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Proposal of Measures for Increasing the Safety Level of Inland Navigation

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ABSTRACT

Navigation along inland waterways was in history used only for the transportation of bulk cargo. However, in the last two centuries inland waterways have been used for transporting containers, general and liquid cargo. The density of navigation in the world waterways is considerable, especially because it is more profitable, when compared to other forms of transport. The increase of the density of navigation along inland waterways has also caused the threats of various undesired occurrences like collisions, stranding, pollution etc. Their decrease may be realised through the implementation of various measures relating to the safety of navigation along inland waterways.

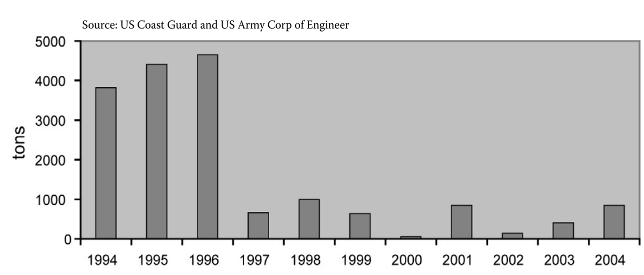
In this paper the authors will present new measures aimed at the increase of the volume of traffic. It is expected that the implementation of new measures will enable optimal planning of navigation and better awareness of potential threats in the waterways.

1. Safety of navigation and inland waterways

Safety of navigation assumes a set of conditions and requirements to be fulfilled by inland waterways, ports, navigation, ships and other vessels, the crew and supervision of implementation of navigational safety regulations (Kasum et al., 2004). Inland waterways refer to the belt of inland waters of particular depths and widths along which navigation is performed.

According to statistics, inland waterways holding up the safest transport sectors (graph 1 and 2). However, further reduce of accidents and increase of safety of inland waterways is considered as necessary. According American Waterway Operators - AWO, it is expected to significantly increase traffic on inland waterways. Waterways could be a great danger in case of threat from terrorism because of its lack of protection and pass through large cities.

Graph 1. Ship accidents per million miles.



Graph 2. The quantity of fuel products and fuel discharged from the barge 1994th-2004 in tonnes.

It can be presented by a general model of route between destinations A and B (Figure 1).

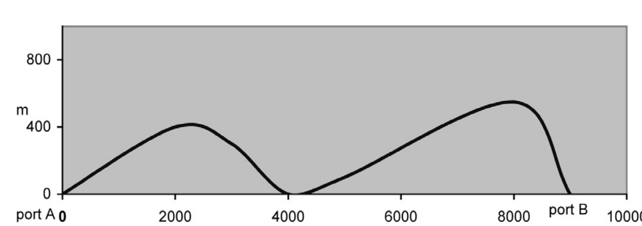


Figure 1. General model of inland waterway

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2. Proposal of new measures

During the navigation along inland waterways various decisions are made. Part of the decisions is based on the information from the environment. Among other subjects, they refer to:

- Limited waterway along the river course,
- Hydrographic characteristics,
- Meteorological characteristics,
- Quantity of traffic in a limited area,
- Limited possibility of manoeuvring ,
- Branching, vicinity of towns and industrial plants, and
- Human error.

Inland navigation is specific also because of the limitation of the waterway along the river course, coastline of rivers, lakes and channels, river widths, number of meanders and radius of meanders, shallow water, water level, dams and locks, and other navigation obstacles, like cables, bridges etc. Such navigation requires frequent manoeuvring and consequently additional attention of the navigator. It is therefore necessary to propose a system of measures for defining limitations of a waterway calculating the coefficients of:

- Width of an inland waterway (K_w),
- Indentedness of an inland waterway ($K_{i,}$), and
- Complexity of an inland waterway (K_c).

The coefficient of width is the ratio between the full length of the waterway along the centreline from the port A to the port B (*l*) and the width of the waterway (w):

$$K_{w} = \frac{l}{w} \tag{1}$$

The coefficient of indentedness of an inland waterway (K_i) is the ratio between the full length of the river shoreline (l_{cl}) and the full length of the inland waterway (*l*):

$$K_{i} = \frac{l_{cl}}{l} \tag{2}$$

The coefficient of complexity of an inland waterway (K_s) is the ratio between the total number of navigation threats ($\sum_{i=1}^{n} o$) and the length of the inland waterway (*l*). Navigation threats are threats like dangerous depths, shallow waters, locks, bridges, cables etc.:

$$K_{s} = \frac{\sum_{i=1}^{n} o_i}{l} \tag{3}$$

Navigation along inland waterways is considered dangerous also because of unfavourable hydrographic characteristics of a waterway (Kasum et al., 2004; Kasun, 2003), especially when the water level and water currents reach extreme values. Water level and water currents may cause difficulties when manoeuvring the ship and cause complications in case of pollution, passing by other ships, drifts in rivers bends, entering channels, undesired increase or decrease of speed, dangerous objects brought by current, etc. When estimating the safety of sailing along a particular inland waterway it is proposed to use a coefficient of meander state of the river (K_b) (4). It is the ratio between the sum of river bends lengts ($\sum_{i=1}^{n} b$) and the full length of the waterway and it provides information on the meander state of the river course.

$$K_{b} = \frac{\sum_{i=1}^{n} b_i}{l} \tag{4}$$

As in maritime navigation, meteorological properties may be a threat for ships in inland navigation in terms of safe manoeuvring of the ship. The ice may cause damages on the hull. The fog and reduced visibility jeopardise a safe manoeuvring of the ship in narrow passages and along the areas of higher traffic intensity. The wind may cause the drift of the ship in risky areas such as entrances to estuaries and channels or it may lower the water level, as, for instance, in La Plata- Buenos Aires (Port of Buenos Aires, 2008).

From the aspect of meteorological influences, safe passage may be expressed by a coefficient of safe passage (K_{sap}). It equals the ratio between the total number of navigable days of safe passage ($\sum_{i=1}^{n} d_n$) and the number of days in a year:

$$K_{sap} = \frac{\sum_{i=1}^{n} dn_i}{365} \tag{5}$$

Visibility coefficient (K_{vsb}) is the ratio between the total number of days with reduced visibility ($\sum_{i=1}^{n} d_{rvsb}$) and the number of days in a year:

$$K_{vsb} = \frac{\sum_{i=1}^{n} drvsb_i}{365} \tag{6}$$

It is considered that the intensity of traffic in limited area of inland waterways is relatively high. In inland waterways, it is often navigated in the vicinity of locks, dams, industrial areas, narrow channels etc. Due to high traffic intensity in a relatively small area there is a higher probability of collision with other ships. Therefore, traffic density (*Gp*) of a waterway can be measured. It equals the ratio between the total number of ships (V_b) and the length of the waterway *(l)*:

$$G_p = \frac{\sum_{i=1}^{n} Vb_i}{l} \tag{7}$$

In inland navigation there are relatively stronger water currents than in maritime navigation. Because of the nature of a waterway, ship manoeuvrings are more frequent and the distances from land and navigating objects are smaller in comparison to maritime coastal navigation.

Besides navigational hazards such as shallow waters, junctions of waterways and the like, inland waterways are intersected by road and railway bridges. They are additional threat to the safety of navigation. Rivers connect towns with the sea and have numerous tributaries for irrigation of agricultural areas, operation of industrial plants etc. Ports in such areas are of smaller capacity than marine ports, but they have a significant trend of traffic increase (Jolié, 2006).

It is proposed to use measures for estimating potential human, material and other hazards (Kasum, Vidam and Baljak, 2006). In this way the density of various infrastructures in inland waterways can be measured, for instance:

- Density of inhabited places along the waterway G_{nm},
- Population density along the waterway G_{na}, and
- Density of potentially jeopardised objects along the waterway G_{no}.

It is considered that the density of inhabited places along the waterway (G_{nm}) equals the ratio between the total number of inhabited places along the waterway (N_m) and the length of the waterway (l) (Kasum, Vidam and Baljak, 2010; Vidan and Kasum, 2009):

$$G_{nm} = \frac{\sum_{i=1}^{n} Nm_i}{l} \tag{8}$$

Population density along the waterway (G_{na}) is the ratio between the number of inhabitants there (S) and the length of the waterway (l) (Kasum, Vidam and Baljak, 2010):

$$G_{na} = \frac{\sum_{i=1}^{n} S_i}{l} \tag{9}$$

The density of potentially jeopardised objects along the waterway (G_{no}) is considered to equal the ratio between the number of jeopardised objects (O) and the length of the waterway (l) (Kasum, Vidam and Baljak, 2010):

$$G_{no} = \frac{\sum_{i=1}^{n} O_i}{l} \tag{10}$$

Human negligence is a crucial factor in the situation of crisis. It can refer to accidental pollution of water, erroneously operating dams and lock, wrong estimates when manoeuvring and the like. The coefficient of hazard due to human error can be expressed as a ratio between the number of accidents caused by human error ($\sum_{i=1}^{n} n_{hm}$) and the length of the inland waterway (l) (INE, 2007):

$$K_{hm} = \frac{\sum_{i=1}^{n} nhm_i}{l} \tag{11}$$

It is proposed to determine the interval values above the new coefficients hydrographic survey of the waterway. On the basis of possible values, it is necessary on the waterways to determine the assessment of possible risks to safety. Ratings should be to determine the scale (Table 1).

Table 1. Risk assessment system for safety and security of the vessel on the navigable way.

The threat to the safety of navigation	Description	Mark
The great danger to safety and security of navigation	Actual or permanent suspension of navigation due to inability of navigation	3
Moderate risk to the safety and security of navigation	Navigation is only possible to the nearest shelter or safe fairway. Shelter or safe waterway would have to be near the current position. Sailing must not include shipping area 3.	2
Small danger to safety and security of navigation	Navigation is possible with the greatest caution	1

These measures can be expressed as a function of variables that defines the safety:

$$S_g = f(K_w, K_i, K_s, K_b, K_{sap}, K_{vsb}, G_p, G_{nm}, G_{na}, G_{no}, K_{hm}) \tag{12}$$

These ratings should enter the charts for the designated areas. On based assessment system, the measures undertaken to protect the shore and the boat.

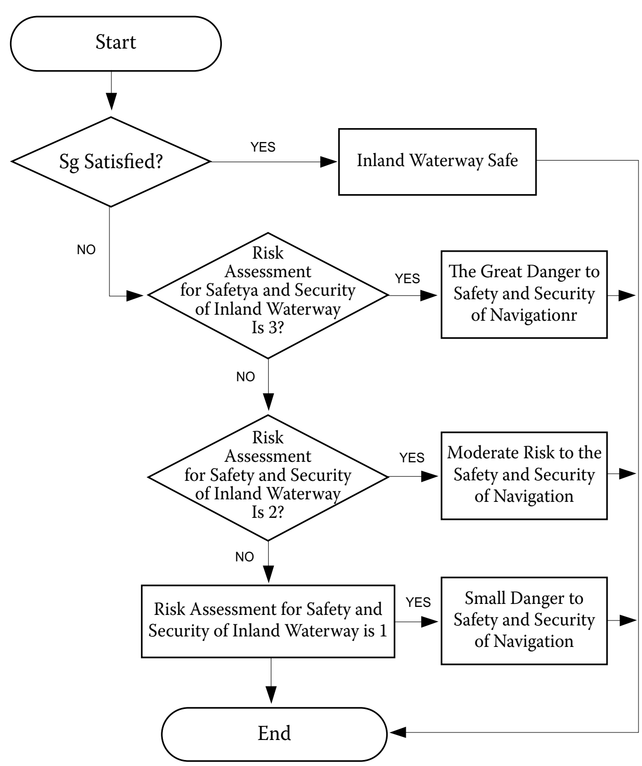

Figure 2. Decision algorithm and evaluation of safety and security on inland waterways.

Measures protection based on the estimated risk for the safety and security could be implemented based decision-making algorithm as shown in Figure 2.

In order to increase safety factors in inland waterways, the results presented in the proposed measures might be included in the information content of river maps and navigational publications. For example, the proposed measure of the coefficient of hazard due to human error could be presented as:

- Red mark (**o**),
- Orange mark (o), and
- Green mark (o).

Source: http://www.fgs.wsv.de/produkte/kartographie/argo_encs/index.html

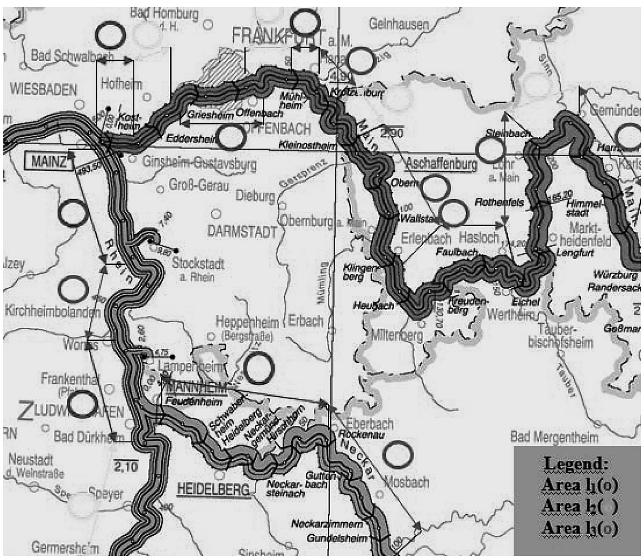

Figure 3. Example of areas with different values of the estimated coefficients of human errors in navigational area of the Rhine and Main.

The red mark indicates the area with frequent accidents caused by human error.

The orange mark indicates the area with infrequent accidents caused by human errors.

The green mark indicates the area with no accidents caused by human error.

The example of navigation along the rivers Main and Rhine shows the estimated coefficients of hazard due to human error (Figure 3). According to publications[1], it is estimated that the industrial area of Frankfurt A/M[2], the city of Frankfurt and approaches to it are considered hazardous for navigation due to a possible human error. The similar situation relates to bridges due to their relatively low height.

In the areas close to obstacles, such as dams, junctions, bridges, shallow waters and channels the possibility of accident caused by human error is relatively high, and the relevant coefficients reach middle values.

The areas with no hazards that have relatively low coefficients of hazard caused by human error are in the areas where navigation is unobstructed, traffic density is low or medium, depths are safe etc.

[1] http://www.buergerimstaat.de/2_00/rhein.pdf
[2] Frankfurt am Meine

It is necessary to apply the adequate statistical processing of the valid data in real examples. In many various countries such data are often unobtainable, as they are considered protected data related to crucial European and/or national infrastructures.

3. Implementation of new measures

It is proposed to regard all information related to the safety of navigation along inland waterways as *Inland Water Safety Information – IWSI*. They should be distributed to the user by:

- Regular broadcasting of radio notices related to IWSI.
- Publishing them in river navigation charts, and
- Publishing them in river navigational publications.

Regular broadcast of radio notices related to IWSI need to be classified as *Search and Rescue-SAR*, *Meteo-MET* and *Navigational Warnings-NAVWAR* and the national coordinator for each category need to be appointed (U.S. Coast Guard). In order to follow the data on the safety of the waterway it is necessary to establish the *Inland Water Information Service-IWIS* for all critical areas. The data may be available by means of VHF *(Very High Frequency)* or MF *(Medium Frequency)* devices, NAVTEX, INMARSAT etc. (Kasum, 2006). It is also proposed to organise the global coordination service of such information – *World Wide Inland Water Information Service – WWIWIS* (Kasum, Vidam and Baljak, 2010).

It is necessary to establish standards in the production of river navigation charts similar to *Electronics Chart Display and Information System-ECDIS* that are already in use in river navigation. In order to increase the navigation safety level it is necessary to expand their information content with, for instance, new proposed measures.

It is necessary to propose standards in the production of river navigational publications by integrating IWSI into their information content that otherwise would congest the content of river navigation charts.

It is also proposed to use the suggested approach in the development of new measures in order to establish international standards and their world-wide implementation.

4. Conclusion

The use of inland waterways in global traffic is constantly increasing. The increase of traffic consequently increases the possibility of collision and of other undesired events. By increasing the navigational safety level it is possible to decrease consequential damages.

It is, therefore, necessary to develop international standards relating to *Inland Water Safety Information – IWSI* and the like. In order to increase their accuracy, availability and reliability it is proposed to establish a global coordination service – *World Wide Inland Water Information Service - WWIWIS.* It is proposed to distribute IWSI to the users by regular broadcasting of radio notices, by publishing river navigation charts and navigational publications.

It is assumed that the implementation of the new measures proposed in this paper will significantly affect the increase of safety level of inland waterway navigation.

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