New Opportunities on the Danube Corridor

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1. INTRODUCTION

The Danube is the largest European river with enormous transport potentials; navigable length is around 2400 km, it is shared by 10 countries and connects North Sea and Black Sea (via DM Canal and the Rhine). In spite of this, the traffic on Danube is at a very low level – present utilisation is below 10% of its full capacity. This is mostly due to economical and political factors, as well as unfavourable navigational conditions on the waterway itself. In addition, the Danube fleet is, generally, old and in terrible condition. Consequently the intermodal transport is almost nonexistent on the Danube.

This paper consists of two parts:

1. An introductory part, giving a comparison between the Danube and the Rhine, and summarizing the implications on the container and Ro-Ro transport and the associated ship design, etc. It is concluded that the Ro-Ro vessels are very promising for the Danube waterway, and hence they are treated in more detail in the rest of the paper.

2. A second part of the paper includes a description of the new Danube Ro-Ro concept developed within the CREATING project. An analysis of the transport costs is given; the technical characteristic and the optimization parameters for these vessels are defined. The Ro-Ro vessels discussed here are successors to the first generation of Ro-Ro ships which have operated successfully on the Danube for last two decades.

1.1 Transport in the Danube corridor

The largest trade, by far, in the Danube corridor is conducted via road vehicles (with the exception of bilateral trade between Germany and Austria). Thus, while the market share in the EU15 allocated to the road transport is around 70-75% (with unacceptable ~30% increase during the last ten years), in the SEEC it is above 90%, and increasing in the short term. In addition, of the 5 million per year heavy road vehicles that make the transalpine transit - 1 million passes through the Danube corridor. Out of these, 100,000 use the Ro-La service. Since the majority of this cargo, including a large percentage of Turkish trucks, has to pass through Austria; Austria has become a transport bottleneck on the SEEC – CEC & WEC route. Due to safety and ecological reasons, Austria has, therefore, introduced severe restrictions, such as, for instance, road quotas for non EU trucks, additional taxes for EU non EURO IV engines, etc. Due to these restrictions, and the latest EU driving regulations (working week for drivers of 48 hours), the road transport will certainly become more expensive, and hence less attractive, than it is today. IWT, and particularly the Danube IWT, is the only alternative mode with enormous transport potentials.
1.2 IWW implications on ship design

Maximal vessel dimensions

The Danube has many restrictions that greatly influence navigation. The most important restrictions are the water depth and bridge height (air clearance), defined by LNRL and HWL respectively, and size of the locks. In addition, the Danube is not regulated river (as is the Rhine, for instance), so its navigable conditions vary from stretch to stretch. Taking into account that a) IWW vessel should be designed according to the particular waterway, and b) that all-round clearance between the vessel (or her cargo) and bridge/river-bottom/lock-side should be at least 0.3 m, the maximal allowed vessel dimensions, with possible minor restrictions in sailing during the dry seasons, are:

- $T < 1.7$ m (probably 2 m), $B \leq 11.45$ m for the whole Danube, including the stretch upstream of Straubing-Vilshofen as well as through the DM Canal
- $T < 2.0$ m (probably 2.5 m), $B \leq 23.4$ m downstream of Vilshofen
- The length of self-propelled vessels addressed here is practically unrestricted.

Well balanced ship

The ILUs in IWT are containers, semitrailers or swap-bodies. Consequently, the payload is the brutto mass of loaded container, semitrailer or swap-body. However, for Ro-Ro vessels, it is the deck area, not the mass of payload that is critical – in fact the key metric is the length of standard lane, i.e. it is the lane-meters that are sold. Thus, for Ro-Ro vessels the payload should be considered as payarea, whereas the key parameter for container vessels is the number of TEUs, i.e. the payload should be considered as payvolume.

Proper relation between cargo space and cargo weight is of utmost importance, so that well balanced ships have good ratio of cargo volume to cargo weight.

Cargo in intermodal transport

While containers are stackable - which is their main advantage - semitrailers, trucks, and majority of swap-bodies are not stackable. That is the reason the deck area – lane-meters – are important for Ro-Ro vessels. Taking into account the height of the bridges, water depth, experience gained to date with the first generation of Ro-Ro vessels etc, dedicated selfpropelled Ro-Ro vessel for the Danube waterway should have only one flush deck. The main cargo in this case are loaded trucks and semitrailers of a standard weight allowed on the European roads. This fact permits river Ro-Ro vessels to be designed with a very low draught of less than 1.7 m, thereby permitting operation throughout the year (including dry season). This is of utmost importance for successful Ro-Ro service. In other words, properly parked loaded semitrailers onboard single deck vessel, inherently result in well balanced ships with a draught between 1.6 and 1.7 m. Larger vessel will have larger deck area, allowing larger number of vehicles, but the draught will still be more-or-less the same.
In addition to the various wheeled vehicles, Ro-Ro vessels can transport other cargo - containers and ILUs that are 2.55 m wide, including the so-called heavy cargo and non-standard (voluminous) cargo. In this case, the only practical limitation is the maximum allowed draught of a vessel. Furthermore, cargo does not need to be of uniform box-size, nor is the location of each cargo unit essential. This is exactly opposite to the considerations with the container vessels, meaning that dedicated Ro-Ro vessels are in this sense universal vessels too.

**Hull form of Ro-Ro vessels**

Requirement for a large (flush) deck area for transport of relatively light cargo, result in hulls which are different than those of container vessels – specifically, Ro-Ro vessel hulls do not need to be of full form. Thus catamaran and semi-catamaran (river semi-catamaran is very similar to catamaran, except that the bottom of a bridge connecting twin hulls is immersed) are accepted hull forms for the first generation of Danube Ro-Ro vessels. Nevertheless, other hull forms should also be considered - for example relatively beamy monohulls with a deck beam considerably wider than the waterline beam could be used, etc. Note that the choice of hydrodynamically optimised hull is important from environmental viewpoint, resulting in reduced engine pollution, and in reduced wave wash (large waves often limit speed of a vessel).

**Intermodal shipping on IWW**

Due to water and air draught restrictions, waterborne part of transport of containers on the Danube is less efficient than on the Rhine. On the Danube, a vessel of same size can transport one to two layers of containers less than on the Rhine! Thus, whereas on the Rhine the intermodal container transport is very successful and Ro-Ro service is not (with the exception to passenger cars and similar cargo), the situation is exactly opposite on the Danube – the Ro-Ro service is successful but the container transport is not.

**1.3 Intermodality and IWT**

By definition, intermodal freight transport means the transport of goods in a single loading unit, using two or more modes of transport successively, but without handling the goods themselves. As such, intermodal transport has its main potential in long distance transport, probably on river stretches longer than 500 km. Efficient use of intermodal transport also requires implementation of suitably corresponding logistics - see Fig. 1.
Fig. 1 - IW multimodal possibilities

For intermodality that integrates IWT, the following links of the transport chain are generally necessary:

```
Door ------------------------- to ------------------------- Door
⇓                             ⇑
Land transport               Land transport
vê                                 vê
Transhipment ⇒ Waterborne transport ⇒ Transhipment
```

In both cases (container and Ro-Ro technology) the first and last links (land transport) are more or less the same, and are unavoidable. Therefore, further consideration is limited only to the remaining portion of the transport chain, i.e. two transhipments and waterborne transport.

**Transhipment**

Lo-Lo transhipment of containers is efficient only if dedicated equipment is used, such as for example, spreaders, expensive gantry cranes (for massive transhipment of containers), reach stackers (for smaller terminals), etc. Otherwise, transhipment will be relatively slow and therefore unacceptable. Furthermore, for successful utilization of container technology it is often necessary to have transhipment equipment in the hinterland as well as at the ports, both, at the final destination and the origin points, along with all the necessary expertise and experience of use at all points. In the Danube region this is often not the case.

Contrary to Lo-Lo, the Ro-Ro transhipment of trucks and trailers is simple and fast, and there is no need for expensive cargo handling equipment either in the ports or places of cargo origin/destination. So, Ro-Ro terminals are actually large parking places, and the only necessary transhipment equipment – the ramp – often belongs to dedicated Ro-Ro vessels. Once ashore, the wheeled cargo can immediately move away from congested
port area, which is another advantage of the Ro-Ro service. However, Ro-Ro technology needs more space in the terminal facilities.

There are a number of technically feasible solutions for ship-to-shore Ro-Ro interchange - depending on stowage pattern of vehicles on deck, local morphology etc. For point-to-point service the longitudinal loading pattern (first-in/last-out) offers simpler and cheaper solution than the transverse loading pattern (random access pattern), and was therefore used on all existing vessels. A concrete slope is currently used on most river terminals, although platform sliding on the concrete slope (similar to launching platforms in the shipyards) is probably a better solution for future Ro-Ro vessels.

1.4 The importance of hinterland

In review of possible transport projects, the industrial and infrastructural development of the Danube hinterland are often neglected, such as, for example, modal shift projects, intermodal transport, etc. Intermodal transport possibilities are often compared to those on the Rhine - although there are striking differences between the Rhine's and the Danube's hinterland. The Rhine passes through the most developed parts of the World, while the development of the Danube hinterland varies, but is generally bellow that of the Rhine. With some exceptions in the Upper Danube, all kinds of transportation infrastructure - roadway, railway, transhipment facilities in the ports and in the hinterland, etc. - are generally in bed shape. Upgrades in the infrastructure in all ex-East-European countries are required for initialization of modal shift projects. This important fact is often neglected and proven intermodal solutions that “work on the pattern river” - Rhine - are sometimes suggested for the Danube.

Table 1 provides an overview of the characteristics of the Rhine and Danube, which influence the respective shipping solutions.

<table>
<thead>
<tr>
<th>The Rhine</th>
<th>The Danube</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Regulated river, guaranteed depths, often 3.5 m</td>
<td>• Not regulated river, shallow water on many sectors, occasionally 2.5 m</td>
</tr>
<tr>
<td>• Developed hinterland and transport infrastructure</td>
<td>• Undeveloped hinterland and transport infrastructure</td>
</tr>
<tr>
<td>• 850 km navigable</td>
<td>• Long river, 2400 km navigable</td>
</tr>
<tr>
<td>• Developed logistics</td>
<td>• Undeveloped logistics concepts</td>
</tr>
<tr>
<td>• General knowledge about IWT potentials does exist</td>
<td>• Sufficient knowledge about potentials of IWT does not exist</td>
</tr>
<tr>
<td>• Awareness about EST exist</td>
<td>• Awareness about EST does not exist</td>
</tr>
<tr>
<td>• Inland ports traffic: 1st Rotterdam - 110 mil.t, 2nd Duisburg - 50 mil.t</td>
<td>• Inland ports traffic: 25th Regensburg - 2 mil t</td>
</tr>
<tr>
<td>• 84% &amp; 34% of European selfpropelled and pushed barges fleet, respectively</td>
<td>• 4% &amp; 44% of European selfpropelled and pushed barges fleet, respectively</td>
</tr>
<tr>
<td>• 56% tkm of EU15 IWT (IWT of EU25-EU15 +RO+BG accounts to only 5% tkm of EU25)</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 - An overview of the Rhine and the Danube
1.5 Comparison of Ro-Ro and Lo-Lo technologies on the Danube

An analysis of the cost/benefit trade-offs for Ro-Ro vessels is somewhat different from that for container vessels. The reason for this is that Ro-Ro vessels have to compete with road transport, which nowadays absolutely dominates in Europe and particularly in the Danube corridor. Nevertheless, since Ro-Ro vessels should transport semitrailers and trucks, they should not be considered simply as an alternative to the road transport, but as a “intermodal partner” to the road mode, which enables the long distance haulage to be more environmentally and economically sustainable. Comparison of Ro-Ro and Lo-Lo technologies is given in Table 2.

<table>
<thead>
<tr>
<th>Pros &amp; Cons for Container vessels</th>
<th>Pros &amp; Cons for Ro-Ro vessels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Service</strong></td>
<td><strong>Service</strong></td>
</tr>
<tr>
<td>Well established service and technical solutions already exist on the Rhine – that experience can be applied to the Danube. Nevertheless, establishing successful service on the Danube demands that containerisation is widely accepted, especially in the hinterland. IWT of containers along the Danube corridor presently has to compete with the railway transport more than with the road transport.</td>
<td>Public Ro-Ro service, open to all road users, should be organised/designated for the Danube corridor. There are no similar solutions which could be copied from other rivers but first generation of very successful vessels do exist on Danube itself. Ro-Ro service + pre- &amp; end-haling (short distance trucking to/from origin/destination) is an alternative to the long distance transalpine trucking.</td>
</tr>
<tr>
<td><strong>Hinterland</strong></td>
<td><strong>Hinterland</strong></td>
</tr>
<tr>
<td>Developed hinterland, transport infrastructure and an established tradition of using containers is required. Application of logistic concepts is essential. Neither of these is the case with the Danube yet (with exception of the Upper Danube regions).</td>
<td>No need for developed hinterland, logistics etc. since the only necessary Ro-Ro “partner” – the truck – already enables door-to-door service.</td>
</tr>
<tr>
<td><strong>Cargo</strong></td>
<td><strong>Cargo</strong></td>
</tr>
<tr>
<td>Stackability of containers (and other stackable ILUs) is great advantage – this increases the efficiency of waterborne transport. Besides the maritime ISO containers (for international/intercontinental trade), use of long, pallet-wide ILUs (stackable swap-bodies) is expected to increase in inter European trade.</td>
<td>Cargo does not need to be of uniform size or weight, nor is its deck location essential. However, wheeled cargo is unstackable, which is a disadvantage. Transportation of non-standard cargo (in size and weight) is also possible. Semitrailers optimised for side loading/unloading of pallets is easier and cheaper to use than usual front-loading of other ILUs. Possibility to carry variety of cargo types and ILUs is also an advantage.</td>
</tr>
<tr>
<td><strong>Transhipment and Port facilities</strong></td>
<td><strong>Transhipment and Port facilities</strong></td>
</tr>
<tr>
<td>Vertical Lo-Lo transhipments are expensive. For best results dedicated transhipment equipment is necessary. Container terminals should have an access to railway and road infrastructure (trimodal container terminals). Nevertheless, the main problem on the Danube is insufficient number of containers required to amortize the investment needed for the dedicated equipment of any type.</td>
<td>Horizontal Ro-Ro transhipment is simple and cheap. Transhipment equipment (the ramp) usually belongs to the vessel. Ro-Ro terminals are large parking places and are, therefore, minor infrastructural investment.</td>
</tr>
<tr>
<td><strong>Vessels</strong></td>
<td><strong>Vessels</strong></td>
</tr>
<tr>
<td>Danube container vessels can transport two and occasionally three container layers only, due to low water depth and insufficient bridge heights (on the Upper Danube). From hydrodynamical viewpoint, longer vessels – high L/B ratio – are more efficient and therefore environmentally more acceptable. Only ILUs with a max width of 2.5 m can be stowed in the standard 11.4 m beam vessels - this is an increasing hindrance to use of present vessels.</td>
<td>Ro-Ro vessels are inherently low draught vessels (T &lt; 1.7 m, so navigation during dry seasons is enabled) with large flush deck-area. Larger vessels with unaccompanied, point-to-point service (with longitudinal stowage onboard), equipped with own transhipment equipment (the ramp), are more efficient than alternative types of Ro-Ro vessels (accompanied, bus-stop service with transverse stowage).</td>
</tr>
<tr>
<td><strong>Transport costs</strong></td>
<td><strong>Transport costs</strong></td>
</tr>
<tr>
<td>Waterborne part of transport is cheap (due to the stackability of ILUs) but transhipment costs might be higher than expected, presently depending on the ILU type used. Roughly in IWT, 2 container layers are necessary to achieve the breakeven and at least 3 layers are needed for sustainable profit.</td>
<td>Cost of Ro-Ro transport, compared to the long distance trucking (the main competitor) might be very attractive along the Danube corridor since origin/destination distances are often more than 1000 km. Ship travel time is not much longer than road-time. There are other benefits (compared to the road transport mode) which are not expressed in monetary terms. Due to low transhipment costs, the overall transport costs might be lower than expected.</td>
</tr>
</tbody>
</table>

Table 2 – Pros and cons of container and Ro-Ro vessels in the Danube context
1.6. Remarks concerning the intermodal vessels on the Danube

Comparison of container and Ro-Ro services is not easy, mostly because these are two different intermodal services with different good and bed points. So, it might be expected that both of them will find a place on the Danube; the question is when.

IWT of containers is inherently more efficient intermodal solution due to their stackability and stowability. Nevertheless, given that the Danube is not regulated and that it has shallows in several sectors, container vessels with lower carrying capacity (than on the Rhine, for instance) should be considered as a feasible solution. Barge trains with partly loaded barges would probably give good results. In any case, sufficient number of containers is necessary for successful IWT and that depends very much on the development of regional economy along the Danube corridor.

The Ro-Ro technology may be deployed immediately, giving exceptional results in the near-term and mid-term future - until the containerisation and intermodality become the norm, not only in the Danube corridor itself, but also in its hinterland. Furthermore, taking into account that dedicated Ro-Ro vessels are also universal vessels, their usability and efficiency look very promising throughout their lifetime.

2. STATE OF THE ART OF Ro-Ro SERVICE ON THE DANUBE

2.1 The vessels

The Ro-Ro service has been functioning very successfully for the last twenty or so years – operated by the ex state owned Bulgarian company SOMAT, which is currently privately owned by Willi Betz. This service transports semitrailers, and occasionally trucks, on the route Vidin-Passau-Vidin with optional stops in Vienna and Linz. Approximately 4500 trailers/year are transported in 90 round trips per year, with a fleet of four dedicated Ro-Ro vessels with capacity of 50 trailers each. The round trip lasts two weeks, but could be shortened to 11 to 12 days. Besides these, Willi Betz nowadays transports smaller vehicles onboard double-deck Ro-Ro barges (barge-train consists of two barges and a pushboat).

Two of above-mentioned four dedicated Ro-Ro vessels on the Danube were built in Degendorf (Fig 2) and were of semi-catamaran hull type, and two (full catamarans) were built in Serbia (Fig. 3). Their main characteristics are very similar and are summarized below:

- \( L_{oa} = 115 \) m
- \( B_{oa} = 23 \) m
- \( H = 3.0 \) m (ships built in Serbia 3.3 m)
- \( T = 1.65 \) m
- Cargo capacity 1372 tons (49 semitrailers of 40’, 28 t each)
- \( P_B = 2 \times 830 \) kW
- \( v = 18 \) km/h
- Crew accommodation for 12 persons (16 on ships built in Serbia)
Abovementioned successful service was emulated in 1992 on much shorter Budapest-Passau route by Hungaro Lloyd, using converted Danube IIb barges, with capacity of 32 trailers each, with a typical convoy consisting of 2 barges and a pushboat. Nevertheless, Willi Betz is by far the most important Ro-Ro player on the Danube, with ships which operated successfully even during the crises (e.g. use of a pontoon bridge in Novi Sad 1999-2005 etc).

2.2 The Ro-Ro terminals

The Ro-Ro terminals are equally important, and are now located in Regensburg and Passau (Germany), Linz and Vienna (Austria), Bratislava (Slovakia), Gyor, Budapest and Baja (Hungary), Vidin and Rousse (Bulgaria) and Izmail (Ukraina). Note however that on a stretch of more than 500 km, between Baja and Vidin on the Middle Danube, there are no Ro-Ro terminals at all, so that the one that is planned to be built in the vicinity of Belgrade might be a good investment.
Former experience (SOMAT, Willi Betz) indicated that Vidin (Danube km 793) and Passau (Danube km 2233) were preferred to, for instance, Linz or Regensburg (which is too far away upstream with few bottlenecks). See Figures 4 and 5.

![Figures 4 and 5 - Ro-Ro terminals in Passau-Schalding (Danube km 2233) and in Vidin (Danube km 793) (Popov, 2005)](image)

3. **A NEW DANUBE Ro-Ro CONCEPT DEVELOPED WITHIN THE CREATING PROJECT**

3.1 **About CREATING - Concepts to Reduce Environmental impact and Attain optimal Transport performance by Inland NaviGation**

CREATING is a project carried out for DG Research as a STREP (Specific Target Research Project). Led by SPB (Stichting Projecten Binnenvart, Holland), 29 project partners from 9 countries are participating in CREATING. The project’s objective is to develop new inland ship concepts that are economically and environmentally competitive to the all-road transport, which could, as a consequence, enable modal shift of cargo from roads to inland waterway. At least four concrete examples of innovative ships for the European IW should be developed by the project. Considered, Ro-Ro vessel for the Danube waterway is the first, of several candidate projects. In accordance with the CREATING guideline that calls for involvement of a shipper to guarantee feasible, reliable and realistic ship design, Willi Betz (already mentioned in the Section 2) was the shipper involved in the Danube Ro-Ro project. DST (previously VBD) from Duisburg, Germany is the work package leader responsible for the vessel design, while hull form optimization and hydrodynamic characterization was performed by MARIN, Holland. The principal innovative elements in the particular Ro-Ro design, include a very shallow draught hull form of unusual proportions, hull form and propulsion optimization for low power requirement etc. Ro-Ro designs that were developed within CREATING should be regarded as next Ro-Ro generation - successors to existing vessels depicted in Figures 2 and 3.
3.2 Problem definition

In this study, service costs for long haul trucking are compared to the intermodal service costs using the Danube Ro-Ro vessels, for routes from WEC to SEEC and back. Taking into account that for this route the Ro-Ro terminals of interest are located in Passau and Vidin, Frankfurt/M-Sofia-Frankfurt/M route is analysed in more details. For the purpose of comparison, a shorter route - whose waterborne part is still longer than 1000 km per direction - Frankfurt/M-Belgrade-Frankfurt/M is discussed as well, but to a lesser extent.

Design requirements for the Danube Ro-Ro vessel were developed in accordance to Willi Betz requirements, and are as following:

- Unaccompanied service with point-to-point operation.
- Selfpropelled vessels able to transport semitrailers of 40 and 45 feet on the main deck and smaller vehicles (5.0 m passenger cars and 6.6 m vans) in the tweendeck.
- Pushed barges optimized for transport of smaller vehicles only.
- Axle pressure of 15 t and 1.5 t for semitrailers and smaller vehicles, respectively.
- Vessels designed primarily for the route Vidin-Passau-Vidin, with round trip of 12-14 days at most.
- Days in operation of 340 per year (25 days per year reserved for the maintenance, possible conversions, etc.), i.e. year-round transport capacity, of approximately 5000-6000 semitrailers of 40 and 45 feet or 25000-30000 cars per direction, based on 25 round trips per year.
- Ro-Ro loading/unloading method not specified, but is assumed that ship ramps similar to those on present vessels, as well as the transhipment technology already in existence at Danube terminals are used.
- Service frequency or seasonal distribution not specified. Uniform year-round distribution is assumed.
- All other crucial parameters necessary for ship design are not specified, meaning that the vessels are optimized to the existing rules and recommendations, and in accordance with the Danube waterway experiences gained so far with the first (successful) generation of vessels, etc.

Vessels that are discussed in the text were designed by and data concerning the waterborne part of intermodal transport chain originate from DST, Duisburg.
3.3 Waterborne Ro-Ro transport

Different vessel types could be designed to these requirements. This was done iteratively, starting from the vessels derived from the existing ones, or from the designs made prior to the CREATING project. The vessels considered were:

- SRRV – Small Ro-Ro Vessel
- PRRB – Pushed Ro-Ro Barge
- LRRV – Large Ro-Ro vessel

Assumed vessel characteristics and waterborne costs including the transhipment and pre- & end-hauling costs, were evaluated, and compared to the all-road transport costs. The results obtained were analysed and new vessel types were derived to optimize the results. Conclusion was – the larger the vessel the better, so a Very Large Ro-Ro Vessel - VLRRV was derived from LRRV, by lengthening her so that one additional row of semitrailers could be carried. This approach resulted in innovative Ro-Ro vessels for transport of semitrailers and smaller vehicles, designed in accordance to the Danube waterway requirements.

The principal vessel characteristics, along with the characteristics of the EXisting 25 year old CATamaran/semicatamaran vessel – EXCAT shown in Figure 2 and 3 - are presented in the Table 3.

<table>
<thead>
<tr>
<th>Main dimensions</th>
<th>SRRV</th>
<th>PRRB</th>
<th>LRRV</th>
<th>VLRRV</th>
<th>EXCAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length overall</td>
<td>m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breadth max</td>
<td>m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breadth moulded</td>
<td>m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth moulded</td>
<td>m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Draught (without ballast)</td>
<td>m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air draught</td>
<td>m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deadweight</td>
<td>t</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Payload</td>
<td>t</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carrying capacity 45° or 40° trailers and 5 m long passenger cars</td>
<td>18 or 21</td>
<td>-</td>
<td>42 or 49</td>
<td>42 or 49</td>
<td></td>
</tr>
<tr>
<td>Loading case considered here</td>
<td>ESTR</td>
<td>29</td>
<td>63</td>
<td>73</td>
<td>45</td>
</tr>
<tr>
<td>Power installed</td>
<td>kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>g/kWh</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investment (new vessel)</td>
<td>mil.EUR</td>
<td>3.2</td>
<td>1.5 +3.5 pb</td>
<td>10</td>
<td>10.1</td>
</tr>
</tbody>
</table>

Table 3 - Main characteristics of the Danube Ro-Ro vessels considered in CREATING

Several loading cases were assumed for all vessels, varying from cases consisting of all-vans or all-cars to mixed loads of semitrailers, cars and vans. Since it was necessary to compare transport and transhipment costs for different loading cases, a new nominal loading unit was introduced – ESTR, standing for Equivalent Semi-TRailer (one ESTR consists of 6 cars, or 2 vans, or 2 vans + 1 car, all of specified dimensions). So, for instance, LRRV can transport 102 ESTR (equivalent to 204 vans) or 63 ESTR
(equivalent to 45 semitrailers and 112 cars). This approach enables comparison of Ro-Ro vessels loaded with different cargo. It should be noted that vessel stowing rate for vans is better than semitrailer’s stowing rate, which is opposite to that for the cars. Hence, there are relatively large variations in the ESTR capacities per vessel between some loading cases.

Note that triple-deck PRRB (a convoy of 2 barges and a pushboat was assumed) designed for transport of small vehicles only is excluded from further discussion here; only vessels that can transport semitrailers - SRRV, LRRV and VLRRV - are examined.

Whereas vessels were designed to Willi Betz requirements aimed primarily for Passau-Vidin-Passau route, Passau-Belgrade-Passau route is also analysed. The final values adopted for all cases are as following:

- Total voyage duration (upstream + downstream):
  - Passau-Vidin-Passau: 216 hours at 16 km/h and 247 hours at 14 km/h
  - Passau-Belgrade-Passau: 166 hours at 16 km/h and 189 hours at 14 km/h
- Transhipment time (total) in all cases is 40 hours
- Distance: Passau-Vidin 1440 km; Passau-Belgrade 1070 km
- Lifetime of a new vessel: 30 years
- Fuel price: 0.45 EUR/lit
- Crew (EE) in all cases: 5 (total annual cost EUR 155000)
- Total annual capacity was based on 25 round trips per year for Passau-Vidin-Passau route. Round trips for route Passau-Belgrade-Passau were not specified. Annual number of days in operation is 340
- Reloading costs: assumed 150 and 50 EUR/trailer and 30 and 10 EUR/van (or car) in Passau and Vidin (Belgrade) respectively.

3.4 Costs

Transport costs and other important data for round trip Frankfurt/M-Sofia-Frankfurt/M are as following (adequate data for route Frankfurt/M-Belgrade-Frankfurt/M are given in parenthesis in italics):

- Total trucking (all-road) costs are EUR 3400 (2450), distance travelled 3378 km (2592), i.e. 1.01 EUR/km (0.95) and fuel consumption is 1155 lit (875).
- Pre- and end-hauling (trucking) costs are EUR 900 (600), distance travelled 1322 km (900), that is 0.68 EUR/km (0.67) and fuel consumption is 470 lit (300).

According to the above trucking costs, and transhipment costs in Passau and Vidin (Belgrade) that are around EUR 400 (depending on the loading case), follows that the waterborne costs on the route Passau-Vidin-Passau (Passau-Belgrade-Passau) should be below 2100 EUR/ESTR (1450), with fuel consumption of less than 685 lit/ESTR (575).
3.5 Intermodal transport costs

For loading case specified in the Table 3, total intermodal transport costs were evaluated, i.e. waterborne, transhipment and pre- and end-hauling for route Frankfurt/M-Sofia-Frankfurt/M for two ship speeds of 14 and 16 km/h were considered. This is given in the Table 4.

<table>
<thead>
<tr>
<th>Vessel type</th>
<th>16 km/h</th>
<th>14 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Waterborne (\text{w. trshpmnt}) costs EUR</td>
<td>Total intermodal costs EUR</td>
</tr>
<tr>
<td>SRRV</td>
<td>1934</td>
<td>2834</td>
</tr>
<tr>
<td>LRRV</td>
<td>1777</td>
<td>2677</td>
</tr>
<tr>
<td>VLRRV</td>
<td>1616</td>
<td>2516</td>
</tr>
<tr>
<td>EXCAT</td>
<td>2369</td>
<td>3269</td>
</tr>
</tbody>
</table>

Table 4 - Intermodal transport costs (route Frankfurt/M-Sofia-Frankfurt/M)

The direct costs and savings shown above are of primary importance for the transport users. Nevertheless, also important - for the society as a whole - are the indirect costs, mainly driven by the poisons gas engine emissions. Under the assumption that ship and truck engines are of the same generation, i.e. emit the same quality and quantity of emissions (which is not the case for EXCAT but further discussion is beyond the scope of this paper), the total fuel consumption for intermodal and all-road transport are also compared. Fuel consumption and consumption index are given in the Table 5.

<table>
<thead>
<tr>
<th>Vessel type</th>
<th>16 km/h</th>
<th>14 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lit/ESTR</td>
<td>Consumption index</td>
</tr>
<tr>
<td>SRRV</td>
<td>1664</td>
<td>1.44</td>
</tr>
<tr>
<td>LRRV</td>
<td>1254</td>
<td>1.09</td>
</tr>
<tr>
<td>VLRRV</td>
<td>1181</td>
<td>1.02</td>
</tr>
<tr>
<td>EXCAT</td>
<td>1703</td>
<td>1.47</td>
</tr>
</tbody>
</table>

Table 5 - Fuel consumptions (route Frankfurt/M-Sofia-Frankfurt/M)

Although there are slight differences in the total transport costs among the vessels analysed, all vessels enable cheaper transport than the all-road transport. However, whereas in terms of transport costs the new vessels (SRRV, LRRV and VLRRV) are better options than EXCAT (see Table 4), when it comes to the fuel consumption it is evident that only LRRV and VLRRV are environmentally much more acceptable. This is especially pronounced when sailing at lower speed, i.e. at 14 km/h instead at 16 km/h.

Actually, SRRV enables cost effective intermodal transport due to its much lower capital cost (she was intentionally designed to be a cheap vessel) and not due to its low fuel consumption. Besides, SRRV was not hydrodynamically optimized to the same extent as larger vessels, meaning that optimization would further lower fuel costs and therefore, incrementally reduce the intermodal transport costs. Nevertheless, 11 SRRV
have the same capacity as 5 LRRV and can offer double departure frequency, which may be a very important aspect from the shipper’s viewpoint.

However, all three new concepts – SRRV, LRRV and VLRRV – show enormous advantage over the older generation EXCAT (considered to be an advanced vessel compared to others presently sailing along the Danube), and therefore highlight the technological progress over the last 25-years.

For Frankfurt/M-Belgrade-Frankfurt/M route only LRRV is considered. It should be noted that besides being shorter, the route to/from Belgrade has only pre- or end-hauling (Frankfurt/M-Passau-Frankfurt/M), while the previous route considered has both pre- and end-hauling (Frankfurt/M-Passau-Frankfurt/M and Sofia-Vidin-Sofia). For this case data similar to that given in Table 4, is presented in Table 6.

<table>
<thead>
<tr>
<th>COSTS (for LRRV)</th>
<th>V = 16 km/h</th>
<th>V = 14 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waterborne with transhipment (EUR)</td>
<td>1418</td>
<td>1301</td>
</tr>
<tr>
<td>Total intermodal (EUR)</td>
<td>2018</td>
<td>1901</td>
</tr>
<tr>
<td>Cost index (EUR)</td>
<td>0.82</td>
<td>0.78</td>
</tr>
</tbody>
</table>

Table 6 - Costs for route Frankfurt/M-Belgrade-Frankfurt/M

Taking into account that Passau-Belgrade-Passau route is 2 x 370 km shorter and without pre- or end-hauling (Belgrade area is O/D point), the cost indexes obtained for both routes are surprisingly similar. Nevertheless, total lost time (in both directions) due to the intermodal transport and longer via-the Danube-route (compared to direct all-road door-to-door transport) is only 3 days (4 for 14 km/h), compared to 5 days (6.5 for 14 km/h) needed for Frankfurt/M-Sofia-Frankfurt/M route. This fact makes Belgrade an interesting O/D point for intermodal transport.

3.5 Cost structure

Cost structures for all-road and intermodal transport for roundtrip Frankfurt/M-Sofia-Frankfurt/M and Frankfurt/M-Belgrade-Frankfurt/M are depicted in Figures 6 and 7. Both diagrams are valid for LRRV only and for the loading case considered. Note that cost structures are relatively similar for both destinations, although, in general, comparison of different routes is not justified due to different waterborne and pre- and end-hauling lengths and therefore different voyage durations.

3.6 Some characteristics of Large Ro-Ro Vessel - LRRV

The vessel design was performed by DST; special attention was paid to hull form optimization (the so called panel code RAPID was applied by MARIN), as the hull is of unusual proportions – L/B=5.8, B/T=12.5 – with a very shallow draught of only 1.65 m (see Table 3). Total required propulsion power for v=16 km/h is around 1000 kW (at h=5 m, propellers in nozzles with a diameter of only 1.4 m). For propulsion 3 environmentally friendly high-speed truck engines are anticipated with reduction ratio of around 5:1.
Fig. 6 - Cost structure per ESTR, route Frankfurt/M-Sofia-Frankfurt/M

Fig. 7 - Cost structure per ESTR, route Frankfurt/M-Belgrade-Frankfurt/M
Auxiliary engines are of around 680 kW and bow thruster of 400 kW. Note that the bow is optimised for low resistance and low wake wash. This, however, requires use of the sliding platform on concrete slope when reloading (instead of just a folding ramp). Bow access equipment consists of 2 ramps (l=4 m, b=6 m). In the tweendeck only smaller vehicles can be transported, while the main flush-deck is used for larger vehicles (semitrailers). Access to the tweendeck is via the elevator (SWL=10 t) as this is cheaper and more efficient than a ramp. General arrangement plan of LRRV is shown in Fig. 8.

![General arrangement plan of LRRV](image)

Fig 8 - General arrangement plan of LRRV

### 4. CONCLUDING REMARKS

The Danube Ro-Ro transport concept is examined to explore the possible utilisation of the Danube Waterway as an alternative for the undeveloped and insufficient road and railway networks. The aim of the proposed transport service concept is to overcome the problems and bottlenecks of road transportation, such as insufficient roadway infrastructure in SEEC or jams on the trans-Alpine routes through Austria, along the major East-West transport axis coinciding with the course of the Danube River (TEN Corridor N°VII). The concept that is presented is fully in line with current European initiatives, i.e. it enables sustainable mobility of goods under the best possible conditions - keeping in mind environmental protection and economic competitiveness.
Intermodal transport shows savings of around 20% to 25% over all-road transport, based on the cost per ESTR (see Figures 6 and 7), depending on the exact route and ship speed. The net lost time due to ship speed and longer via-the-Danube route, is 3 to 6 days, depending on the route and ship speed. Concerning transport of smaller vehicles only, the savings are larger for loading cases that include more vans than cars, since LRRV and VLRRV are not designed for car transportation. The triple-deck PRRB is more convenient for car and van transport alone, while VLRRV is the most efficient for cargo consisting of the semitrailers and smaller vehicles (in the tweendeck). SRRV is always least efficient, but has an advantage of three times smaller capital cost per ship and double departure frequency (for same transport capacity as LRRV).

Approximately 50% of the total intermodal costs is due to waterborne transport itself, 15 to 20% to transhipment costs, and the rest to pre- and end-hauling. Of the 50% due to waterborne transport, approximately 20-30% is due to fuel consumption (depending on ship speed), 30% is due to the investment costs, and 35-40% is due to the other waterborne costs. The labour costs – drivers and crew – make up only around 10% of total intermodal costs.

An increase in fuel price and labour costs would impact all-road more than intermodal transport costs. Ro-Ro utilisation of less-than-100% would significantly decrease the benefits. However, the 25 round trips/year per vessel for route Frankfurt/M-Sofia-Frankfurt/M is relatively conservative and could be increased up to 28-31 round trips/year (depending on ship speed) if service scheme of 364 instead of only 340 days/year would be applied. This might be sufficient to compensate ship utilisation of less than 100% and hence could be regarded as reserve. Shorter route Passau-Belgrade-Passau has advantage of having much shorter voyage time and therefore smaller lost time (due to intermodal transport), which results in more round trips per year.

All vessels considered - SRRV, LRRV, VLRRV - were cost effective for both ship speeds (having a cost index of around 0.70-0.80). For the lower speed of 14 km/h the fuel consumption index (and poisonous emission index) is around 0.85 and 1.1 for LRRV/VLRRV and SRRV respectively. For higher speed of 16 km/h the consumption index is around 1.0, 1.1 and 1.45 for VLRRV, LRRV and SRRV respectively, showing again the benefits of larger vessels. It should be noted, however, that Ro-Ro ships, in general, have relatively high specific energy consumption, hence exhaust emissions too. Still they are justified from an environmental point of view as they relieve congested road network and therefore reduce congestion, accidents, noise etc. The disadvantages of technologically outdated EXCAT relative to VLRRV are shown to be around 25-30% reduction in cost effectiveness, and 35-45% higher fuel consumption (per ESTR).

It should be underlined that several other benefits which cannot be quantified in monetary terms may be achieved with intermodal transport and Ro-Ro vessels, such as, for example, the elimination of the well known problem concerning the insufficient truck quotas for non-EU trucks when transiting Austria, safety, availability of transport for non-standardised cargo onboard the single flush-deck, etc.
ABREVIATIONS & NOMENCLATURE

CEC – Central European Countries
CREATING – Concepts to Reduce Environmental impact and Attain optimal Transport performance by Inland NaviGation
DG TREN – EC, General Directorate for Energy and Transport
DM Canal – Danube-Main Canal
EE – East European
EILU – European Intermodal Loading Unit
EST – Environmentally Sustainable Transport
ESTR – Equivalent Semi-TRailers
EXCAT – EXsting (CATamaran) vessel
HWL – High Water Level
ILU – Intermodal Loading Unit
IWT – Inland Water Transport
IWW – Inland Water Way
LNRL – Low Navigation and Regulation Level
Lo-Lo – Load-on – Load-off
LRRV – Large Ro-Ro Vessel
O/D – Origin – Destination
PRRB – Pushed Ro-Ro Barge
Ro-La – Road-Rail combined transport
Ro-Ro – Roll-on – Roll-off
SEEC – South East European Countries
SWL – Safe Working Load
TEU – Twenty feet Equivalent Unit (ISO 20’ container)
WEC – West European Countries
VLRRV – Very Large Ro-Ro Vessel

B – Vessel beam (m)
H – Vessel depth (m)
h – Water depth (m)
L – Vessel length (m)
Pₐ – Installed power (kW)
T – Vessel draught (m)
v – Vessel speed (km/h)

REFERENCES


CREATING WP3-Ship design, Internal reports and presentations regarding the Danube Ro-Ro vessel.


