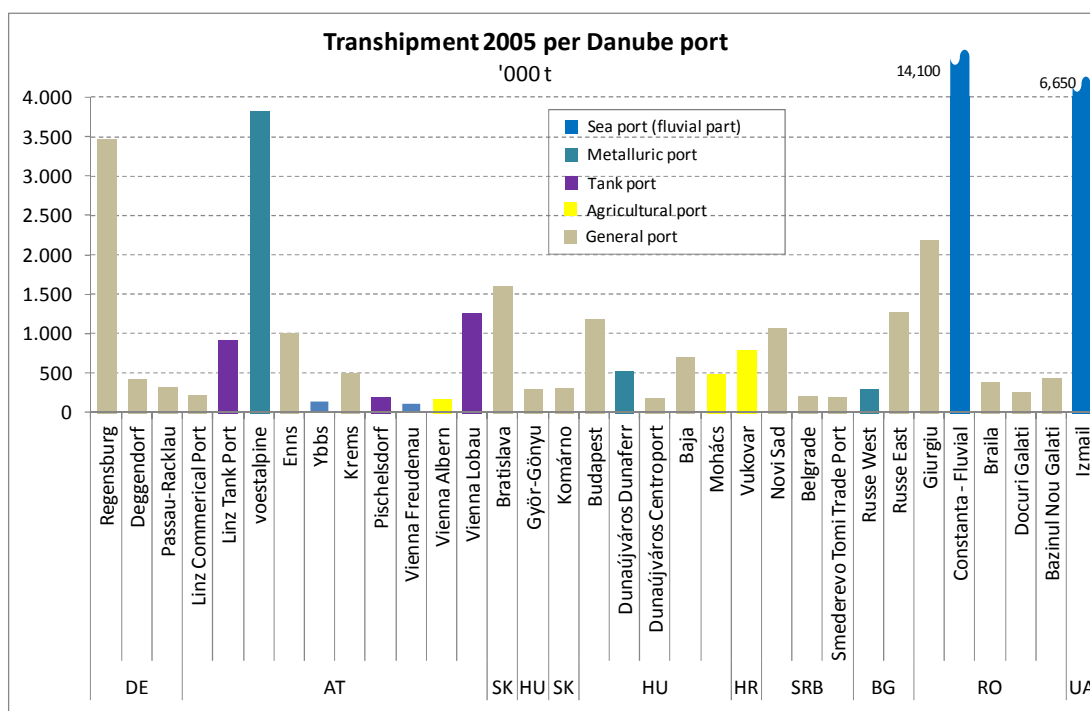
- **Agricultural products and fertilizers:** Agricultural products as well as fertilizers are transhipped in the ports of Linz commercial port, Enns, Krems, Pischelsdorf, Vienna Albern, Győr, Baja, Vukovar, Smederevo Tomi Trade, Novi Sad, Ruse, Constanta and Braila.
- **Containers:** Container transshipment is reported for: Regensburg Enns, Krems, Vienna Freudenu, Bratislava, Budapest, Belgrade and Constanta. These ports provide the necessary infrastructure for transshipment, stuffing and stripping of containers as well as sophisticated logistic services.
- **Sea ports / transshipment to hinterland:** The by far largest port in the Danube Region is Constanta with about 11.7 mn tons transshipment (2012). Other sea ports are Galati, Braila, Giurgiulesti and Ismail.

Ports and container transports

The port infrastructure is tailored to the industry partners in the port hinterlands. At present, many ports are not designed to time- and cost-efficiency which is essential for the future development of container transportation. This implies that port infrastructure needs adaptations after the improvement of the Danube infrastructure. Adaptations are needed when developing new cargo flows, particularly when the full container market increases significantly. Currently the project “DaHar – Danube Inland Harbour Development” aims at harmonising the long-term logistic development of small and medium sized Danube ports.

In order to shift transport volumes to Danube navigation, logistic and infrastructural measures have to be implemented. Among others, the most important ports should try to transform themselves into multimodal logistic hubs.

Figure 6: Important Danube ports by type and IWT transshipment 2005



Source: OIR based on port statistics and <http://www.danubeports.info/>;

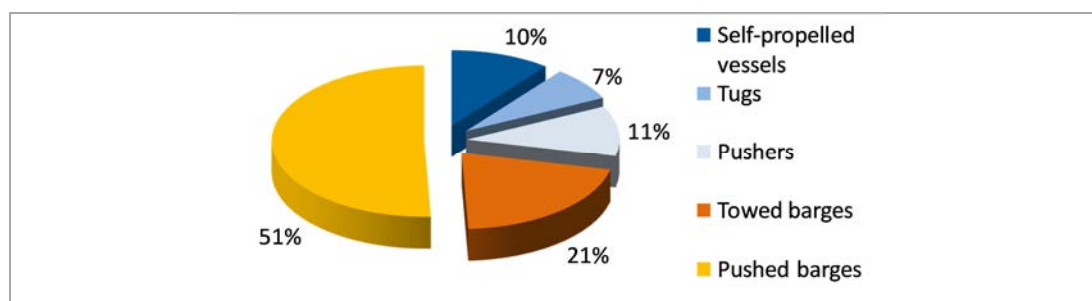
Note: Constanta Fluvial including cabotage.

2.5 Danube fleet

Vessel types

Pushed convoys with one or more barges dominate the transport organisation on River Danube, which is in contrast to Rhine shipping, where the share of goods transported by self propelled vessels is high. **Motorized vessels** (self propelled vessels, pushers and tugs) account for 27% of the Danube fleet, while 73% of the vessels are part of convoys (with pushed or towed barges). The carrying capacity of convoys is even larger (89% pushers and barges and only 11% self propelled cargo vessels). Whereas a large number of tugs exists, most of them have little engine power and are designated to manoeuvres in the ports, not to goods transportation.

Figure 7: Breakdown of the Danube fleet by vessel type for 2010



Source: Danube Commission, statistical handbook 2010

The main vessel configuration used in Danube navigation is a convoy of one pusher and 2, 4 or 6 barges, which suits well to the transport of high volumes of bulk cargo. Convoys usually have longer average transport distances with more crew members working in shifts. This results in larger accommodation spaces compared to the Rhine vessels.

Age structure

In general vessels for inland navigation are older than maritime ships. The Danube fleet makes no exception. The persistence of Danube vessels is high: the average age of the fleet amounts to 34 years⁵. While numerous new vessels joined the fleet in the 1980ies, new investments were made cautiously since the 1990ies. From 1990 to 2010 the number of pushers increased only slightly and the number of barges declined considerably. As a result of depreciation the number of self propelled vessels even decreased by 50%.⁶

Low investment in new vessels

Whereas in the last years shipping companies invested in the re-engineering of existing vessels, there was almost no investment in new vessels. 87% of the pushers were built before 1991, 88% of pushed barges and 96% of the self-propelled vessels (Danube Commission, 2008). With other words, only 13% of pushers, 12% of pushed barges and a mere 4% of self-propelled vessels were built in the last 22 years.

The decisive factors behind this development have been the weak economic prospects: The goods structure in the Danube region changed from low-value to high-value goods, while low valued bulk goods have developed weakly. Raw oil transports by IWT were substituted by pipelines and the fall of the iron curtain eased road and rail transportation. As a result, the shipping companies restrained from investments into new motorized vessels.

Yet, in the last years shipping companies increasingly invested in the re-engineering of existing vessels. This comprised actions to assure the compatibility of the vessels with latest rules and regulations, the decrease of fuel consumption and emissions, the increase of engine power and reliability, as well as the decrease of operations costs.

Figure 8: Pusher with one barge



Source: SDG / Navrom

The conclusion is that new vessel designs should respond to the requirements derived from the characteristics of the vessel's cargo. The transport market on the Danube is currently dominated by general and bulk cargo, while container transport presents a niche market.

5 Danube Commission (2008): Statistical Yearbook 2006.

6 CCR (2012): Market observation 2012-1, p. 30

Consequences for vessel design

Given the long lifetime of inland navigation vessels on the Danube, new vessel design should take into account the future use of the ship for other purposes, e.g. container transports, when it comes to the dimensions of the vessel. Thus, a vessel design for the transportation of bulk goods shall consider the size of containers and must not prevent the efficient transport of containers by unfitting dimensions.

Primarily, new vessel concepts should apply the latest technological achievements in order to increase efficiency, safety, cleanliness and comfort according to the current standards. The following two types of vessels should be taken into consideration for new vessel design:

- Self-propelled multi-purpose vessel: Operational for bulk cargo or containers, good manoeuvring characteristics, additional crew comfort
- Convoys of pusher + barge(s): The main advantages of the proposed pusher concept are, that they can adapt to different fairway depths, lock dimensions as well as differences regarding the transport volumes, which vary upstream and downstream. Furthermore, they can change the number of barges transported relatively quickly and can thus be used on all sections on the Danube.

Tank vessels are used for relative short distance transports, thus can better adapt to the navigation conditions. There might be demand for new tank ships, if LNG would be used in the future as fuel for navigation.

Good-practice examples

Most of the latest good practice examples of vessels focus on solutions for Rhine shipping and self-propelled container vessels. At present container transport is a niche market on the Danube (see chapter on transport market). Thus the research focused on other good practice examples with relevance for Danube inland navigation. Three of them are shown in the following.

- Touax Rom shipping multipurpose barges

A barge can load 144 TEU in three layers, has a cargo capacity of 1.585 tons and a draft of 2.25 m. They can be used for dry bulk cargo, containers or high & heavy transport.

- Ro-Ro-Barges and self-propelled Ro-Ro vessels

Ro-Ro-liner services successfully operate the Danube since 1982 starting with four self-propelled Ro-Ro vessels. New concepts for the next generation of Ro-Ro vessel and barges have been elaborated in the EU project CREATING and follow-up studies e.g. by D. Radojčić.

- Re-engineering of river vessels by Navrom

The example shows that retro-fitting of the existing fleet is surely a strategy that will be followed for existing vessels in the fleet. After re-engineering the fuel consumption was reduced by about 30% and NOX-emission were diminished by more than 50%. Thus the re-engineering measures induced by EU regulation and economic reflections led to promising results which justified the efforts of investment.



Figure 9: Pusher of the NAVROM fleet, Source: Navrom

2.6 Prerequisites for investments

In the last years shipping companies have increasingly invested in the re-engineering of existing vessels, but there was little investment in new vessels apart from barges (see 1.6), and almost no investment into new motorized vessels. The decisive factors behind this development have been:

- Though there was considerable growth of high-value goods in the Danube Region, inland navigation could not gain any substantial share of the transport of those goods. Container transports on river Danube do almost not exist (anymore).
- Unfavourable nautical conditions have been numerous, which prevented reliability and increased considerably transport cost. Without investment in waterway infrastructure (upgrade to 2.5m draught) any investment in new vessels is unfavourable for the shipping companies compared to the use of old and already depreciated equipment. In other words: investment in new vessels will probably only happen if cost-efficiency of transport is assured by more stable navigation conditions.

3. Main dimensions and innovative technical solutions

Treating ship design, three steps are primordial:

- Determining the given operation conditions
- The selection of optimum vessel dimensions
- Choosing the best equipment for the vessel

The operation conditions have been treated in the second chapter, and in this third chapter the definitions of vessel dimensions and operation speed should be approached. As the last step for the technical concept for the innovative Danube vessel, the appropriate propulsion and equipment had to be determined.

3.1 Selection of optimum vessel dimensions

3.1.1 Convoy configuration and optimum speed

An investigation of the variation of the design parameters and the effect of the waterway restrictions, especially shallow water and current velocity has been made on the basis of existing model test results of Development Centre for Ship Technology and Transport Systems (DST), Duisburg, and Vienna Model Basin (SVA). Some of the model test results are displayed in Figure 10.

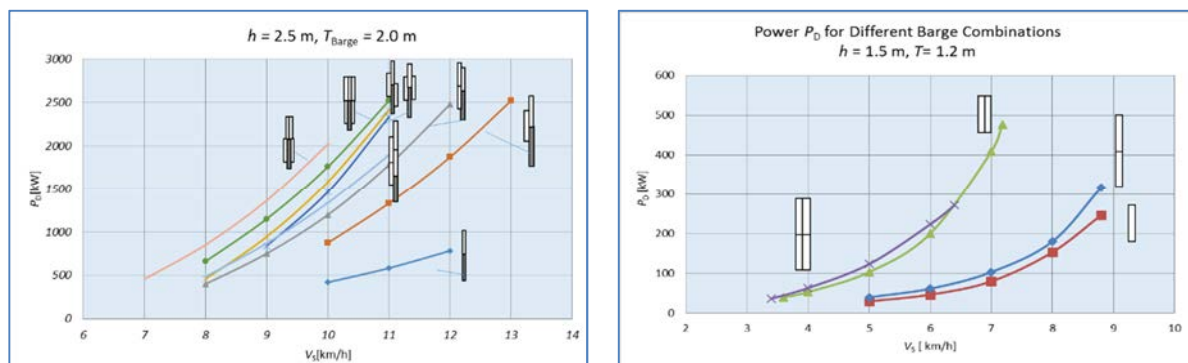


Figure 10 Examples for power consumption of different tug-barge trail formations
(h = water depth. T = ship draught. PD = delivered power)

Convoy configuration

The arrangement of a convoy can be favourable or unfavourable with regard to energy consumption depending on the length/breadth ratio, as shown in Figure 10. Barges should be operated with maximum possible draught optimised for the expected water depth and taking into account the hydrodynamic barge (tug – convoy) characteristics. The limit is influenced by the dynamic squat. Pushed barge convoys have an advantage compared to self-propelled barges, as a pusher can have much less draught than a fully loaded barge, and the propulsion devices are not exposed as much to the danger of touching the ground. For the design of barges high draughts could be advantageous.

Effect of short section of shallow water

Short sections of shallow water (or threshold condition) have an increasing negative effect on the transport efficiency due to the draught reduction imposed on the vessels. In Figure 11 the effect of a threshold condition can be demonstrated: A water depth of $h = 3,50$ m is available for the voyage, but one short shallow water section with a depth of only $h = 2,00$ m obliges

the ship operator to reduce the draught of the vessel to $T = 1.7$ m. As this reduces the payload of the vessel, it appears that the specific energy consumption (expressed as kWh/per tkm) of the voyage is increased by up to 37 % compared to a voyage performed at the full draught of $T = 2.5$ m.

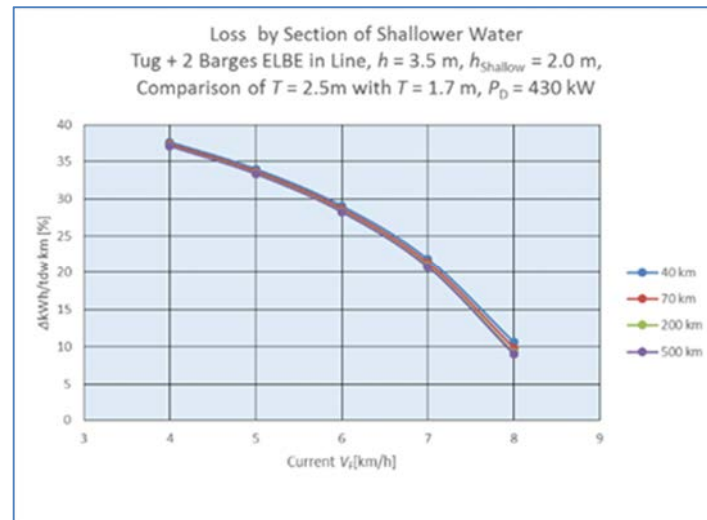


Figure 11 Effect of Short Section of Shallow Water [Source SVA Vienna]

At low current speed, as this is typical for many lower Danube sections, this effect is the most pronounced. Reason for this is the fact that the ship with the smaller draught of $T = 1.7$ m will achieve a higher speed vs. ground when travelling upstream against a strong current, compensating at least partly the effect of reduced payload.

Speed power optimisation

The consideration here was to investigate whether the efficiency can be improved by adjusting the engine loading to the conditions of the waterway. As an example there were investigated a single Barge (ELBE) and a Barge – Barge Combination. For both cases an installed power of 1000 kW was assumed.

At lower current velocities the optimum speed turns out to be quite low which has the effect that in this case the engine loading would be low as well.

The savings which can be achieved by such a load control is shown in Figure 12. The X-axis shows the percentage of the loading of the installed power (100%) and the Y-axis the savings on fuel consumption by the adjusted power depending on the flow velocity of the river. In the case of the single barge it is up to 25% and in the case for the Barge – Barge combination up to 15%, depending on the current velocity V_f . This consideration only focuses on the energy consumption.

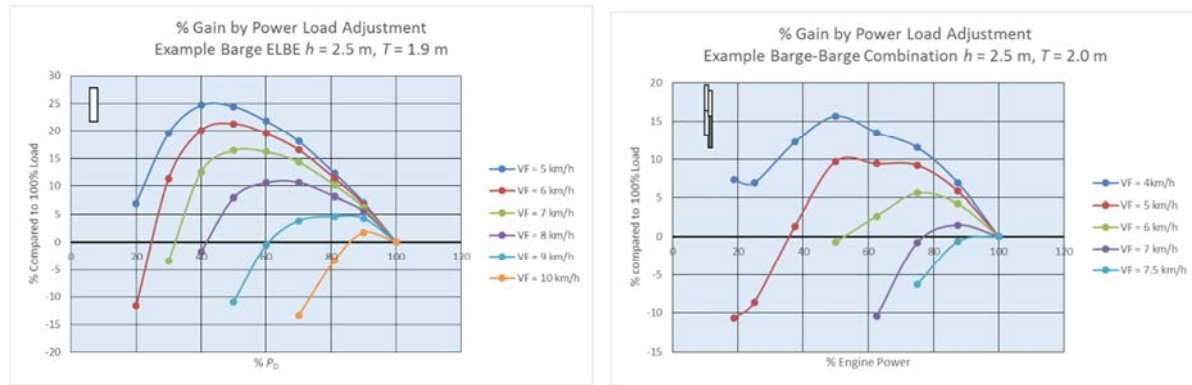


Figure 12 Examples for gain of fuel consumption (Power) by power load adjustment [Source SVA Vienna]

This indicates that sophisticated automatic engine load control which allows for water depth, current velocity etc. can produce high energy savings without high constructional expenditure. For the optimisation of the profit of the barge operator additional considerations have to be made especially with regard to personnel expenditure in connection with the time consumption.

An important finding of the performed analysis is: All river engineering measures which increase the water depth, especially in the short sections of shallow water, have an essentially higher advantage with regard to energy efficiency than any improvement on some river barges. Not only that the attainable advantage by the improvement of the navigation conditions can be bigger than design measures on barges, river engineering affects all ships, existing ships (more than 3000 in operation on the river Danube) and new ones as well. Therefore river engineering should by far be preferred with regard to the economic performance of inland navigation and to the economy of the member States.

Nevertheless new powering concepts, engine technologies, different fuels (LNG e.g.) which will result in lower exhaust pollution values should be considered in the design of innovative vessels.

3.1.2 Energy efficiency for self-propelled vessels

The main objective of this analysis was to establish a reliable benchmarking tool with respect to energy efficiency of inland self-propelled cargo vessels that could be used in ship design or for evaluation of energy efficiency of existing vessels. Since well introduced indicators for sea-going ships already exist, the Energy Efficiency Design Index (EEDI) and the Energy Efficiency Operational Indicator (EEOI) introduced by the IMO, it seems reasonable to apply the same methodology on self-propelled inland vessels.

However, due to various reasons related mostly to specific navigating conditions of inland vessels, the EEDI as it was defined by IMO could not be used for reliable comparison of their energy efficiency. Therefore, within this research, a modification of the existing approach was elaborated. Unlike IMO the EEDI which is based on predetermined engine power (75% of installed engine power) and on achieved ship speed V_S [km/h] (reference speed), the modified EEDI (EEDI*), adjusted to inland vessels, is based on predetermined service speed of the ship and on corresponding engine power P_{Bref} [kW] (reference power) required for achieving that speed.

$$EEDI^* = \frac{P_{Bref} \cdot SFC \cdot CF}{DWT \cdot V_S} \left[\frac{g \text{ CO}_2}{t \cdot km} \right]$$

Here DWT is the payload of the vessel in [t], $C_F[g/t]$ is emission of CO_2 per ton of fuel, and SFC is specific fuel consumption [g/kWh]. In order to establish a reliable tool for evaluation of energy efficiency of inland self-propelled vessels an attempt was made to apply IMO recommendations for evaluation of the EEDI. For the purpose of this analysis the database that consists of 94 Danube self-propelled cargo vessels was used.

Simple mathematical models for evaluation of parameters were developed by means of regression analysis. They describe the influence of ship speed (Froude number based on water depth in case of shallow water).

Consequently, unlike the EEDI of IMO, which depends only on ship deadweight (for each type of ship), the suggested EEDI* depends on:

- the ship deadweight DWT [t]
- the ship speed V [km/h]
- the relation between speed and water depth, expressed as “Froude depth number” F_{nh} ⁷

Reference baselines are substituted with the appropriate reference surfaces that can be used for ship energy efficiency evaluation. Reference surfaces derived for deep and shallow water for considered Danube ships are shown by 3D charts in the figure below.

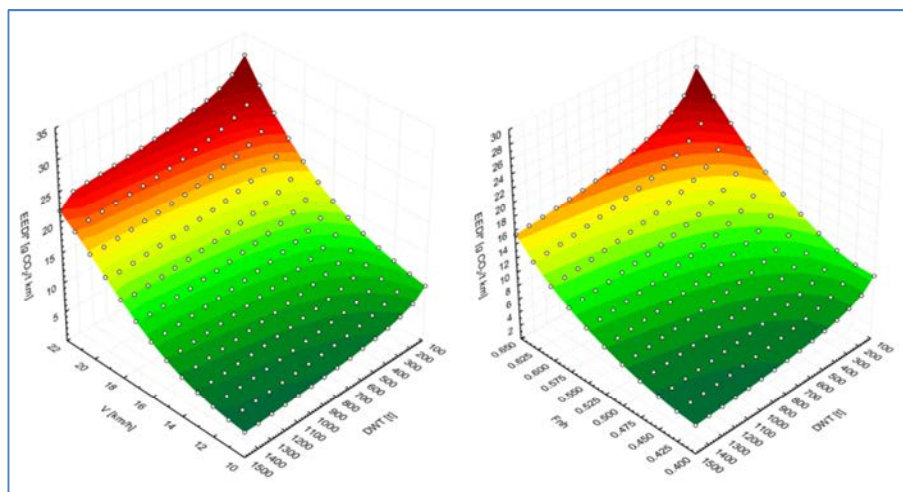


Figure 13 EEDI* reference surfaces for deep water (left) and shallow water (right)
[Source Simic, University of Belgrade]

The drawback remains that the data base for these reference surfaces is based to a large extend on ships with deadweight well below 1500 t, whilst we expect the innovative Danube ship to have a payload in a considerably higher range.

⁷ The non-dimensional “Froude depth number” is defined as $F_{nh} = \frac{v}{\sqrt{g \cdot h}}$, where v [m/s] is the velocity of the ship, g [m/s²] is the acceleration due to gravity, and h [m] is the water depth.

3.1.3 Performance indicators and transport efficiency of pushed barge convoys

To evaluate each of the introduced performance parameters, it is crucial to know the relationship between the convoy power and speed. In the present investigation, for this key relationship an original computer code CONVOY, earlier developed at the University of Belgrade, was applied. CONVOY calculates the power-speed relationship using a mathematical model based on artificial neural network (ANN) method, developed from old but systematic experimental investigation of pushed barge convoys performed at DST. The code enables the variation of speed of pushed formation, its length and breadth, its draught (or deadweight), and the water depth, covering practically all the combinations relevant for the Danube transportation. From that point of view, the code is clear and sound.

It has, however, a serious shortcoming. It is based on the measurements performed with just one push boat model, and just a single set of propellers, so neither the push boat dimensions, nor the propeller characteristics could be varied in the numerical analysis. In the present analysis, this shortcoming is overcome by assuming that the power delivered to the propellers varies due to the different engine loading.

Influence of convoy configuration

In the first example, the profit coefficient p is presented for a number of barge formations as a function of the convoy deadweight, for constant power delivered to the propellers (Figure 14). In all the calculations given in the diagram, the power delivered by the push boat engines is kept to $PD = 1000$ kW, the water is relatively deep ($h = 7.5$ m), river speed is $v_c = 3$ km/h and the convoy is supposed to sail upstream. Costs and prices are assumed as realistic as possible, and their change could be easily applied. Costs of transport (fuel only) are supposed to be depended of:

- Fuel cost in EUR/ton? $k_f = 847.4$ €/t,
- the specific fuel consumption $\mu_f = 219$ gr/kWh
- The freight rate is supposed $k_c = 0.01$ €/(t·km), independent of mass of cargo and journey duration.
- The reference speed is assumed as $v_{ref} = 10$ km/h,
- Deadweight $m_{ref} = 10000$ t.
- The convoy configuration, expressed as number of barges in front of the pusher. Example "P+2+2" means: Pusher + first row of two barges + second row of two barges

On each of the p -lines, six dots (markers) are set, which correspond to six different barge draughts, starting from 1.5 m to 4 m, with 0.5 m steps.

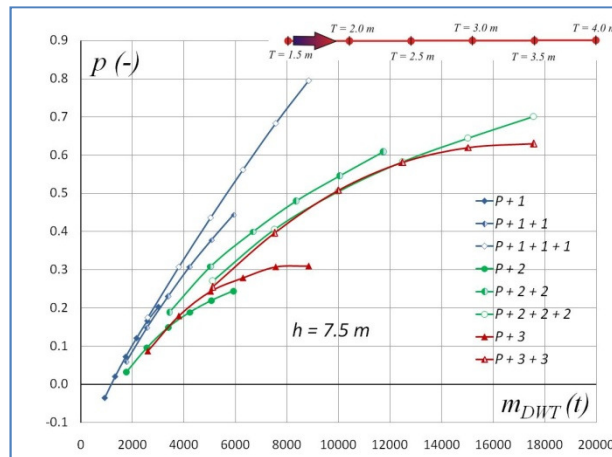


Figure 14 Example of a profit coefficient calculation for different convoy configurations as function of convoy deadweight, for constant push boat power. In the given example, it is supposed $PD = 1000 \text{ kW}$, $h = 7.5 \text{ m}$, $vc = 3 \text{ km/h}$, upstream voyage.

[Source: Hofman et al. / University of Belgrade]

In a similar way, several other problems, such as possible differences in freight rate for up-stream and downstream transportation, influence of water depth, influence of river current, etc. could be analysed. In all of these examples, the push boat power is supposed constant. Therefore, the examples correspond to problems with just one given push boat, working with different barge formations, in different conditions. Such problems may be very interesting for inland shipping companies, in the analysis of proper freight rates, optimal formations, etc. Therefore, the described procedure could be used for improvement of performance of existing push boats and convoys.

Influence of convoy speed

Further calculations, also with variable propulsion power, confirm that the increase of draught is always beneficial from the profit rate point of view. However, the main feature of all the diagrams (example on Figure 15) is the occurrence of profit coefficient maximums, indicating that there is a technically realistic speed of transport which gives the maximum profit. That is optimal or economic speed of the transport, v_{ec} . The values of maximum profit and the corresponding economic speeds are clearly marked on the diagram, and connected by dashed lines.

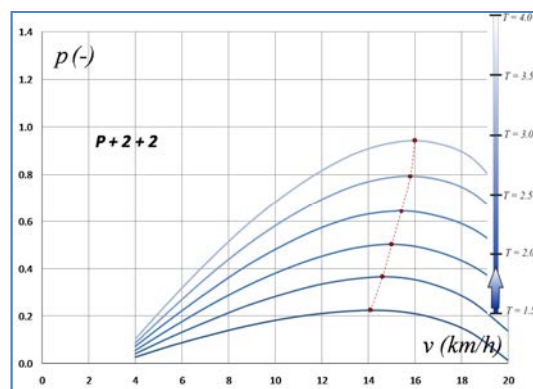


Figure 15 Example of a profit coefficient vs. convoy speed over ground v , for a single convoy formation and a range of convoy draughts, calculated without current.

[Source: Hofman et al. / University of Belgrade]

Influence of water depth

As it could be expected, the depth of the waterway has large influence on the economic speed. The influence of decrease of water depth on the maximum profit coefficient is always negative. A typical example of power change due to shallow water influences, obtained by the computer code CONVOY, is presented in the figure below.

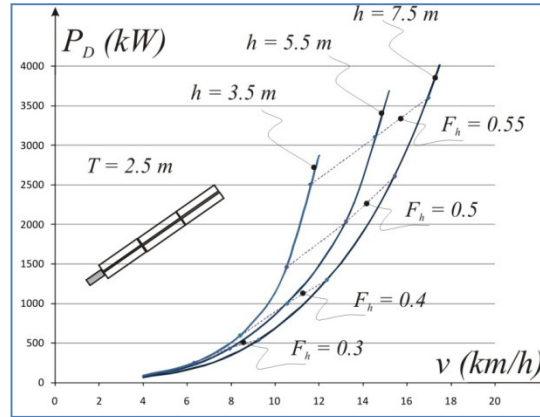


Figure 16 Delivered power as function of speed over ground, for P + 2 + 2 + 2 convoy formation, for three different water depths, calculated without current. [Source: Hofman et al. / University of Belgrade]

The diagrams in the figure below show that not only the maximum profit p_{max} , but also the corresponding economic speeds and optimal powers are being reduced with the decrease of water depth h .

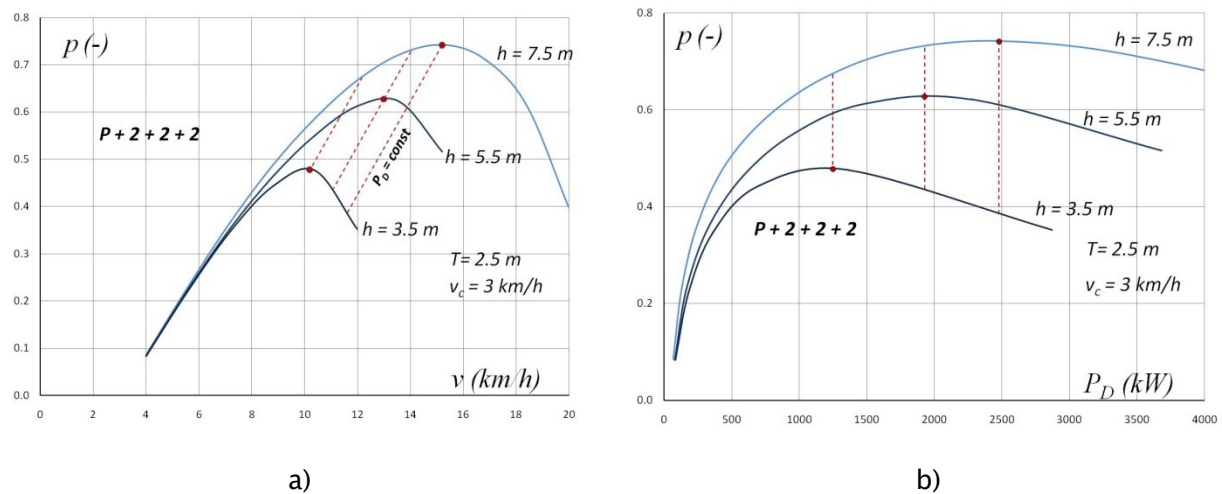


Figure 17: Profit coefficient as function of a) convoy speed and b) delivered power, for three different water depths. Convoy formation is P + 2 + 2 + 2, $T = 2.5$ m, and the river has the speed $v_c = 3$ km/h. [Source: Hofman et al. / University of Belgrade]

So, to follow the variation of economic speed, i.e. to gain the maximum profit rate for the actual waterway depth, the push boat would have to change the power if the water depth changes. In other words, the push boat with constant power could not gain the maximum profit rate, in case of changing water depth. It should be capable to change its speed deliberately, and adapt the power to the depth of the waterway.

Energy efficiency of convoys

If the Energy Efficiency Index (EEI) values are evaluated for different convoy formations as function of deadweight for constant convoy speed, a diagram presented in Fig. 18b is obtained. As could be seen, the results are very different from the constant power case (Fig. 18a), with much more scattering between the different barge formations. So, the question is: which power or speed to take as relevant for EEI calculations?

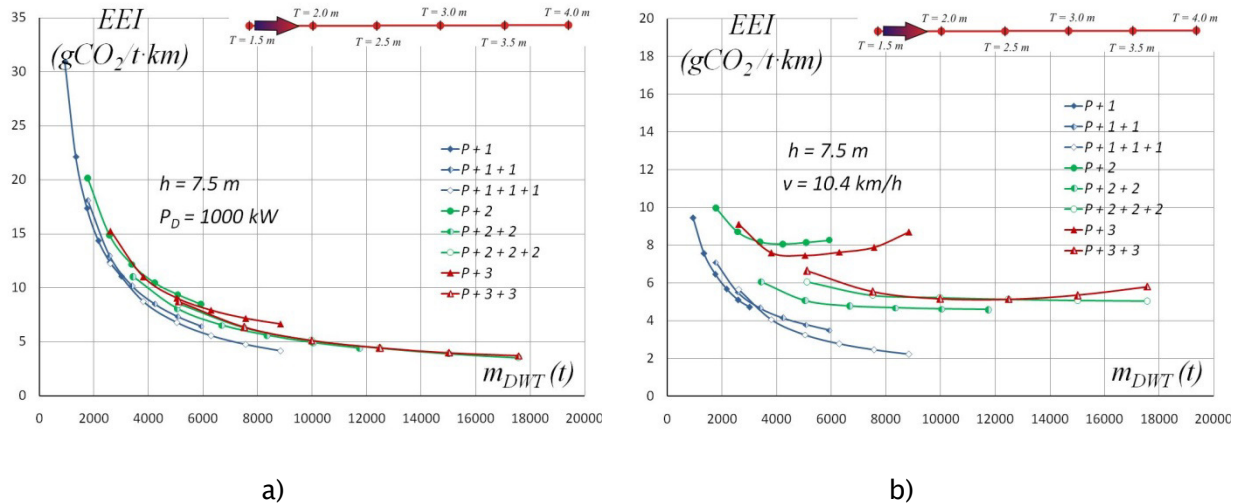


Figure 18 EEI values for different convoy formation as function of deadweight m_{DWT} , for: a) **constant delivered power** ($P_D = 1000 kW$.) and b) **constant convoy speed over ground**. ($10.4 km/h$) [Source: Hofman et al. / University of Belgrade]

To overcome the problem, EEI values are calculated as function of deadweight, but for particular **economic speeds**, (Figure 19). The obtained values do scatter between different barge formations, but for all of the formations, and all of the deadweights, they are in the relatively close range of $EEI = 9 - 13 gCO_2/t \cdot km$. This implies that, if the economic speed is taken as relevant, the maximum EEI value could be supposed independent of barge formation or convoy deadweight.

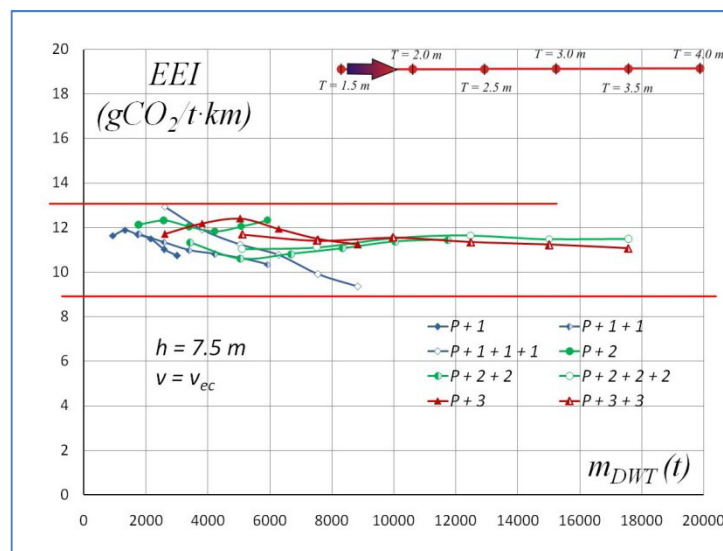


Figure 19 EEI values as function of deadweight, for appropriate economic speeds [Source: Hofman et al. / University of Belgrade]

The proposition to take the economic speed of a convoy as relevant for EEI calculations, and to take reference EEI values independent of the barge formation and convoy deadweight, should be understood just as one of the possible approaches, and should be elaborated in more detail in some further investigations.

3.1.4 Conclusion for the vessel dimensions

It appeared that the energy efficiency of Danube vessels and convoys could not be definitely determined with the different methods. None of the approaches described in the preceding chapters gave a concluding result for the determination of the main dimensions, so the issue remained open unless a more general cost performance calculation method was defined. This approach will be described in chapter 4.

3.2 Best equipment and innovative devices

The selected solutions or devices should have a good relevance to the core market of the Danube shipping, and should put less focus on niche markets. From different sources, for example the “NAIADES innovation data base” (www.naiades.info/innovations) a list of innovations and/or devices was compiled. As result of a systematic approach, a shortlist (Table 1) was selected from a total of about 50 project descriptions and devices.

Shortlist of innovative devices

No.	Innovation	Innovative aspects
1.	WWF–Danube Vessels	Shallow draught self-propelled container vessel; Shallow draught push boat
2.	Adjustable tunnel	flexible adjustment of propeller inflow to draught astern
3.	LNG as fuel for inland navigating vessels	New application of mostly existing techniques that has not been applied yet in inland navigation, but is successful in other sectors.
4.	Line Shaft type Contra Rotating Propeller	Recovery of rotational stream energy losses by CRP
5.	Developing the use of natural gas	Alternative to diesel.
6.	MoveIT!	Different approaches of hydrodynamic improvements
7.	Smooth	Air layers on the bottom reduce ship friction
8.	Streamline	Higher number of propulsors
9.	NEWS–FP7	Developing and validating a novel container ship

Table 1: Shortlist innovative devices

In order to assess the solutions with the best economic and ecological benefit, it was important to define carefully the criteria of evaluation. Innovative technical solutions will have in general an “owner” or “maker” interested in the commercial application of the device. This side is of course responsible to describe as precisely as possible the technical and economic properties of the device. For the collection and compilation of these data, an assessment table as simple questionnaire form was issued to the interested parties.

Innovative Device		"N A M E"		
Short Description of main features				
Status of development				
Proof of concept by:				
Web Site and / or publications				
Owner: Organisation and contact person				
Impact on	+ / -	%	Referring to	Remark
Ship resistance				
Propulsion efficiency				
Lightweight				
Deadweight at given draught				
Safety of navigation				
Cargo handling				
Fuel cost or other variable cost				
Crew cost				
Investment cost				

Table 2: Assessment table for innovative devices

The feedback for the assessment table was not that easy to obtain, and for more than one device no data collection was possible. The evaluation of the received feedback on the enquiries and on the published content (websites, press releases, brochures) has led to an assessment resumed in Table 3.

No.	Innovation	Suitable for IDV	Assessment result
1.	WWF–Danube Vessels		Performance will be assessed
2.	Adjustable tunnel		Suitable for self propelled vessels with high performance
3.	LNG as fuel for inland navigating vessels		Commercial application expected to be available at mid-term.
4.	Line Shaft type Contra Rotating Propeller		No response on information request
5.	Developing the use of natural gas		Preference to LNG (3.)
6.	MoveIT!		Suitable for existing ships
7.	Smooth		As application on pushed lighters
8.	Streamline		No response on information request
9.	NEWS–FP7		(see below)

Table 3: Evaluation results for innovative devices

The project 9 on the list, "NEWS-FP7" was not taken into consideration for different reasons: On one side it appears quite excluded to increase the number of transported containers per vessel, as the available cargo hold volumes are already exploited at nearly 100% by existing ships types. The number of 4 containers in the breadth is generally achieved by "Class V" vessels navigating on the Danube and the RMD canal. Published preliminary concepts even show a comparatively low container capacity and the non-conformity with the ADN rules for transport of dangerous goods. Also a claim to increase the propulsion "up to 30%" is not realistic as existing ships have already reached a high degree of efficiency. "Adaptable draught" is a claim that requires proving, as published preliminary concepts are not showing an increased ballast water volume. The main counter-argument to the NEWS-FP7 remains in the fact that ship operators need multi-purpose ships, able to transport as well bulk and containers; this is particularly relevant for Danube operation. This concept evaluation is based on preliminary and published concepts, and is perhaps to be revised with availability of definite project results.

The shortlist on innovative devices was discussed and finalized during the project meeting in May 2013.

Promising Innovations applied to Danube ships

From the shortlist of innovations and innovative devices, a project meeting in May 2013 selected three options appearing to be most promising for the utilisation on an innovative Danube vessel:

- "Flexible Tunnel" will reduce fuel cost and improve propulsive or energy efficiency (EE) of motor vessels. First calculations show that an additional investment of will pay back within a few years of operation.
- "Air lubrication" will reduce fuel cost and improve EE. First calculations show that an additional investment of 100 k€ will pay back within 5 years of operation. An application of the device on pushed barges should be investigated with priority.
- LNG: Even taking into account the additional investment, the reduced fuel cost can lead to the reduction of operating costs. This innovation has also the best impact on reduction of emissions, especially NO_x, SO_x, and soot particles.

4. Comparison of different vessel concepts

The aim of this work package is the development and assessment of first vessel concepts. For this approach, in a first step, the level of performance for the different ship types and ship concepts is investigated under realistic conditions of Danube navigation. This allows to identify the most promising vessels and, in the second step, to propose improvements and to give recommendations for the modernisation of the fleet.

4.1 Cost and performance calculation

The software tool used to compute cost and performance of an inland waterway transport (IWT) vessel has been developed by DST in the scope of the KLIWAS – project. This tool is able to use comprehensive data bases:

- Information on river depth and current speed for different Danube sections
- Economic ship properties for fixed and variable cost
- Hydrodynamic ship performance as function of draught, water depth and ship speed
- Water depth scenario for longer time periods

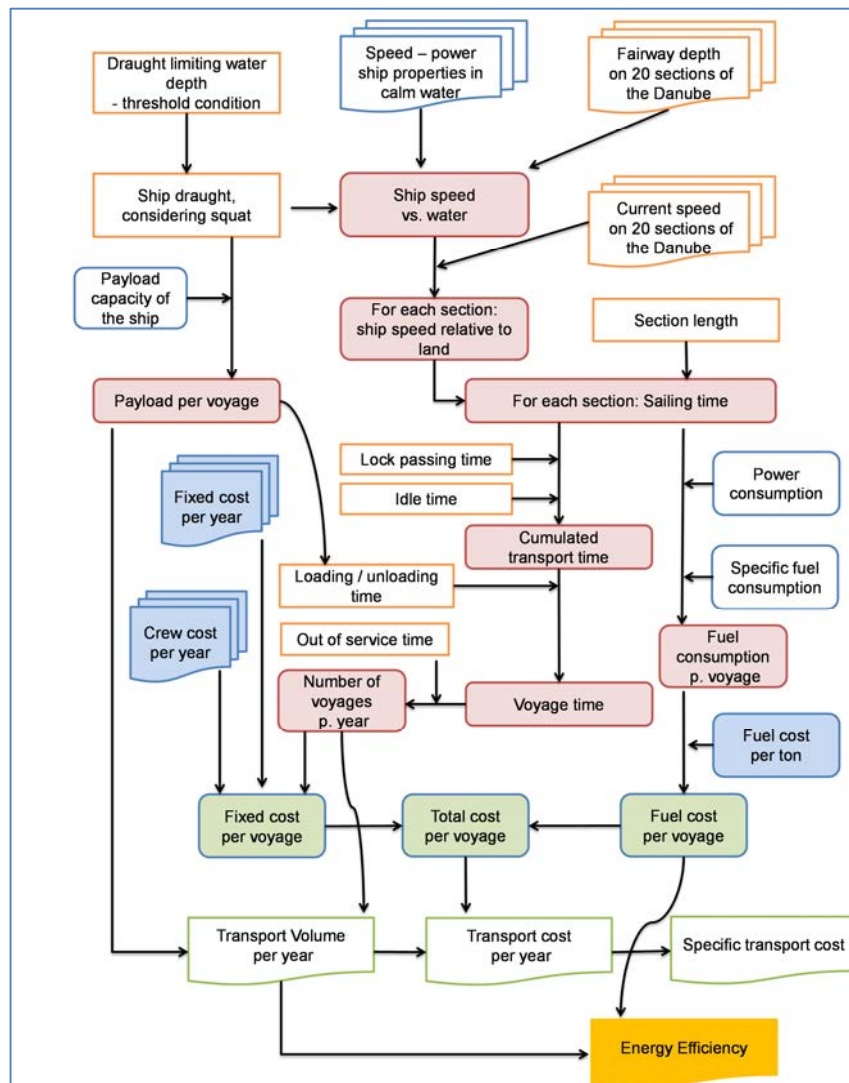


Figure 20: Cost/performance calculation scheme [Source DST]

Basic waterway data:

1. Based on input by viadonau, a simplified Danube river model was defined, with 23 sections of different water depth and the corresponding current speeds.
2. A typical operation scenario on the waterway with low, normal and high water periods was defined.

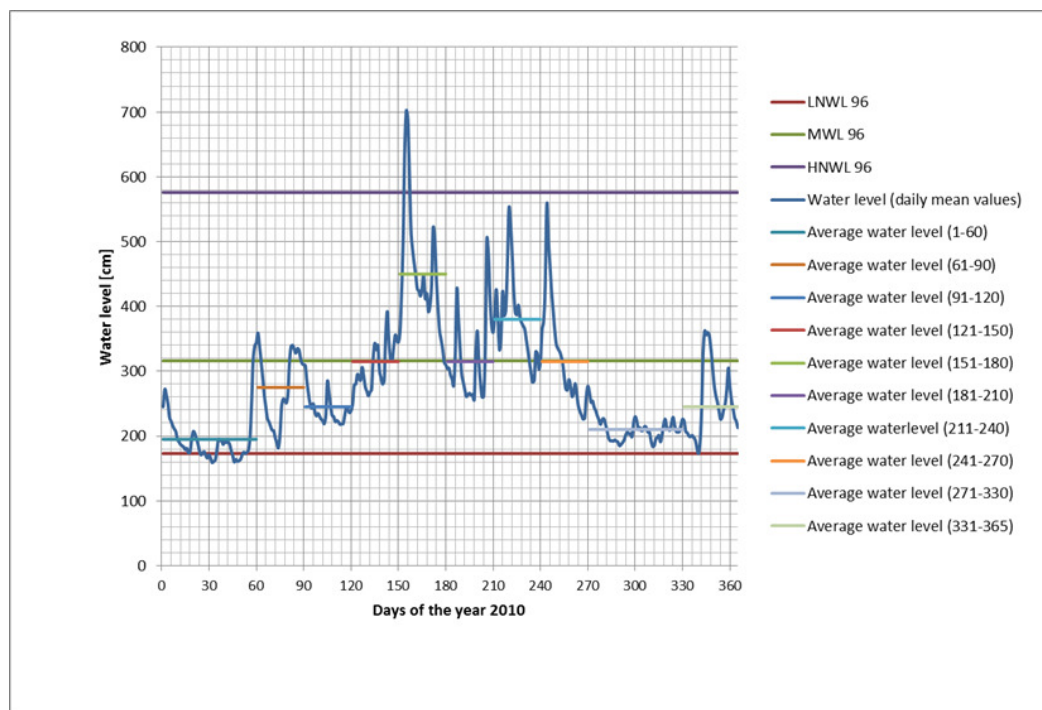


Figure 21: Water depth history in 2010 (Pegel Wildungsmauer) [Source viadonau]

Properties of basic ship types

The project considers mainly the ships types that are transporting the largest cargo shares on the Danube, as can be seen in chapter 2; these are bulk and so far only a small share of high valued finished goods and containers. The basic ship types in the table below include ships in standardised dimensions (class IV, V and VI) and also and ships with increased breadth, which have appeared on the river Rhine.

Short name	Description	Length	Breadth	Design Draught
		L [m]	B L [m]	T L [m]
SMV	Europe ship class IV	85.00	9.50	2.80
A15	Increased breadth, low draught	105.00	15.00	2.00
GMS	GMS class V	105.00	11.40	2.80
XGMS	Increased breadth	105.00	15.00	2.70
PB+4B	Convoy class VI	200.00	22.80	2.70

Table 4: Danube basic ship types

For each basic ship type, the speed/power curves for a complete range of water depths and draught are included in the calculation tool, derived from reference ships. The motor vessels

were also calculated as a convoy with one barge. This model considers the various influences and cost components of IWT, which are aggregated to the main components as follows:

- investment and insurance costs (capital costs, fixed costs),
- labour costs (fixed costs) and
- fuel and lubrication costs (variable costs).

The capital costs are treated by means of a linear depreciation of the total investment. The period of depreciation is based on the whole economic life of the vessel, which is defined in this study as 25 years. In addition thereto interest costs on capital have been accounted for by 6% of the half investment. The yearly repair and maintenance costs are accounted with 12.5 €/t cargo capacity. The insurance costs per year are based on a fixed component of € 13,000 per ship and a cargo capacity dependent component of 5€/t. The overhead costs are approximated with 3% of the total fixed costs.

For the labour costs a differentiation has been made to the ship size. Operation mode B, with 24/24h of navigation applies to all vessels. The crew wage level has been set according to information from ship operators.

- Crew cost and investment costs are treated on the annual basis (as with costs per year).
- Secondary performance or cost parameters (e.g. loading / unloading cycles, time spent in ports and locks etc.) are considered only if they are related to different concept dimensions.

Ship properties required for the calculation in the afore-mentioned software are at least the following:

Name	Symbol	Unit	Comment
Design Draught	T	m	Largest draught to be considered in calculations
Displacement	Disp	t	Displacement at design draught
Cargo capacity at T	DW	t	Calculated as difference Disp – Lightweight
Minimum Draught	T_{min}	m	Smallest draught for a manoeuvring and exploitable ship. A remaining deadweight is defined as “DW at T_{min} ” for T_{min} . The capacity for draught between T_{min} and T will be interpolated as linear function.
Nominal Engine Power	P	kW	Power delivered to the propeller at cruising speed; the installed engine power is usually higher.

Table 5: Ship properties

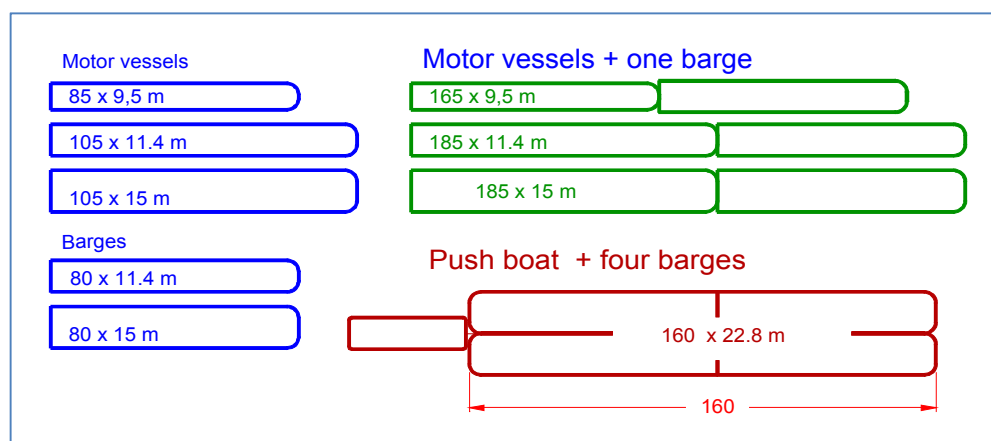


Figure 22: Ship dimensions

4.2 Calculation setup

Waterway scenario

The year 2010 is used as reference year, as in this year the navigation was possible without interruption. The recorded water levels at Pegel Wildungsmauer are decisive for the allowable vessel draught, but in function of the existing bathymetry of the river the water levels on the other sections of the Danube differ considerably. As example, if for one day the water level is 3,0 m at Pegel Wildungsmauer, the water level in other sections of the river will be deeper, especially on the lower Danube. The calculations take into account these different river sections with different water depth and different current speeds.

Delay in locks

According to the river administration, ships with a beam of 15 m may have more waiting times at the locks. If three vessels in normal breadth ($B = 11$ m) have to pass, these will be handled with priority. For ships with a beam of 15 m, the lock passing time was increased from 1 to 1.2 h, this represents one additional waiting hour on every 5th lock passage.

Speed and Powering

For the cost calculation, it was tried to have ship types operated at a comparable roundtrip time. The theoretical travel times in upstream and downstream direction are given as a reference in the “Manual on Danube Navigation”. In this case it was considered that “even playground” for a performance and cost assessment is attained when the different ships types are operated at common voyage speed level and perform the same number of roundtrips on the complete 1832 km range from Cernavoda to Linz.

Ship Class	Number of voyages per year
Self-propelled vessel	17
Self-propelled vessel+ barge	16
Push boat with 4 barges	13

Table 6: Number of voyages in 2010

These travel times reflect the current experience of ship operators and take into account usual idle time on the Danube.

Voyage mode

The calculation covers voyages on the Danube, with a distance of 1832 km from Cernavoda to Linz. Operating or traveling time of 24/24h was assumed for all ship types. For the performance and assessment, the upstream performance is the most significant:

- Many bulk commodities are transported only in upstream direction and the unloaded voyage downstream is part of the operation scheme.
- The upstream voyage will have the largest part in the fuel consumption.
- Favourable performance in upstream voyage will prevail in downstream condition.

Ship draught

For each voyage, the ship draught is selected according to the water depth that can be expected in the relevant time period. A minimum keel clearance and the influence of squat are taken into account. In the scope of this study, the draught obtained for one voyage is 0.20 m lower than the smallest expected water level (gauge value) at “Pegel Wildungsmauer”. This “rule of a thumb” is common practice of ship operators for the planning of a Danube voyage.

4.3 Calculation results

Calculation results are obtained in detail for each voyage of the time period and as cumulated sum for one year of operation. Table 7 indicates the most relevant cost and performance indicators, the relevant ship parameters are given in Table 8

Criteria	Unit	Remark
EEl	grCO ₂ /tkm	As average
Fuel consumption per year	t / year	Cumulated for upstream voyages
Total Cost per year	€ / year	Cumulated part for upstream voyages
Total Load per year	t / year	Cumulated part for upstream voyages
Cost per ton	€/t	For the upstream voyage of 1832 km

Table 7: Ship cost and performance indicators

Short name	Description	Length	Breadth	Design Draught	Nominal Engine Power	Light Weight	Capacity at T	Investment Cost	Crew Cost (B) per year
		L [m]	B [m]	T [m]	PB	LW	DW	k€ (1000 €)	k€ (1000 €)
SMV	"Europe" ship class IV	85.00	9.50	2.80	500 kW	450 t	1,580 t	3,500 k€	90 k€
A15	Increased Breadth, low draught	105.00	15.00	2.00	800 kW	770 t	2,060 t	4,500 k€	113 k€
GMS	GMS class V	105.00	11.40	2.80	800 kW	670 t	2,350 t	4,000 k€	113 k€
XGMS	"JOWI" Type	105.00	15.00	2.70	1,200 kW	780 t	2,970 t	5,000 k€	113 k€
SMV	+ one barge	165.00	9.50	2.80	900 kW	780 t	3,583 t	4,300 k€	170 k€
A15	+ one barge	185.00	15.00	2.00	1,440 kW	1,200 t	3,790 t	5,600 k€	170 k€
GMS	+ one barge	185.00	11.40	2.80	1,400 kW	1,000 t	4,353 t	5,000 k€	170 k€
XGMS	+ one barge	185.00	15.00	2.70	1,800 kW	1,230 t	5,460 t	6,100 k€	170 k€
PB+4B	Convoy class VI, push boat + 4 barges	200.00	22.80	2.70	1,400 kW	1,320 t (barges only)	8,013 t	7,000 k€	170 k€
Danube Barge		80.00	11.40	2.80		330 t	2,003 t	800 k€	
Danube Large Barge		80.00	15.00	2.70		450 t	2,490 t	1,100 k€	
Danube Large Barge T2		80.00	15.00	2.00		430 t	1,730 t	1,100 k€	

Table 8: Cost and performance parameters for basic ship types

The figures listed in Table 9 have been derived from the results of a complete year of operation in order to display only the cost part relating to the upstream voyages.

	Barges	Roundtrips per year	EEl gr CO2 per tkm	Fuel consumption per year k€ (1000 €)	Total Cost per year k€ (1000 €)	Total Load per year	Spec. Cost per voyage
SMV	0	17	18,6	230 t	356 k€	21.450 t	16,60 €/t
A15	0	17	19,5	380 t	503 k€	33.760 t	14,90 €/t
GMS	0	17	18,9	350 t	473 k€	32.030 t	14,77 €/t
XGMS	0	17	22,2	530 t	628 k€	41.500 t	15,13 €/t
SMV	1	16	14,8	390 t	554 k€	45.710 t	12,12 €/t
A15	1	16	19,1	640 t	759 k€	58.400 t	13,00 €/t
GMS	1	16	17,5	560 t	699 k€	55.980 t	12,49 €/t
XGMS	1	16	19,4	780 t	891 k€	70.510 t	12,64 €/t
PB+4B	4	13	14,4	700 t	927 k€	85.050 t	10,90 €/t

Table 9: Calculation results for one year of operation for basic ship types on upstream Danube voyage

For each ship type, the cost of a voyage depends much on the available water depth and the feasible draught.

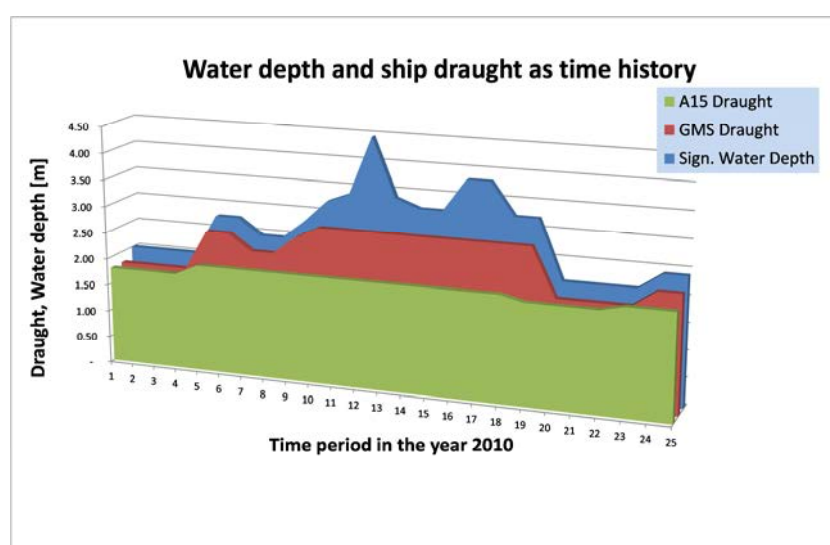


Figure 23: Time history of draught for the year 2010 [Source DST]

The time history of the ship draught (Figure 23) shows the close relation between water depth and draught: In this calculation mode, the availability of sufficient cargo is assumed, and the ships take always as much load as possible with the seasonal fairway conditions, up to the limit of the largest allowable draught.

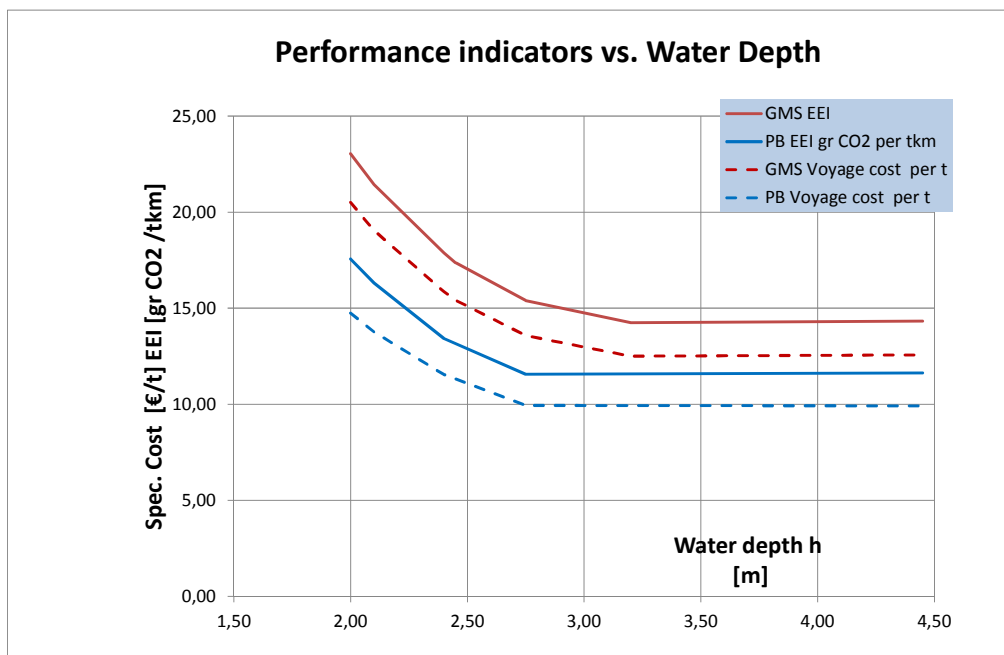


Figure 24: Cost and energy efficiency vs. water depth [Source DST]

Figure 24 shows that the performance indicators for vessels operating on the Danube are depending to a large extend on the available water depth. For example, it can be derived that an voyage performed at a water depth of $h = 2,0$ m will have about 50% higher specific cost and 50% more energy consumption compared to the voyage done at a level of $h = 3,5$ m. It becomes evident that for a large part of the year, vessels on the Danube are operating in conditions of severely reduced water depth: Any increase in available water depth will result in better cost and energy efficiency of ship operation. Also at reduced water depths, in the range below $h < 3$ m, the pushed barge convoy shows a better performance than the self-propelled vessel.

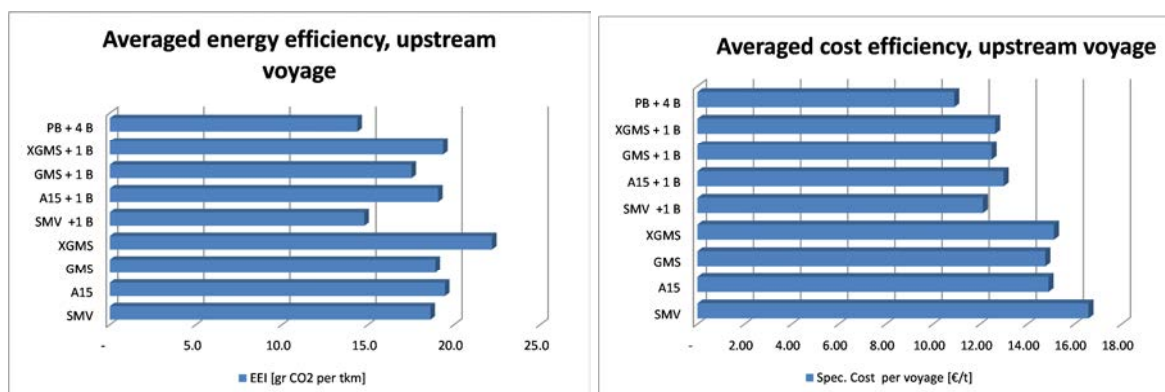


Figure 25: Energy and cost efficiency for different basic ship types [Source DST]

The data displayed in Figure 25 and Figure 26 is based on the averaged values for one year of operation in different water depth. What becomes evident is the difference in cost efficiency for the different ship classes “Single vessel / single vessel + one barge / pushed barges convoy”.

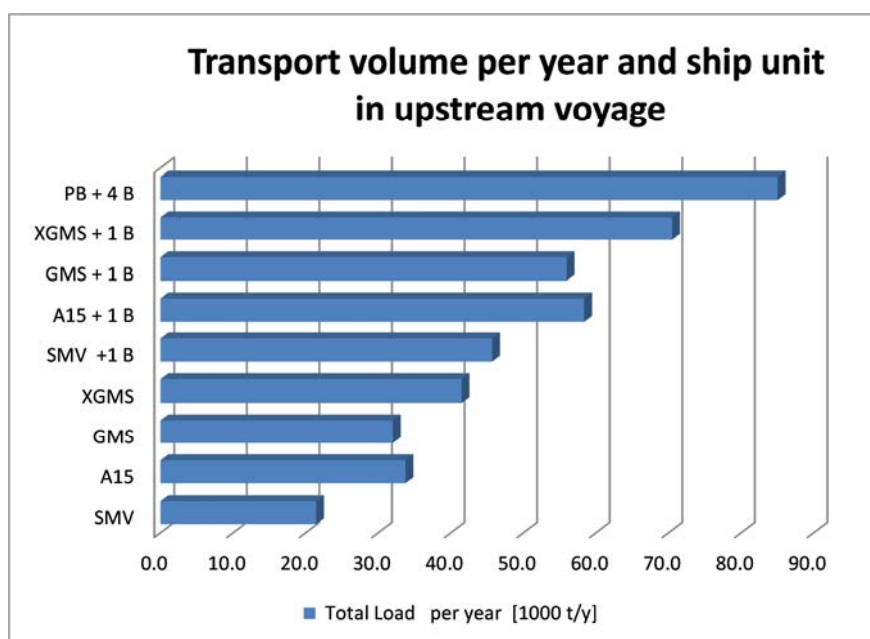


Figure 26: Transport volume per unit for different basic ship types [Source DST]

This difference appears also clearly in Figure 26, where it can be seen that the transport performance of the pushed barge convoy is by far exceeding the other ship classes.

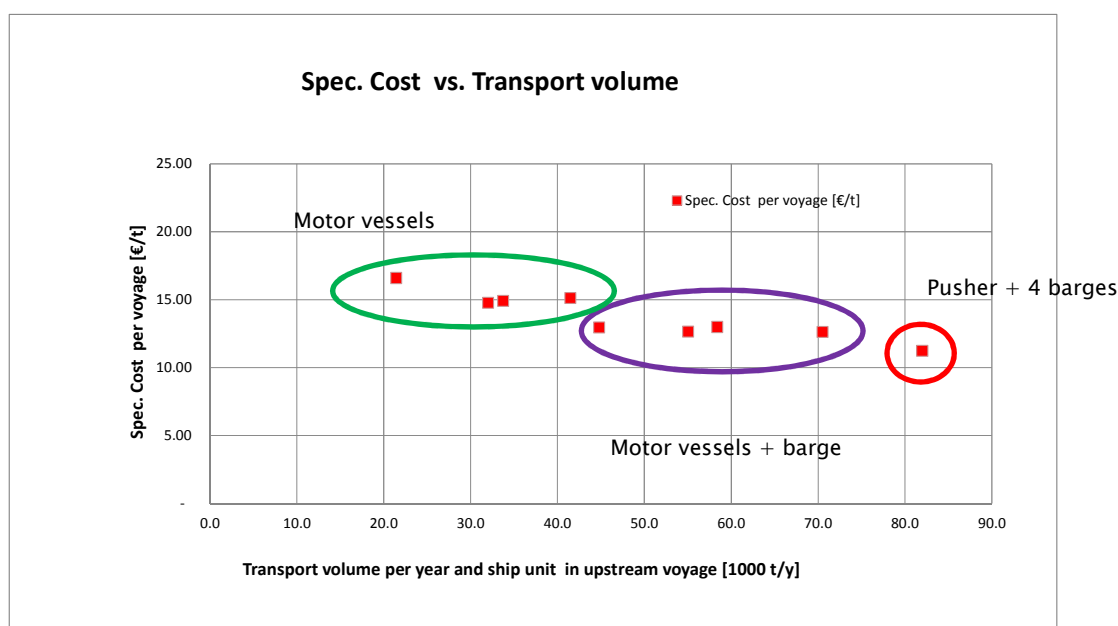


Figure 27: Transport performance for different basic ship types [Source DST]

Figure 27 shows the relation between the transport performance per year and the specific transport cost: The pushed barge convoy has the best position both for transport volume and for low specific transport cost.

Remark: The numerical values in Table 8 and Table 9 have to be considered as indicative, as fuel costs, investment costs and crew wages are subject to large and unforeseeable changes. Furthermore, risk and benefit margins, insurance etc. are not considered. These figures above with results of upstream voyages at full payload are valid and intended to be used only for **comparison** between different ship types.

4.4 Conclusions

Self-propelled vessels

The conclusions for the self-propelled vessels include the different versions of this ship type:

- It is only in combination with a pushed barge that the motor vessels come close to the cost and energy efficiency of the pushed barge convoys.
- No performance and/or cost advantages can be expected from a vessel breadth increased from 11.4 to 15 m.
- The least cost-effective self-propelled vessel (i.e. the one that attains the highest specific costs) is the small, Europe class vessel. The conclusion is valid in both cases: when the vessel is operated separately or in a convoy with a barge. This ship type could be competitive only in case of a specific cargo demand, available in small lots in the range of 1000 t.

Pushed barge convoys

- The established transport mode on the Danube, based mainly on pushed barge convoys has obviously already taken into account the difficult conditions of navigation.
- The convoy takes best advantages of the specific Danube infrastructure:
 - Locks with class VII dimensions in 34 m breadth and 24 m (upper Danube)
 - The fairway is at locations shallow, but there are no relevant restrictions in breadth.
- The pushed barge convoy offers by far the best possible payload in the case of small available water depth, as the floating volume has the dimensions L x B of about 170 x 22.8 m (4 barges, push boat excluded). Additionally, the weight of the steel structure of barges is lower than the one for motor vessels.
- The push boat + barges convoy proves to be leading in cost efficiency.
- The cost and energy efficiency is even increased by the versatile operation modus of the convoys, as the number and type of barges can be selected in accordance of the prevailing waterway and voyage conditions.

5. Concepts for the innovative Danube vessel

Based on the findings of chapter 4, three innovative vessel concepts are elaborated more in detail, based on a common set of requirements.

5.1 Common requirements and technical design concepts

The scope of this chapter is to set the main characteristics of the vessel concepts, well adapted to the navigation on the Danube River.

The research is focused on:

- Main dimensions in relation with the actual and predicted conditions of navigation – length, breadth, draught, air draft;
- Propulsion solutions for a better efficiency – type of propeller, propeller diameter in relation with draught, number of propellers, type of transmission;
- LNG (Liquefied Natural Gas) fuelling – emission requirements, regulations, gas/dual fuel engines, gas storage and processing, safety requirements, approval procedure;
- Ship concepts – arrangement of different types of pushers and for a self-propelled vessel.

5.1.1 Main dimensions

The convoy or vessel main dimensions – Length, Breadth, Draught, Air draft – are restricted by locks, bridges and in some cases by administration.

Limitations of main dimensions

There are some sectors on the Danube where the main dimensions of the vessels are restricted. These informations are published by the concerned administrations, for example at <http://www.doris.bmvit.gv.at>.

Sector	Remark	Length limit	Lock Breadth	Air draft limit*	Max. number of barges**:
From Sulina to Novi Sad (km 1260)	Main stream, Class VII	310 m Lock Portile de Fier	34 m Lock Portile de Fier	8.15 m 6.60 m at km 1254, will be replaced in near future	no limitation
From Agigea to Cernavoda	Danube Black Sea Canal Class VI	310 m lock – Cernavoda	25 m lock – Cernavoda	18 m	6 barges
From Novi Sad to Budapest (km 1641)	Main stream Class VIc	None	None	8.20 m	6 barges on Hungarian territory
From Budapest (km 1641) to Passau (km 2225)	Main stream Class VIb	230 m	24 m	7.40 m	4 barges
From Passau (km 2225) to Regensburg (km 2379)	Main stream Class VIa	230 m	24 m	5.95 m	4 barges
From Regensburg, (km 2379) to Main River	RMD, Connection to the Rhine sector Class Vb	190 m	12 m	5.95 m	2 barges

* The air draft restriction is in relation with HWL. For normal water level and also in relation with constant water level in locks, the air draft limitation could be considered less severe. Reference values are 7.50 m up to Passau and 6.00 m upstream from Passau.

** The standard barge's dimensions are considered to be L x B = 77x11.40 m

Table 10: Restricted main dimensions of different Danube sectors

Length

The pusher length is limited by the locks length.

The condition is that the convoy, pusher + barges fit into the lock.

6 or 9 (2+2+2 or 3+3+3) convoy fit in 275 m => maximum pusher's length = 44 m

2 (1+1) convoy fit in 190 m => maximum pusher's length = 36 m

The maximum length of pusher should be less than:

44 m up to Regensburg

36 m from Regensburg to Main River in 2 barge convoy

Breadth

The vessel and/or convoy breadth is mainly limited by the locks width.

The condition is that the pusher fits into the 12 m lock and the pusher + side by side barge fit in 24 m lock. This limits the maximum breadth of pusher to 11.4 m.

This means also that the self-propelled vessel with a breadth exceeding 11.4 m – for example $B = 15$ m – is severely disadvantaged as

- The Rhine–Main–Donau Canal will not be accessible.
- It will not be possible to take one barge by the side. This is a severe disadvantage on the Upper Danube for the downstream voyage.

Air draft

The vessel height over the waterline is limited by the bridges vertical clearance. The condition is that the vessels shall have an air draft less than:

- o 7.40 m up to Passau
- o 5.90 m from Passau to Main River

The air draught is reduced by:

- o lowered wheelhouse and collapsible mast
- o in some special cases, additional ballast could be considered

Draught

The vessel draught is of course limited by the water depth. Considering a keel clearance of 10–20 cm for the convoy (only in critical points) and the possibility for navigation having a probability of 96%, the pusher should be fully manoeuvrable and carry a part of stores at a draught of $T = 1.7$ m. This reflects the fact that the draught of existing pushers generally exceeds $T = 2.00$ m, and this is considered by ship operators as a severe disadvantage for Danube navigation.

The limitation of the pusher draught at 1.7 m is also a safety measure for the worst case scenario.

The minimum draught for safe operation of an innovative self-propelled vessel is defined at $T_{\text{MIN}} = 1.60$ m. This will enable the vessel to be kept operational at low water depth seasons and to continue the transport tasks with reduced capacity.

5.1.2 Propulsion

The purpose is to investigate the requirements for propulsion power and the effect on efficiency for different propulsion layouts.

Requirements for propulsion power

Legal requirements are given by national administrations, still expressed in the older “horse power” unit HP. The most relevant is the regulation valid on the – Danube – Black Sea Canal (DBSC), stipulating an installed engine power of “6 tons of cargo per installed power [HP]⁸. A speed criterion of 13 km/h⁹ (on deep water without current) is applicable not only for some Danube sectors, but also on the Rhine. Table 1 indicates the resulting requirements for propulsion power.

Convoy	Displacement criteria 6 tons cargo per HP	Speed criteria 13 km/h
2 barge convoy (1+1)	4000 t / 6 => 670 HP	55 kN thrust => 690 HP
4 barge convoy (2+2)	8000 t / 6 => 1350 HP	110 kN thrust => 1400 HP
6 barge convoy (2+2+2)	12000 t / 6 => 2000 HP	180 kN thrust => 2250 HP
9 barge convoy (3+3+3)	18000 t / 6 => 3000 HP	260 kN thrust => 3250 HP
Self-propelled vessel, designed for one additional barge	4000 t / 6 => 670 HP	55 kN thrust => 690 HP
Self-propelled vessel, designed for three addi- tional barge	8000 t / 6 => 1350 HP	110 kN thrust => 1400 HP

Table 11: Required propulsive power, by national administration

Owner requirements: Usually, based on experience, the owners ask for high installed power. For example, NAVROM asks for at least 1800 kW, preferably over 2400 kW. For the self-propelled vessels, the speed expectations are higher and the engine power is substantially higher than the demands resulting from regulations.

⁸ RNC – Reguli de Navigatie pe Canalul Dunare-Marea Neagra (Romania) – Cap. II, art 9.1

⁹ RND – Regulamentul de Navigatie pe Dunare (Romania) Part III A, art. 3.2

Propulsion design

With the necessity to obtain a high propeller thrust with a comparatively low ship draught, the following approach is useful:

- Propellers are used together with a propeller nozzle
- The diameter of the propeller is selected as high as possible
- The number of propellers is increased

Table 12 and Table 13 indicate the performance of different propulsion setups, in this case for a required thrust of 180 or 260 kN.

Number of propellers	2	3	4
Required power / propeller [kW]	785	472	327
Required total power [kW]	1570	1416	1308
Difference [%]	0	-9.8	-16.7
Power-thrust ratio [kW / kN]	8.72	7.86	7.27

Table 12: Propulsion data for a required total thrust of 180 kN

Number of propellers	2	3	4
Required power / propeller [kW]	1300	775	535
Required total power [kW]	2600	2325	2140
Difference [%]	0	-10.6	-17.7
Power-thrust ratio [kW / kN]	10.0	8.94	8.23

Table 13: Propulsion data for a required total thrust of 260 kN

The decreasing of propeller load, using more propellers, has an excellent benefit on required power, at same thrust.

Transmission of the power to the propellers

The possible variants for transmission indicated in Table 14.

Transmission	Direct shaft via gear box	Azimuth thruster	Electric transmission	Hydraulic transmission
Reliability	good	medium	medium	low
Losses (%)	3–5	7–8	8–10	15–18
Cost	low	medium	high	high
Maintenance	simple	medium	complex	Complex
Remark		exposed to the damage easy propeller maintenance without docking high manoeuvrability, no rudders required	power management system can be implemented additional diesel generators are not required high electric power available for bow thruster (if installed) possibility to use constant rpm engines	

Table 14: Characteristic differences in power transmission systems

Power management:

The power management on board is necessary to deliver and especially to produce at any time the exact amount of necessary energy required from the propulsion and auxiliary systems of the vessel.

In the case of inland waterway vessel several different operating conditions can be distinguished:

- upstream/downstream
- fully loaded / partly loaded / unloaded convoy
- cruise / manoeuvring

The necessary propulsion power in the above conditions could vary from 30% to 100% of the installed power.

Running with all engines in low rpm means an increasing of specific fuel consumption (g/kWh) by up to 10%. On the other hand, for an engine with constant rpm, the specific consumption increases by up to 5% at 50% load. The solution consists of stopping the unnecessary engines. In case of electric transmission, automated start or stop of the generators according to the required power will keep all propellers running also at low load.

In case of shaft line transmission when more than two propellers are used, the central propeller and engine(s) can be stopped. The disadvantage consists in the additional drag produced by stopped propellers.

5.1.3 LNG fuelling

In the recent years, the shipping industry has discussed the use of LNG as fuel to be a viable solution in order to comply with the near future requirements for emission level (NO_x, SO_x, particles).

Despite of high initial investment cost, the solution of LNG brings benefit to the owner, from the difference in price compared with gasoil. This benefit increases if the cost of different devices for emission reduction (mandatory in near future in case of gasoil) is also considered.

At present time, the major problem consists in the lack of regulation regarding the use of LNG as fuel on inland ships and on the other hand the lack of LNG infrastructure (transport, storage, and bunkering) along rivers. Progress is made by the Central Commission for the Navigation of the Rhine (CCNR), Classification Societies and the national administrations to define these regulations. Based on preliminary rules and regulations, the design, reception and operation of the first river vessels fuelled by LNG has been possible.

Regarding the technology of LNG as fuel (regulations, engines, storage, etc.), it is well developed for marine applications, therefore, it can be expected that first applications will be implemented in inland waterway transport in the near future

From a safety point of view, two alternative system configurations may be accepted:

1. Gas safe machinery spaces: Arrangements in machinery spaces are in compliance with the provisions of IGC Code, Chapter 16, such that the spaces are considered gas safe under all conditions, normal as well as abnormal conditions i.e. inherently gas safe.
2. ESD protected machinery spaces: Arrangements in machinery spaces are such that the space itself acts as the pipe enclosure required by IGC Code, Chapter 16. In the event of abnormal conditions involving gas hazards, emergency shutdown (ESD) of non-safe equipment (ignition sources) and machinery is to be automatically executed while equipment or machinery in use or active during these conditions are to be of a certified safe type.

Engines

Technology: there are currently three natural gas engine technologies used for marine applications:

- 1) spark-ignited lean-burn, gas only
- 2) dual-fuel diesel pilot ignition with low-pressure gas injection,
- 3) dual-fuel diesel pilot ignition with high-pressure gas injection.

Protection walls:

- 1) single walled engine valid only for ESD arrangement
- 2) double walled engine valid for Gas safe arrangement

Operation mode:

- 1) constant rpm for power generation application
- 2) variable rpm for direct drive propulsion

Approval

A specific aspect of ship propulsion is the requirement that the engines are approved by a Classification Society. There are three categories:

- 1) with type approval certificate
- 2) approved at special request and supervision
- 3) not approved for marine use

In this moment (end of 2013) the gas engines listed below are available:

Engine	Power [kW]	Fuel	RPM	Application, Operation mode	Protection Walls	Approval Certificate
Wartsila L20DF	1050; 1400	Dual Fuel	Variable	Direct/ Gen-set	Double	Yes
Caterpillar 3512C	1140	Dual Fuel	Variable	Direct	Single	special
Bergen C26:33L6PG	1460	Gas only	Variable	Direct / Gen-set	Double	Yes
Mitsubishi GSR	360; 720; 960	Gas only	Constant	Gen-set	Single	Yes
Caterpillar 3516C	1550	Dual Fuel	Constant	Gen-set	Single	special
Caterpillar G3516C	1550	Gas only	Constant	Gen-set	Single	special
Scania SGI	235; 190; 100	Gas only	Constant	Gen-set	Single	special

Table 15 Available LNG engines in the year 2013

Other manufacturers start to develop different gas engine and in the next years a wider range of engines is expected to be available.

Due to the lack of LNG infrastructure, in order to assure a good flexibility in fuel supply, the dual fuel engines are recommended in this moment. Probably, in the future when a reliable supply chain for LNG will be developed, the gas only engines will become to be favourites.

Propulsion architecture

There are few variants of propulsion architecture, using gas engines:

- a) classic: engine – gearbox – shaft line – propeller; require direct drive engines
- b) electric transmission: engine – generator – transformers/convertors – electric motor – propeller (possible azimuth); can use “constant rpm” engines
- c) composite: direct drive + electric

Gas storage and processing

Different types of gas packs are available. Basically, the gas pack consists of:

- storage tank (normally type C vacuum insulated)
- tank room which contains the re-gasification unit, valves etc.
- gas valve unit included in tank room or arranged in the engine room
- bunkering station

Special precaution should be taken for the arrangement of gas pack in relation with safety requirements.

Approval procedure

In condition of lack of regulations, the approval procedure for the use of LNG as fuel on board of an inland waterway (IWW) vessel is made case by case.

At present, the procedure is as follows:

- Plan approval and Hazid study to be done by Class in cooperation with the designer and builder of the vessel.
- Preparation of the recommendation (including annexes) by Class
- The application will be send from Class to the authority who will issue the statutory certificates
- This authority will send in the application of the recommendation to the CCNR / EU technical working group in Strasbourg
- Presentation by the applicant in the CCNR / EU technical working group (first meeting)
- Discussion of the documents in the CCNR / EU technical working group (second meeting)
- Finalize the discussion on the recommendation in the CCNR / EU technical working group (third meeting)

The whole process will take about 1 year. The CCNR / EU working group meets 4 times a year. In 2014 it's in mid-February, early June, mid-September and early December.

The recommendation has to be sent by the authority who certifies the vessel. According to the IWW legislation this can be any authority independent from the country where the vessel is registered. In practice a great part of the Western European IWW fleet is certified by the Netherlands Shipping Inspectorate (NSI) although not all these vessels are registered in The Netherlands. Since 2010 the statutory certification has been delegated from NSI to Lloyds Register (LR). From now on, LR can issue not only the class certificate but also the statutory certificates (on behalf of NSI). This is independent from the country of registry.

This whole process for getting a recommendation is necessary due to the lack of legislation. But at this moment the concerned administrations are working on setting up the legislation for gas-fuelled IWW vessels.

It is planned that this new chapter of the Rhine Vessels Inspection Regulations will be implemented on January 1st 2015. This new chapter is based upon the IGF Code and the Rules for Methane Gas Fuelled vessels.

5.2 Vessel concepts

In the scope of the project, three different ship concepts were worked out.

5.2.1 Classic pusher design concept

The concept of this ship is developed in order to demonstrate the feasibility of a pusher having an installed power of (or brake power of) 2400 kW a draught of only $T_{\min} = 1.6$ m, and which is complying with all the requirements regarding actual regulations and dimensional constraints on the Danube.

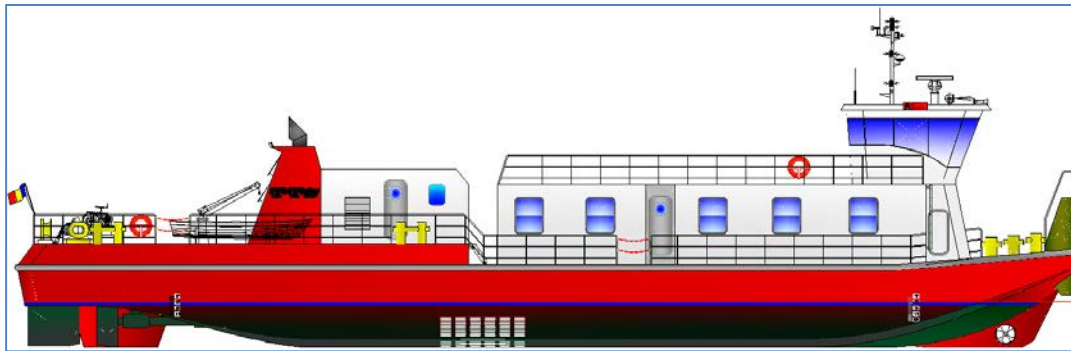


Figure 28 Pusher as classic design concept [Source SDG]

Dimensions:

- Length over all 36.00 m
- Breadth 11.40 m
- Depth 2.80/3.50 m
- Design draught 1.60 m with remaining stores of about 50 t
- Air draft normal –7.50 m, in special conditions – 5.90 m

Propulsion:

- Type: 3 x Fixed Pitch Propeller (FPP) in nozzle, shaft lines water lubricated
- Power: 3 x 800kW (CAT 3508 B 746 kW / 1600 rpm, rating A, or equivalent)

Capacities:

- Ballast: 95 m³
- Fuel Oil: 105 m³
- Fresh water: 20 m³
- Sewage: 20 m³

Performance

- Range: 180 running hours at 90% Maximum Continuous Rating (MCR)

15 day fresh water/sewage

1300 km upstream, 2500 km downstream

- Thrust: 240 kN at cruise speed of 12 km/h
- Crew: 8
- Displacement:

Lightship: 300 t

Full load: 415 t

Subdivision

- Compliance with the regulations concerning damage stability
- double hull except engine room where double side is missing
- tank arrangement in order to assure a good trim in any loading condition

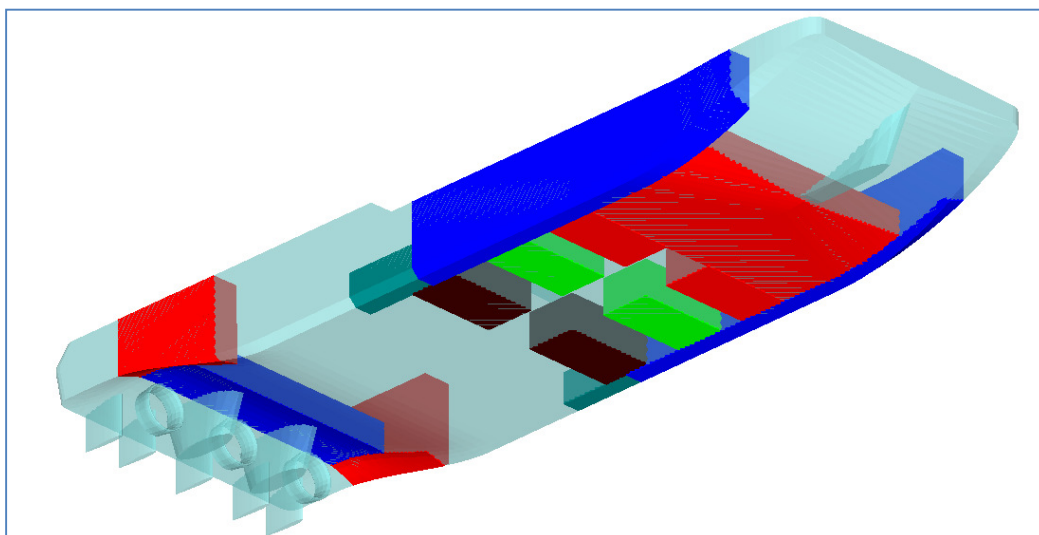


Figure 29 Pusher with internal arrangement [Source SDG]

Machinery

- steering – five rudders electro hydraulic driven
- propulsion – 3 x FPP propellers (1.45 m diameter) in nozzle
- transmission
 - 3 x shaft lines water lubricated
 - 3 x gearboxes, reversible
 - 3 x elastic coupling
- engines – 3x diesel engines CAT 3508 B 746 kW / 1600 rpm (or equivalent)
- cooling – box coolers
- generators

- 2 x 60 kWe in engine room
 - 1 x 35 kWe harbor generator, on deck, air cooled
- Bow thruster – optional – 1 x 120 kW hydraulic driven from Power Take Off (PTO) on central engine

Arrangement

The ship arrangement is divided in two separate areas:

- mechanical and propulsion area in aft part which contain
 - steering room
 - aft deck store
 - engine room
 - funnels
 - aft roof which includes engine room access, CO₂ room, harbour gen-sets, workshop, mechanical store
- accommodation area in fore part, totally separate from noise and vibration areas (engine room, propeller area)
 - two under deck compartments for tanks and related equipment
 - fore peak
 - superstructure on main deck
 - wheelhouse
- Superstructure
 - all crew spaces are arranged in the superstructure on one level
 - two single cabins with own sanitary space (toilet and shower)
 - three double cabins with own sanitary space (toilet and shower)
 - mess room
 - galley, food store and garbage room
 - ship's office
 - accommodation store
 - laundry, change room
 - under the wheelhouse are arranged the lifting system and deck store;
 - option: the superstructure could be fitted with dampers. In this respect the connections between hull and superstructure will be of elastic type

Wheelhouse

- large wheelhouse with excellent visibility;
- a lifting system is necessary only when containers are transported; could be installed: a lifting system with abt. 5 m stroke.

Deck

- two aft anchors and windlasses
- mooring bollards aft, center and fore
- one towing/coupling bollard fore in centre line
- tugger capstan aft
- 2x coupling winch and 2x2 flat bollards aft

- 4x coupling winch and 2x3 coupling bollards fore
- option – towing hook and chock 40 t
- service boat with davit

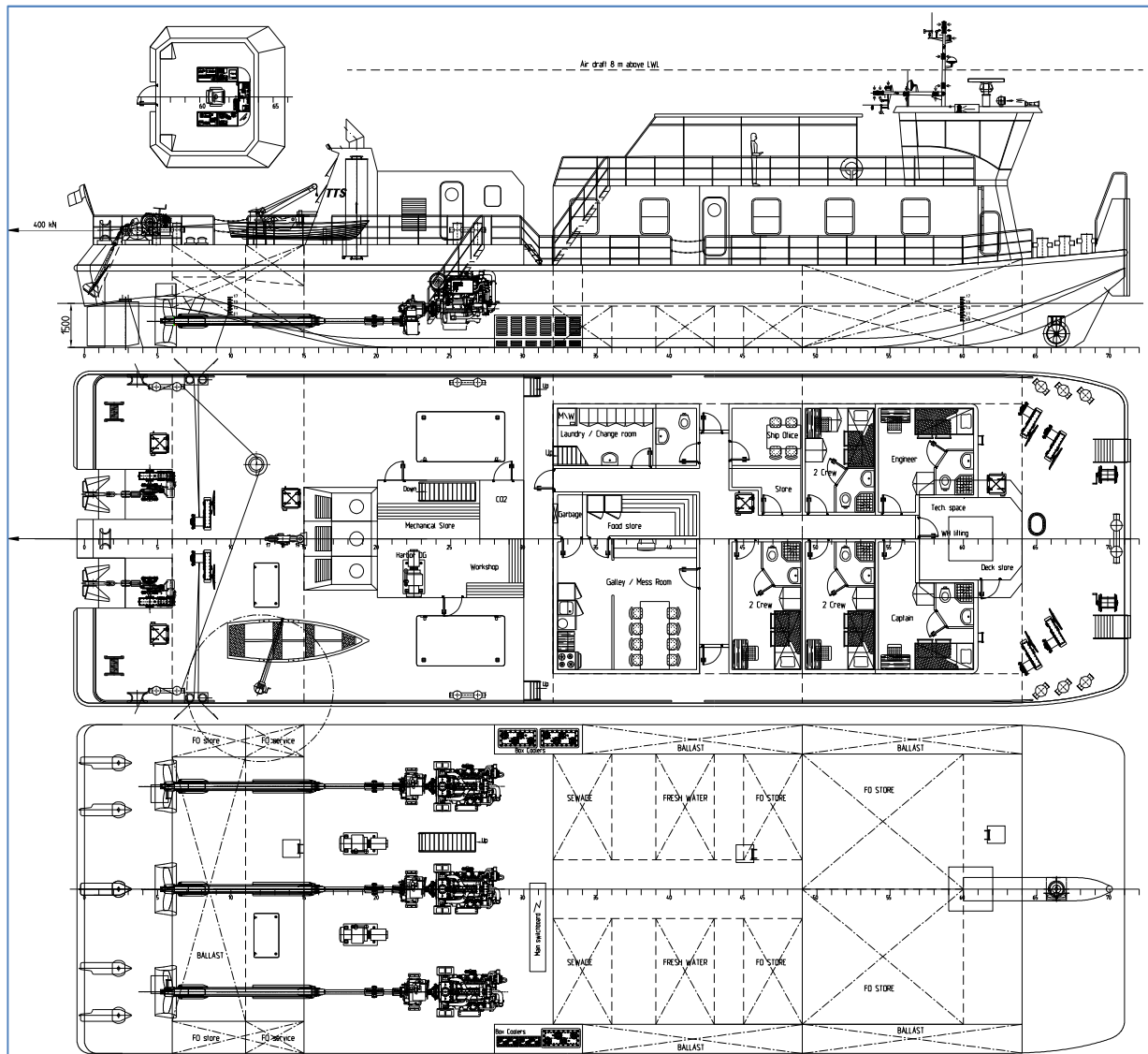


Figure 30 “Classic” pusher – General Arrangement [Source SDG]

5.2.2 LNG pusher design concept

The concept of this ship is developed in order to demonstrate the feasibility of a pusher disposing of an engine power 2400 kW, in combination with a reduced draught of $T = 1.7$ m, using a new trend of LNG fuelled ship fuelled ship complying with all requirements regarding actual regulations and dimensional constraints on Danube.

This new design of push boat should consider the below requirements:

- to use LNG as fuel and engine to be able to run on diesel also
- to include all modern and innovative solutions for propulsion
- to assure a good comfort on board (spaces, noise, vibration)
- to be adapted to the actual and future waterway characteristics
- to be able to operate the actual fleet of barges
- to be to be fully compliant with actual and future Rules and Regulations applicable on European inland waterways.

Dimensions:

Length over all	39.00 m
Breadth	11.40 m
Depth	3.00 m
Design draught	1.70 m with remaining stores of about 50 t
Air draft	normal –7.50 m, in special conditions – 5.90 m

Propulsion:

Type:	3x800 kW azimuth L drive, electric driven
Generators	3x Wartsila 6L20DF 880 kW / 1000 rpm, dual fuel, 98% gas; 2% diesel

Capacities:

Ballast:	100 m ³
Fuel Oil:	70 m ³
LNG:	140 m ³
Fresh water:	19 m ³
Sewage:	19 m ³
Crew:	8

Performance

Range:	Gasoil (DO) only: 120 running hours = 1400 km (slack water)
	LNG only: 120 running hours = 1400 km (slack water)
	15 day fresh water
Thrust:	270 kN at cruise speed of 12 km/h

Displacement:

Lightship: 370 t

Full load: 520 t

Skeg:

- one skeg fore for protection and for reduction of bow wave height in free running condition and accommodation the bow thruster
- two skegs aft for azimuth thruster protection and course stability;

Subdivision

- Compliance with the regulations concerning damage stability
- double hull except peaks
- tank arrangement in order to assure a good trim in any loading condition

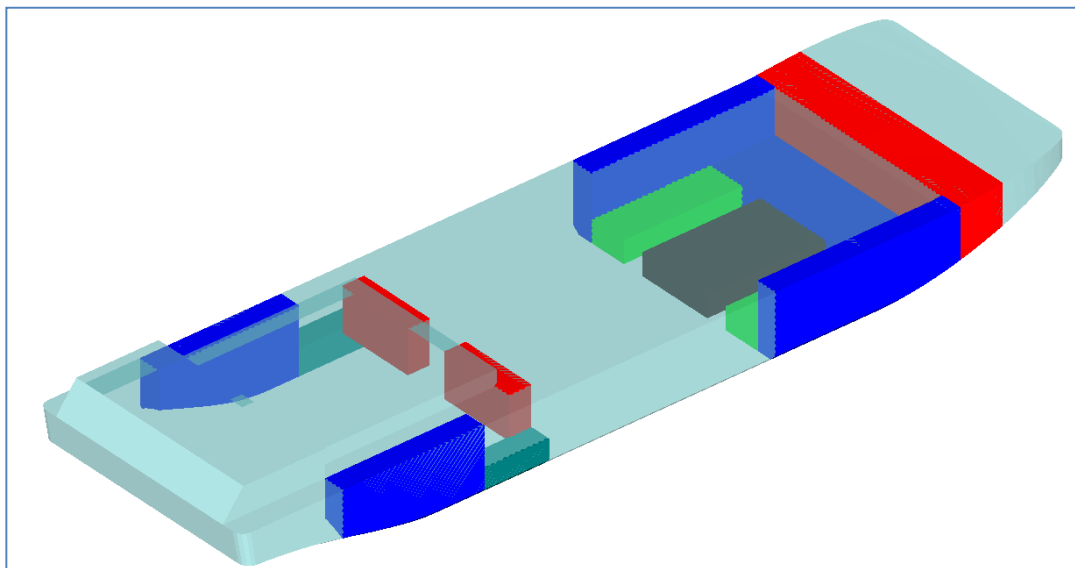


Figure 31 LNG Pusher with internal arrangement [Source SDG]

Machinery

- steering – 360° rudder propeller
- propulsion – 3x azimuth L-drive, electric driven, FPP propellers (1.45 m diameter) in nozzle
- transmission – electric, power management system
- main generators – 3x dual fuel engines Wartsila 6L20DF 880 ekW / 1000 rpm (or equivalent)
- harbor generator – 1x 35 ekW on deck, air cooled
- bow thruster – optional – 1x 120 kW electric driven

Arrangement

The ship arrangement is divided in four separate areas:

- Thrusters area
- Generator area
 - generator rooms
 - funnels, silencers and air intake systems

- aft roof which includes engine room access, CO₂ room, harbor DG, workshop, mechanical store
- LNG area
- accommodation area in fore part totally separate from noise and vibration areas

Superstructure

- all crew spaces are arranged in the superstructure on two levels
 - two single cabins with own sanitary space (toilet and shower)
 - four double cabins
 - common sanitary space (toilet and shower)
 - mess room
 - galley, food store and garbage room
 - ship's office
 - accommodation store
 - laundry, change room
- under the wheelhouse: lifting system and deck store

Wheelhouse

- large wheelhouse with excellent visibility;
- a lifting system is necessary only when containers are transported; could be installed: a lifting system with abt. 5 m stroke.

Deck

- two aft anchors and windlasses
- mooring bollards aft, centre and fore
- one towing/coupling bollard fore in centre line
- 4x coupling winch and 2x3 coupling bollards fore
- service boat with davit

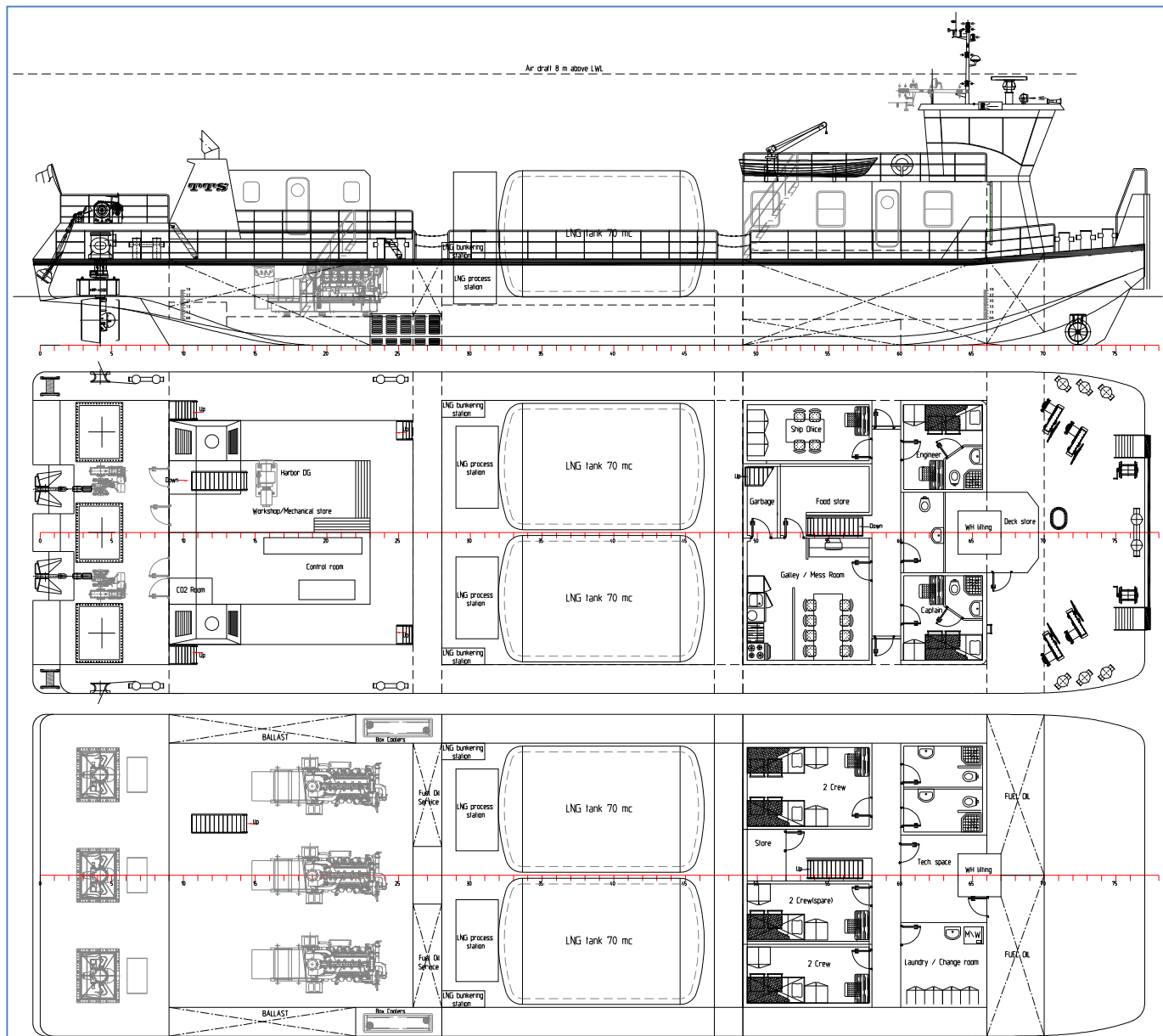


Figure 32 Danube "Azimuth-dual fuel - electric" push-boat - General Arrangement [Source SDG]

5.2.3 LNG self-propelled vessel

The concept of this vessel is developed in order to demonstrate the feasibility of a self-propelled vessel powered by 1500 kW at 1.6 m draught, with a versatile utilisation as single vessel or as a convoy with one barge or even three barges. The use of LNG fuel is proposed. Two different hull concepts are possible:

- a) The bow of the self-propelled vessel is blunt, and the vessel is operated in permanence as a convoy together with one conventional barge.
- b) The bow of the self-propelled vessel has a conventional bow form, and in case of convoy operation, a dedicated barge with an adopted aft form is used.

Both versions are equivalent from the performance point of view, and the operation conditions or preference of the owner will influence the choice. In the following descriptions, the version b) with a conventional bow is used.

This new design of the self-propelled vessel considers the below requirements:

- Usage of LNG as fuel and engines being able to be operated also with gasoil
- Inclusion of all modern and innovative solutions for propulsion
- Assurance of a good a good comfort on board (spaces, noise, vibration)
- Adaptation to the actual and future waterway characteristics
- Full compliance with actual and and future rules and regulations applicable on European inland waterways.

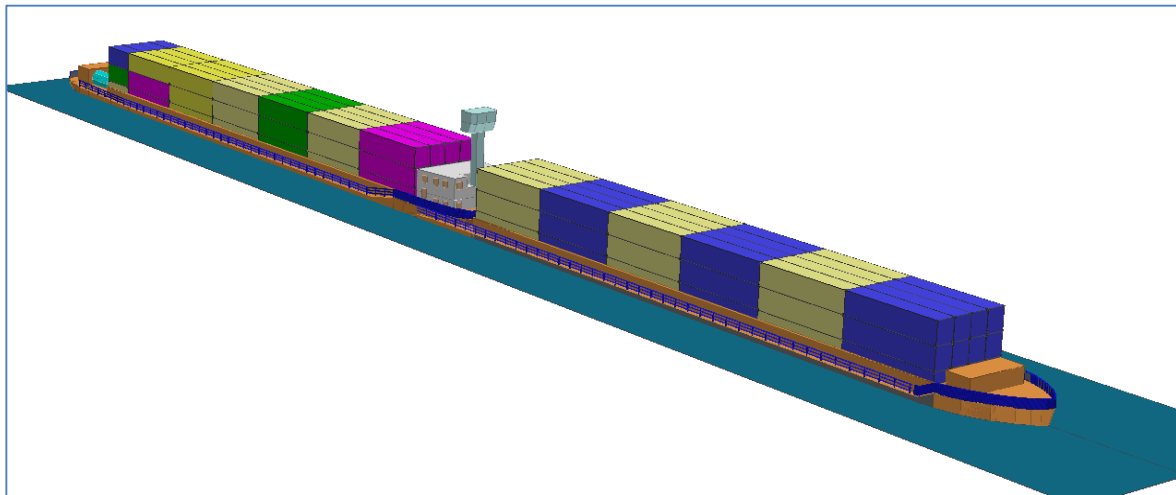


Figure 33 Self-propelled LNG vessel, operated as convoy with container load
[Source DST]

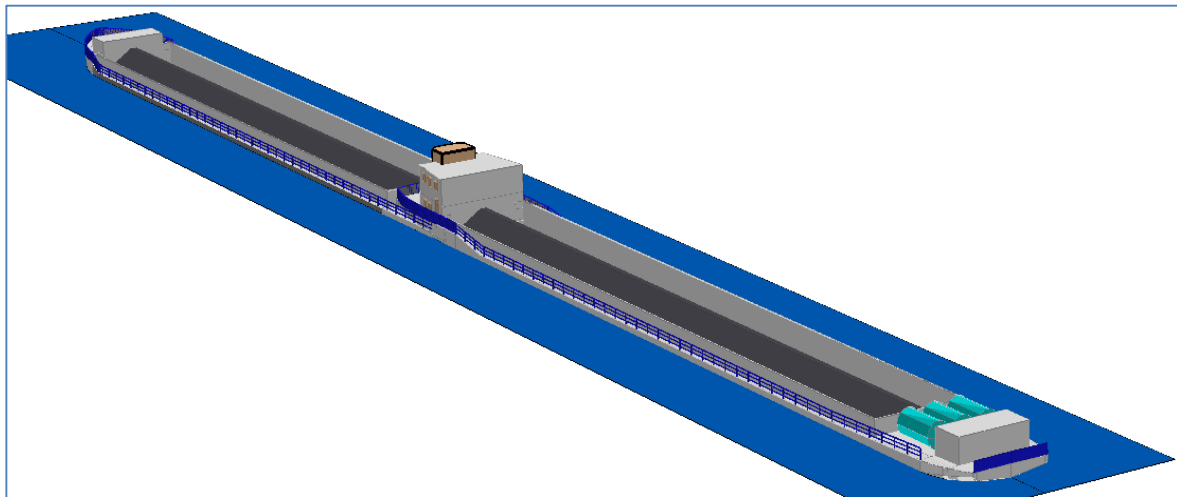


Figure 34 Self-propelled LNG vessel, operated as convoy with bulk load [Source DST]

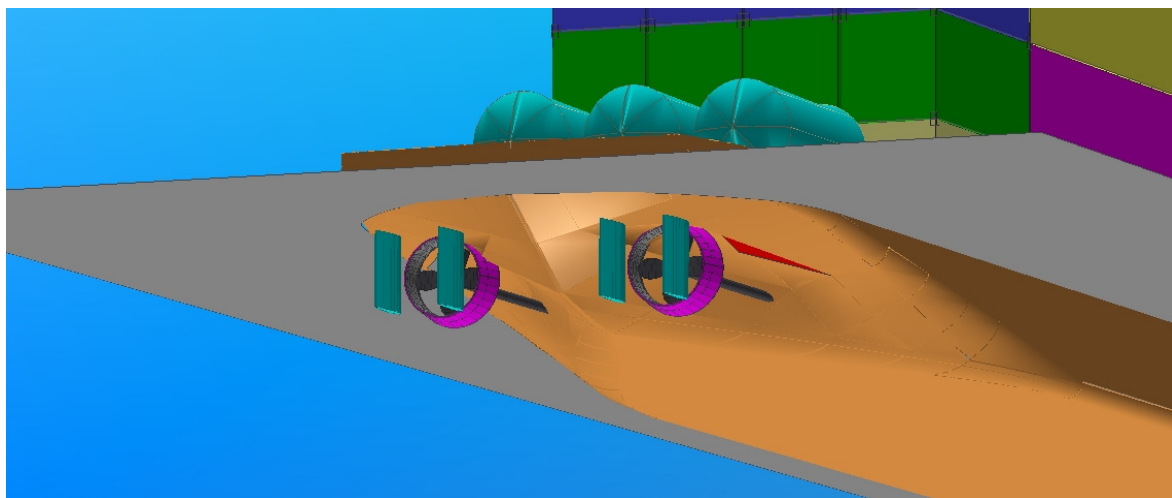


Figure 35 Self-propelled LNG vessel, view on aft body [Source DST]

Dimensions

Length over all: 105.00 m, with a barge of 85 m, 190 m are not exceeded.

Breadth 11.40 m

Depth 3.10 m

Maximum draught 2.80 m, fully operational at $T_{\min} = 1,60$ m

Air draft 7.50 m

Propulsion

Type: 2 x 750 kW direct propeller shaft

Main engine 2 x Wartsila 6L20DF dual fuel, 98% gas; 2% diesel

Capacities

Ballast: 867 m³

Fuel Oil: 90 m³

LNG: 140 m³

Fresh water: 19 m³

Sewage: 19 m³

Crew: 8

Performance

Range:

DO only: 120 running hours = 1400 km (slack water)

LNG only: 140 running hours = 1800 km (slack water)

15 day fresh water

Displacement and capacity:

Lightship: 670 t

Payload at T = 2.80m 2350 t (stores included)

Configuration	Dimensions L x B	Bulk load capacity	Container Capacity
Single self-propelled vessel	105 x 11.40 m	2200 t at T = 2.8 m	208 TEU
Convoy with one barge	190 x 11.4 m	4180 t at T = 2.8 m	400 TEU
Convoy with three barges	190 x 22.8 m	8140 t at T = 2.8 m	784 TEU

Figure 36: Motor vessel capacities

Subdivision

- Compliance with the regulations concerning damage stability
- double hull except peaks
- tank arrangement in order to assure a good trim in any loading condition

Machinery

- propulsion – 2 x direct drive, FPP propellers (1.75 m diameter) in nozzle
- harbor generator – 1x 35 ekW on deck, air cooled
- bow thruster – optional – 1 x 350 kW diesel driven

Arrangement

The ship's arrangement is divided in five separate areas:

- Engine room and aft roof which include engine room access, CO₂ room, harbour generator group, workshop, mechanical store
- LNG area
- Cargo hold
- accommodation area in the bow

Cargo hold

The cargo hold with a breadth of 10.05 m is large enough to take 4 ISO containers in one breadth, and 13 TEU in length. Cargo hold scantlings are dimensioned for the requirements of iron ore bulk load.

Superstructure

- all crew spaces are arranged in the superstructure at the bow on two levels
 - two single cabins with own sanitary space (toilet and shower)
 - four double cabins
 - common sanitary space (toilet and shower)
 - mess room
 - galley, food store and garbage room
 - ship's office
 - accommodation store
 - laundry, change room
- under the wheelhouse are arranged lifting system and deck store;

Wheelhouse

- large wheelhouse with excellent visibility;
- a lifting system is necessary only when containers are transported; could be installed: a lifting system with abt. 5 m stroke.

Deck

- one aft anchors and windlasses
- mooring bollards aft, center and fore
- one towing/coupling bollard fore in centre line
- 2 x coupling winch and 1 x 3 coupling bollards fore
- service boat with davit

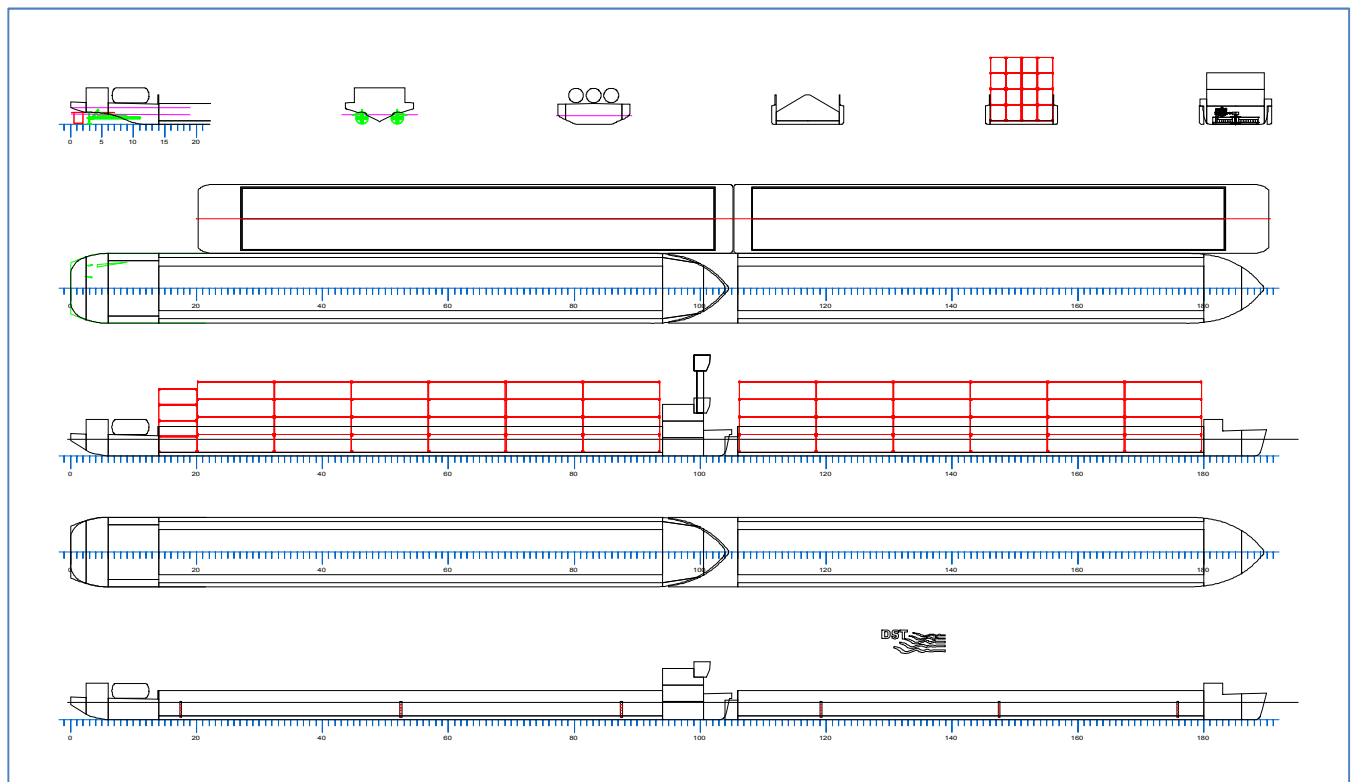


Figure 37 Danube Self-propelled vessel as convoy – General Arrangement [Source DST]

5.3 Cost and performance of the innovative Danube vessels

Based on the cost performance calculations described in chapter 4, it is possible to obtain realistic estimations for the commercial operation of the innovative vessels. Three main cost parameters can be used:

- The cost of LNG fuel per kWh is expected to be at 75 % of the gasoil cost. This cost level was observed in the last years and is expected to prevail at medium term.
- Crew cost will increase, as higher qualification is requested.
- The higher investment increases the capital cost per year.

In this case we obtain for the three different innovative vessels:

Classic pusher design

The design improvements do not influence the propulsive efficiency compared to existing push boats. Fuel consumption, fuel cost and transport performance remain unchanged. The main advantage of the new concept is the improved operation in reduced water depth obtained with the lower pusher draught.

LNG pusher design

The design improvements do not influence the propulsive efficiency but the cost of the employed fuel. On the other side, crew cost and fixed costs are increased. Based on the results of the cost performance calculations, we obtain relevant cost reduction for the transport cost. This advantage in operation cost could by itself justify the investment in a new vessel, and as additional advantage drastic reductions in emissions are possible.

LNG motor vessel

The design improvements with the flexible tunnel will improve the propulsive efficiency in the upstream voyage. Fuel cost is reduced by the utilisation of LNG. On the other side, crew cost and fixed costs are increased, as for the LNG pusher. Based on the results of the cost performance calculations, we still obtain relevant cost reduction for the transport cost. This advantage in operation cost could by itself justify the investment in a new vessel, and as additional advantage drastic reductions in emissions are possible. Compared to the pushed barge convoys, the self-propelled vessel will reach a higher upstream voyage speed and shorter voyage time, making it more interesting for higher value commodities and containers.

Estimated fuel cost reductions

The figures in *Additional investment cost for LNG installation, compared to a gasoil propulsion engines

**Price difference per kWh, LNG compared to gasoil

Table 16 are based on validated data for annual fuel consumptions of pushers in Danube operation. Applying most basic fuel cost evaluations, and based on fuel cost of 850 € per tonne, all the mentioned innovative devices are showing relevant reductions of operating cost, as result of fuel cost savings.

Device	Investment cost*	Initial fuel cost per year	Fuel cost difference**	Fuel cost difference per year
LNG Pusher	750.000 €	1.020.000 €	– 25%	– 255.000 €
Air Lubrication on 4 barges	400.000 €	1.020.000 €	– 10%	– 102.000 €
Flexible Tunnel	200.000 €	816.000 €	– 10%	– 81.600 €
LNG Motor vessel	700.000 €	816.000 €	– 25%	– 204.000 €

*Additional investment cost for LNG installation, compared to a gasoil propulsion engines

**Price difference per kWh, LNG compared to gasoil

Table 16: Estimation on fuel cost reductions for different devices

Especially for the cost relating to LNG fuel, a precise prognosis is not really possible at the time being as the following aspects have to be considered:

- The LNG fuel cost depends on the supply infrastructure, and the cost of this infrastructure is not known so far.
- Regulations for approval and operation of LNG ships on inland waterways are not yet established.
- The investment cost (LNG tanks, gasification devices, control devices...) are not known with precision, at least in the area of dual fuel engines.
- The influence on investment and maintenance costs of the new pollution rules have to be evaluated and taken into consideration. This means, for example, that gasoil fuel engines could, in the future, require additional filter devices. This would reduce the additional cost of LNG installations and probably increase operation cost and fuel consumption of conventional diesel engines.
- It is perhaps not cost saving that promotes LNG solutions but the compliance with the new regulations concerning pollution.

Of course, also without the use of LNG technology, it is possible to design innovative vessels that would outperform the existing Danube fleet. But only the LNG technology will provide a decisive breakthrough for reduction of novice emissions, as well as it will provide an alternative to liquid fuels, which could become more expensive in a near future.

6. Recommendations

Recommendations are given to the European and national authorities for necessary mid and long-term research needs::

1. Motor vessel as Danube type:

The vessel in the dimensions of 105 x 11.40 m, adapted to specific Danube conditions. New engines (Emission class acc. to tier 4) or LNG fuel will reduce emissions. The propulsion should be of high performance to allow the operation with additional barges. A design draught in the range of 2.80 m is recommended in order to be competitive with ships from other European sectors.

2. LNG push boat:

Pushed barge convoys have specific advantages on the Danube and they will continue to contribute to inland waterway transport the largest part of the transport volume (bulk goods). The use of LNG fuel on these ships will have a significant impact on the traffic-induced emissions of inland waterway transport on the Danube.

3. Optimized barges

In case of new barges, optimised convoy dimensions with regard to available lock size and push boat size should be determined. The steel structure of the barges should be redesigned for lower weight at reduced building and maintenance cost.

4. Voyage speed optimisation:

Especially on the river Danube, energy and cost efficiency of the vessels significantly depend on ship speed. So far no appropriate real-time decision-making tool for economic voyage planning is available to the pilot and/or the owner. A real-time voyage assistance tool, that incorporates specific Danube conditions, should be elaborated and tested in practice. This tool could also improve the performance of existing fleet and its use could be extended to other European inland waterways.

5. River information services (RIS)

River information services (RIS) will be more and more important for voyage planning. An improved forecast of the fairway conditions, especially the water depth on different sectors, will help the ship operators to determine before each voyage the most efficient loading of the ships.

6. Energy efficiency benchmarking

The project revealed the complexity of energy efficiency benchmarking of inland vessels. Further research is recommended, including model testing and full scale measurements on the river. This would enable a deeper understanding of the parameters influencing the energy efficiency and lead to better results for the design and operation of inland waterway vessels.

The proposed new vessel types optimise energy-efficiency, minimise adverse emissions in particular air pollutants, increase safety of navigation and decrease the cost of vessel operations. They therefore can be considered as blueprints for further vessel investments of the Danube barging sector.

In order to stimulate investment into new vessels in the Danube Region as part of a long-term inland waterway transport development strategy, apart from stressing the necessity for provision of reliable, improved navigation conditions according to the relevant international agreements, as a basis for the economic success of innovation, the following **implementation steps** are proposed:

1. Definition of pilot deployment projects for each vessel type: In this project phase barge operators which would like to invest into one push boat or one self-propelled vessel shall be identified. The selection of e.g. four companies shall address the specific needs of detailed requirements of cargo as well as the different regional focus of vessel operations. It also shall create a critical mass for wider deployment and shall enable barge operators to become familiar with vessel innovation projects after several decades without hardly any innovation, except RIS.
2. Developing project applications to a selected suitable EU support program (e.g. CEF): The program shall ensure EU financial support as well as the level of publicity which is necessary for a model case deployment.
3. Application to the selected EU program and project implementation preparation.
4. Execution of EU project with design, construction and test operation of proposed vessel solutions.

The results confirm that, under regular, good waterway conditions, transportation carried out with Danube vessels can reach excellent cost and energy efficiency. Innovative devices and optimised ship designs will even improve this situation. On the other hand, the energy and cost efficiency of Danube vessels is depending to a large extent on the waterway conditions, especially the available water depth. Any improvement and better maintenance of the waterway will be profitable to the complete Danube fleet and provide better energy and cost efficiency of inland waterway transport. If the waterway conditions remain unstable or if the present level is degraded, then it will probably not be possible to compensate this by improved or innovative ship design.

Duisburg, Vienna, Belgrade, Galati

20-12-2013