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Preliminary communication

Received: 19th November 2013
Accepted: 4th December 2013

PROPOSED GUIDELINES ON DEVELOPING THE OPTIMISATION MODEL FOR PASSAGE PLANNING IN INLAND WATERWAYS NAVIGATION

SUMMARY

Road transport networks are overloaded by the increasing number of vehicles [1]. *This has resulted in the redirection and the increasing intensity of navigation on rivers, canals and lakes. Transportation by inland waterways of the European Union (EU) represents a reliable, economical and environmentally friendly mode of transport. The latter has been recognized as a key form of transport in the European intermodal transport system. Inland waterways as part of the transport system play an important role in achieving the objectives presented in the* White Paper: Roadmap to a Single European Transport Area*, the transport strategy of the European Commission (EC). The goals of the strategy include increased mobility, reduced fuel consumption and increased employment in the inland navigation. According to these objectives, 50 % of the passenger and cargo traffic at intermediate distances between cities should be transferred from road to rail and water transport. It is reasonable to expect a decrease in Europe's dependence on imported fuel and the reduction of* CO_2 *emissions in transport by 60 % by the year 2050. It is assumed that the increase in traffic density along the rather outdated infrastructure and the diverse means of transport create high costs with regard to fuel consumption. In order to reduce the present fuel consumption and* CO_2 *emissions, this paper defines essential guidelines in the development of optimisation models for navigation in inland waterways.*

Key words: inland waterways, reduction of CO_2 emissions, guidelines, optimisation

1 INLAND WATERWAYS

This chapter presents an overview of the global development of transport along inland waterways by proving insights into statistical indicators.

From the environmental standpoint, navigation in inland waterways is the most acceptable form of transport as the pollution of water and air is small when compared to the road and railroad transportation (Figure 1).

According to the reports on vessel accidents, inland navigation is considered one of the safest forms of transportation due to less congested traffic in inland waterways [4].

The global distribution of inland waterways (Figure 2) can be observed through the statistical data for:

- Europe,
- North America,
- South America, and
- Asia.

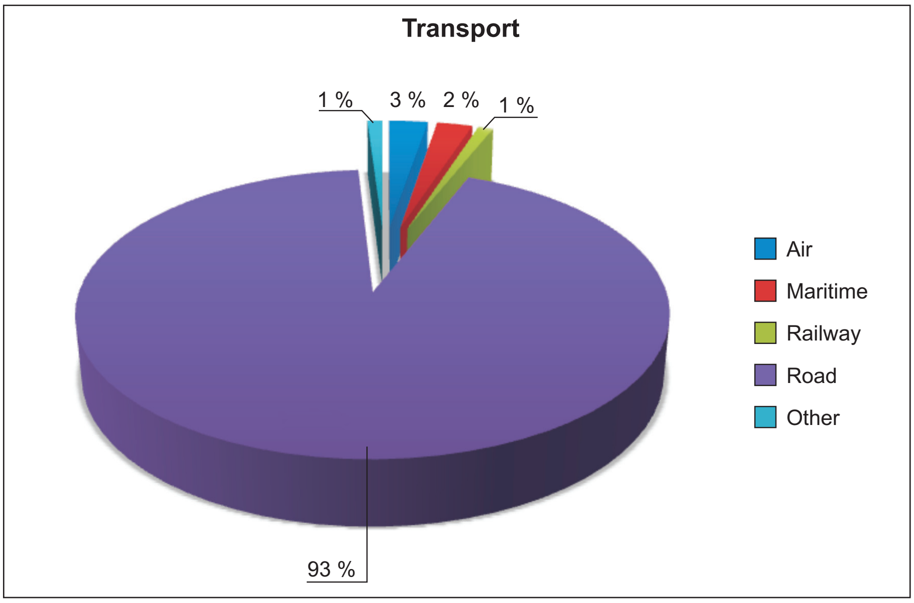

Figure 1 CO_2 emission share with regard to transportation form

Source: www.theodora.com

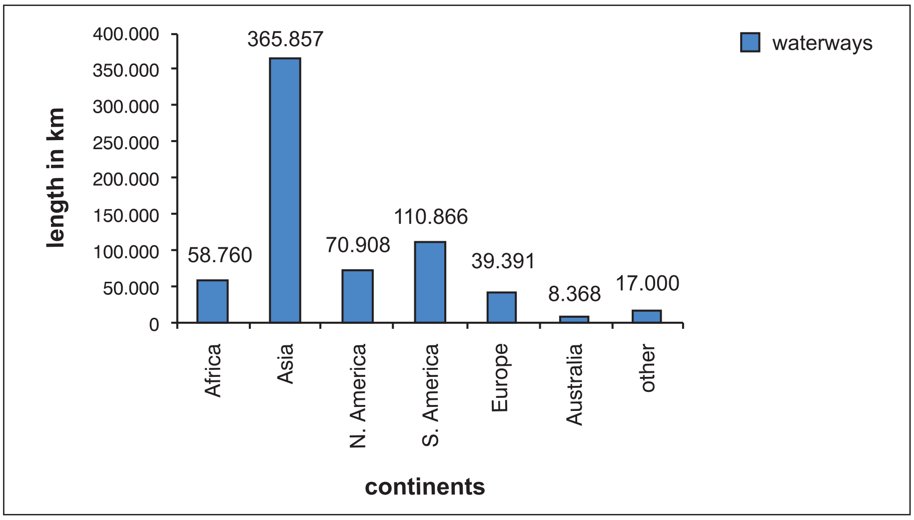

Figure 2 Distribution of inland waterways by continents

Source: www.theodora.com

1.1 European Union waterways

According to their length, the EU inland waterways are ranked fifth in the world (Figure 2). Their length amounts to 39,391 km (Table 1). 14,000 km of these waterways are considered as the forth class or higher ranked waterways[13]. They handle commercial and other forms of transport.

Table 1 Inland navigation in the EU

Length of the inland waterways	39,391 km
Fleet	12,500 vessels
Number of enterprises	9,500
Number of employees in the sector	56,000

Source: *Priručnik za unutarnju plovidbu u Republici Hrvatskoj / Manual for inland navigation in the Republic of Croatia*, CRUP, Zagreb, 2006.

The network of the European inland waterways consists of the following major navigation systems:

- The Rhine,
- North-South Corridor,
- East-West Corridor, and
- South-East Corridor.

The river Rhine is the backbone of the Rhine navigation system. Together with its tributary rivers, the Rhine is the largest and most important inland waterway system for carrying cargo and passengers in the EU. The overall length of the system is about 1,320 km. It is navigable for larger navigation units along 863 km up to Basel, Switzerland. Exceptionally, smaller navigation units can proceed 44 km more to Laufenberg. After a number of regulation construction works, the Rhine has become an inland waterway enabling the navigation of vessels having the draught up to 3.5 m from Rotterdam to Köln, over a stretch of 250 km. The E1 type vessels are able to navigate up to Basel. The area around the river features considerable industrial resources and large cities that use inland waterways as their major means of transport. In addition to the port of Rotterdam, major ports along the Rhine include: Duisburg, Mannheim, Karlsruhe, Strasbourg and Basel. Most of the Rhine ports make use of modern technologies in conveying cargo and passengers. The river and its tributaries are connected to a system of canals. The most important canals are:

- Schelda-Albert, 130 km in length, connecting northern French and Belgian ports to the Rhine,
- Rhine-Marna, 313 km in length, connecting the Rhine to the Seine,
- Rhine-Rhône, 324 km in length, connecting the two rivers, featuring the approach to the Mediterranean Sea, and
- Dortmund-Ems, 269 km in length, connecting the Ruhr basin to the port of Emden.

Through the Dortmund-Ems canal and Mittelland canal the Rhine is connected to the northern and central network of German inland waterways, thereby to the large German sea ports such as Bremen, Hamburg and others. This system of canals connects all major industrial area and sea ports gravitating to the Rhine river area.

It should be noticed that Germany also constructed a system of IV-VI navigation category canals which is 3,000 km long. It includes canalised rivers like the Elbe, the Neckar, the Main and the Moselle. Together with the Danube and the Rhine, they compose the network of inland waterways that handles Germany's entire river traffic and transportation. There are about 50 major river ports in the Rhine area, including the sea ports of Rotterdam, Antwerp, Amsterdam and Gent.

1.2 North American waterways

In North America there is a 70,908 km long network of inland waterways that mainly run through Canada and the United States. Canadian inland waterways are 26,000 km long in total. The river St. Lawrence has most of the waterways that are connected to the Great Lakes. The system is linked to Lake Erie through the Welland Canal and enables navigation along approximately 4,500 km, from the Atlantic Ocean into the Canadian hinterland. The Welland Canal ensures navigation along the natural flow of the Niagara River. The port of Montreal is connected to Lake Ontario through a series of locks. The Great Lakes are connected and have a total area of 95,170 square miles (246,490 square kilometres). This largest area of fresh water in the world naturally connects Canada and the United States. The Hudson River was connected to the Great Lakes by the Erie Canal in 1825, thus connecting the Great Lakes to New York. The Illinois and the Mississippi rivers link the Great Lakes to the interior of the United States and the Atlantic Ocean[3].

There are 41,000 km of inland waterways in the United States of America. The system consists of the coastal and hinterland areas connected with rivers, canals and lakes. Most of the system is formed by the Mississippi River with its tributaries that connect large cities and industrial centres such as Mobile, New Orleans, Houston, Corpus Christi, and Baton Rouge, to the inland ports of Memphis, St. Louis, Chicago, Minneapolis, Cincinnati and Pittsburgh[6].

In the north-western Pacific coastal area, the Columbia Snake system enables navigation up to Lewinston, Idaho. Financial resources for the development and maintenance of the inland waterway systems are collected through the fuel tax. For each gallon (in the US it is equal to about 3.8 litres) spent in inland navigation 20-50 cents are used for further improvement and maintenance of the inland waterways.

1.3 South American waterways

The network of inland waterways in South America is 110,866 km long. It consists of the rivers La Platta, Amazon, Rio Sao Francisco and the Panama Canal. La Platta River is the largest river system in the world which includes the rivers Rio Parana, Rio Paraguay and Rio Uruguay. The Amazon is the largest South America's river. Together with its tributaries it stretches 3,680 km into the continent, up to Peru and Columbia. Brazil is intersected with the Amazon and its tributaries. Due to frequent tidal changes, the waterways are not safe for navigation.

The Panama Canal connects the Atlantic and Pacific Oceans. It consists of several artificial canals, three sets of locks and the Gatun Lake. Built and completed in 1914, the canal is 51 miles (82 kilometres) long and is of great importance to the world trade as it shortens the voyage around South America by 22,500 km [7].

1.4 Asian waterways

There is a large inland waterway system in Asia which is 365,857 km long. China and Russia are the states having the most developed networks of inland waterways. Asian inland waterways include the rivers Ayeyarwady, Ganges, Jamuna-Brahmaputra, Lancang-Mekong, Volga and Yangtze. They have substantially contributed to the rapid development of the areas they run through.

Chinese inland waterways stretch approximately over 119,000 km on 5,600 navigable rivers. The Yangtze River is navigable along approximately 6,300 km, enabling the passage of vessels larger than 1,000 DWT. China has 2,000 inland waterway ports.

Russian waterways include the rivers Kama, Don, Neva. The annual turnover in river ports amounts to more than 200,000,000 tons.

Only 37 % of the available inland waterways are used in India due to poor maintenance and varying hydrographical features. The similar situation is experienced in Indonesia and Bangladesh.

On the basis of insights into statistical data and indicators, it can be concluded that the global inland waterways are very developed worldwide and play a significant role in the global transportation industry.

1.5 Croatian waterways

Administrative monitoring of the navigation safety along the inland waterways in Croatia is performed by state administration bodies that include the Ministry of the Sea, Transport and Infrastructure (Ministarstvo pomorstva, prometa i infrastrukture – MPPI), Inland Navigation Directorate and harbourmaster's offices. The latter are seated in Slavonski Brod, Osijek and Vukovar. Inland waterways of the Republic of Croatia form an 804,1 km network, of which 286.9 km are ranked as international navigable waterways of class IV and higher. A large part of the Croatian territory is situated along the Danube Corridor consisting of three major rivers: the Danube, the Sava and the Drava. They make pat of the VII. European (Danube) Corridor (Table 2). The international navigable class is granted to the rivers: Danube (137.5 km), Sava (132.4 km) and Drava (14 km) [10]. According to the European Agreement on Main Inland Waterways of International Importance (AGN), the navigable waterways of the Danube, the Sava and the Drava, as well as the future Danube-Sava Canal are classified as the integral parts of the European network of navigable waterways, whereas the ports of Osijek, Vukovar, Slavonski

Table 2 Navigable rivers according to the international classification of inland waterways

River	Stretch of the river	Length of the waterway (km)	International class of the waterway
Danube	Ilok – Batina	137,5	VIc
Sava	Račinovci – Slavonski Šamac Oprisavci – Slavonski Brod	102,4 33	IV IV
Drava	Mouth of the Danube – Osijek	14	IV

Source: *Priručnik za unutarnju plovidbu u Republici Hrvatskoj / Manual for inland navigation in the Republic of Croatia*, CRUP, Zagreb, 2006, p. 7

Brod and Sisak are the ports open to international traffic and transport.

The port of Vukovar, situated on the banks of the Danube, is the largest Croatia's inland port in terms of transshipment, handling 414,066 tons per year [12]. The cargo that is transported by Croatian rivers mainly include sugar, chemical fertilizer, corn, iron ore, and crude oil.

The inland fleet features 300 navigation units, out of which around 100 units navigate along the Sava River. The only inland waterway shipping company in Croatia is Danube Lloyd Sisak Ltd (Dunavski Lloyd – Sisak). The potential of the river transport in Croatia would considerably benefit from building the canal Danube River – Sava River from Vukovar to Šamac, which would shorten the waterway by more than 400 km. The canal would nest the inland waterway system of the Republic of Croatia within the European inland waterway network at the desired level. Croatian Parliament brought the Strategy of the river transport development for the period 2008-2018 which is based on the principles defined in *White Paper: Roadmap to a Single European Transport Area* and the principles of the International Commission for the Protection of the Danube River [11].

2 GUIDELINES ON DEVELOPING THE MODEL FOR THE OPTIMIZATION OF PASSAGE PLANNING IN INLAND WATERWAY NAVIGATION

Inland waterway navigation includes the passage along the rivers, canals and lakes. River navigation implies the navigation along natural and canalised rivers and canals. The process of inland navigation is a system determined by essential elements such as:

- waterway,
- transport entity,
- transported entity,
- adjustment of the transported entity to the vessel,
- adjustment of the vessel to the waterway, and
- transport management.

It is obvious that inland waterway navigation features various technical and technological processes. Technological processes vary in their complexity, just like the processes related to the vessel's passage. Their efficiency can be improved by applying an adequate model for optimisation. Prior to modelling, it is necessary to determine the guidelines and it is suggested that these guidelines refer to:

- determining the principle of the optimisation of passage planning,
- planning and implementation of the passage planning, and
- optimisation and modern technologies.

2.1 Determination of the optimisation of passage planning

Optimisation of the passage planning implies making an optimum use of the circumstances that can not be affected. The passage planning optimisation has been widely applied in maritime navigation. By exploring the possibilities of applying the principles of passage planning optimisation, one can determine the guidelines for the optimisation of passage planning in inland waterway navigation.

When optimising the passage planning in maritime navigation, the goal function has to be determined. The goal function is a formalistic and/or mathematical description of the set goal. In order to pick the best option out of an infinite number of possible versions of the voyage, it is necessary to determine the function of the desired goal and the conditions and requirements that have to be met for implementing such a voyage [14].

One of the following goal functions is selected in maritime affairs:

- *Least Distance Route – LDR*,
- *Minimum Time Route – MTR*,
- *Minimum Fuel Route – MFR*, or
- *Minimum Cost Route – MCR*.

The goal function may be one function or a combination of the functions listed above. In the latter case, the methods of determining the optimum passage become much more complex. The goal function is selected by the master [14].

Therefore it is assumed that it is possible to apply the guidelines in determining the principles of sea navigation planning to inland waterway navigation in order to develop a model for the optimisation of passage planning in inland waterway navigation.

2.2 Passage planning and implementation

The passage planning consists of gathering data, studying them and making the passage plan. The relevant data may be grouped into information on the particular vessel, information on the aids to navigation, and information on means of communication. The implementation of passage planning and the supervision of the implementation are based on the data that are continuously gathered prior to and after leaving port. During the navigation, it is necessary to supervise the implementation of the original or subsequently altered passage plan, as well as the assessment of the impact of the newly obtained data. [14]

The implementation of maritime practice adapted to inland navigation is suggested as it is considered that the ways of making and implementing the passage planning in maritime environment are applicable as guidelines on inland waterway navigation.

2.3 Optimisation and modern technology

With regard to determining the guidelines on the optimisation of inland navigation, we should be familiar with the costs related to maintaining the necessary level of safety of navigation. The costs refer to:

- maintaining the necessary level of safety of inland navigable waterways, and
- maintaining the necessary level of the vessel's safety.

It is considered that the maintenance of the necessary level of safety of the inland navigable waterways involves the following costs:

- dredging,
- maintenance of navigation marks,
- maintenance of dams, water gates and locks,
- maintenance of systems of information, supervision, positioning and the like, and
- other costs.

It is considered that the maintenance of the necessary level of the vessel's safety involves the amortisation costs:

- maintenance of the vessel and the vessel's equipment in compliance with the requirements of the vessel's port of registry,
- maintenance of the vessel and the vessel's equipment in compliance with the requirements of the insurance companies,
- maintenance of the vessel in compliance with the requirements of the classification societies, and
- other costs [13].

The technological optimum and, consequently, economical optimum should be determined with the purpose of optimisation of navigation (Figure 3).

From the standpoint of costs, optimisation of passage planning in inland waterway navigation may result in increasing the cargo that is loaded and carried, thus reducing port operations and traffic density. Furthermore, from the standpoint of safety, the decrease in risky practice is expected at critical infrastructural positions and legs of the inland waterway navigation.

It is justified to assume that the application of modern technologies can enhance the optimisation of passage planning in the inland waterways navigation. In maritime shipping, modern technologies may involve the application of the integrated navigation system. It is reasonable to expect that such systems can be adapted and therefore applied to inland navigation in order to achieve similar benefits in the optimisation of the vessels' navigation along inland waterways [8]. Partial or full automation of navigation would certainly reduce the crew required to han-

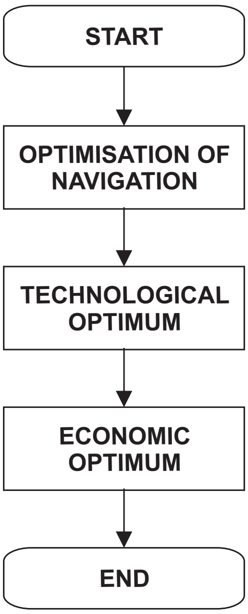

Figure 3 Optimisation of navigation

Source: the Authors

dle the vessel and consequently reduce the overall shipping costs. Generally speaking, services related to the transport of cargo through inland navigable waterways are not expensive. Therefore, as the needs for transportation increase, it will be necessary to cover all inland navigable waterways by digitised charts, to introduce electronic information charts for inland navigation and to implement the *E-navigation* system [5]. The advantages of the E-navigation imply the availability of all system components, including the electronic navigational charts. E-navigation embraces new technologies and ensures their application in line with various navigational and communication technologies. Technical changes may refer to the integration of Electronic Chart Display and Information System (ECDIS), Automatic Radar Plotting Aid (ARPA) and Automatic Identification System (AIS). In addition, it is necessary to apply the so-called blackbox, i.e. to record the information of the vessels' passage by means of Voyage Data Recorder (VDR) and Light Detection and Ranging (LIDAR) [9]. With the purpose of the optimisation of the passage planning in inland waterway navigation, it is considered as justified to adapt the integrated navigation system within the E-navigation system. The adapted applications of these cutting edge technologies – which have been thoroughly tested in seaborne shipping business – to the inland waterways navigation are considered as guidelines on the optimisation of the vessel's inland navigation.

3 CONCLUSION

A considerable increase in traffic and transport along the rivers, canals and lakes has been perceptible in Europe and throughout the world. Unlike the inland waterways in the rest of the world, the ones in the Republic of Croatia have been insufficiently developed. Inland navigation implies a range of technological processes whose level of complexity varies considerably. The technological processes related to the aspect of the vessel's voyage can be optimised. However, Croatia lacks a systemic approach to the optimisation of passage planning in the inland waterways navigation. Therefore the development of a model for the optimisation in line with the suggested guidelines is recommended. The guidelines imply the determination of principles of optimising the passage planning, making and implementing the passage plan, and application and optimisation of modern technologies. The above suggestions may serve as the groundwork for further research aimed at developing the models for optimising passage planning in inland navigation. The positive effects of the application of such models would refer to reducing engine load and energy consumption, reducing the emission of CO_2, increasing the efficiency of shippers, etc. The development and application of the models for optimising passage planning in inland waterways navigation considerably contribute to the economies of various countries that feature various development levels of inland navigation, including the Republic of Croatia. It can be concluded that the development of models for optimising passage planning in inland navigation should follow the guidelines referring to the determination of principles of optimising the passage planning, making and implementing the passage plans, and the application and optimisation of the modern technologies.

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