An analysis of accidents in inland navigation in context of autonomous shipping

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ABSTRACT

The collection of data on accidents in inland navigation is not mandatory in many European countries. The lack of a harmonized methodology or a centralized database of information on accidents makes it difficult to obtain a comprehensive picture of safety on European inland waterways. Consequently, the possibilities for improvement of technical standards are limited. The problem becomes particularly evident in light of the significant navigational challenges such as the introduction of autonomous shipping. Attempting to provide a better understanding of safety in inland navigation, the paper presents the results of an analysis of data on some 700 accidents which took place on the inland waterways in Austria and Serbia, over a 15-year period (2001/2002-2017). The analysis indicates the fundamental conditions in which it would be possible to reduce the human presence or even remove the crew from inland ships.

Keywords: *accidents, inland navigation, autonomous ships, Vessel Train, NOVIMAR*

1. INTRODUCTION

Understanding both the causes and the consequences of navigational accidents is necessary for proper comprehension of the waterborne transport safety. It is also a prerequisite for improvement of ship safety regulations. This becomes particularly important in face of a major system disruption such as the introduction of autonomous shipping.

In recent years, introduction of autonomous ships in inland navigation in Europe has been considered by several initiatives. This prompted a reconsideration of the corresponding regulatory framework. It should be acknowledged that the ship safety regulations are based on explicit safety-by-design requirements which are complemented by mostly implicit operational measures embodied by the concept of “prudent seamanship” (see Bačkalov et al, 2016). Technical standards for inland vessels are no exception in this respect and, in fact, may rely on operational measures even more than safety regulations for seagoing ships, as shown by Bačkalov (2020). Endrina et al (2019) point out that ships are highly dependent on the competence of seafarers. Thus, the removal of crew from ships should be adequately compensated by additional safety-by-design measures.

On the other hand, a high frequency of accidents attributed to human failures, typically in range of 70%-90% is often used as a strong argument in favour of autonomous shipping.[1] For example, a recent study into the role of human factors in accidents in inland navigation in Western Europe pointed out that as much as 70%-80% of accidents were caused by human errors (see van der Weide & Schreibers, 2020).

Therefore, the scope and the features of additional design measures which need to be implemented in place of the crew, requires the understanding of the role of human operators in regular navigation conditions as well as in emergencies. One step towards such an understanding implies the analysis of accidents.

Project NOVIMAR (NOVel Inland waterway and MARitime transport concepts) examines the possibilities for introduction of a specific waterborne platooning concept (the so-called Vessel Train) in short-sea shipping, sea-river, and inland navigation. Vessel Train implies a convoy of several digitally connected vessels, whereby only the first vessel in the convoy (the so-called lead vessel, LV) is fully manned, while the rest of the vessels (the so-called following vessels, FV), being remotely controlled from the LV via a control system, operate either with a reduced crew or with a crew off-duty.

One of the tasks recognized within NOVIMAR was to "identify main hazards for inland navigation and representative accident scenarios where human failure was an important contributor and near-miss scenarios where human action avoided escalation of an initial incident". In part, this task was to be accomplished by analyzing the data on accidents in inland navigation. The collection of such data, however, is not mandatory in many European countries. Moreover, there is no common, European-wide definition of an accident in inland navigation (Klotwijk-de Vries & Espenhahn, 2020). Consequently, the data are not readily available. Furthermore, the methodologies for collection and analysis of data are not harmonized on the European level. In some cases, the data are yet to be extracted from the accident reports which are available at request only. Typically, such reports are not digitized, and they are written in official languages of the riparian states where the accidents took place. The lack of standardization with respect to data collection, results in disparity of information available from different sources and absence of some important data.

As a partner in project NOVIMAR, University of Belgrade gathered the data on 800 accidents which took place on inland waterways of Austria and Serbia over a 15-year period. The data were gathered from two sources: the Federal Ministry of Transport, Innovation and Technology (Bundesministerium für Verkehr, Innovation und Technologie, BMVIT), Austria and the Port Authority of Belgrade (Lučka kapetanija Beograd, LKB), Serbia. After preliminary review of the available data, 702 accidents involving at least 883 crafts were selected for further analysis.

2. AVAILABLE DATA ON ACCIDENTS

BMVIT provided data which were already extracted from the accident reports and systematized in a spreadsheet form. The BMVIT data covered 639 accidents which happened on the Austrian part of the Danube (from 1870 km to 2220 km of the Danube length, see Fig. 1) in period from March 2002 to October 2017.

On the other hand, LKB provided access to full reports of some 161 accidents covering the period from December 2001 to August 2017. The necessary data were extracted from the reports in cooperation with the Centre for Investigation of Traffic Accidents of Republic of Serbia (Centar za istraživanje nesreća u

[1] However, the actual source of such information is difficult to track down.

saobraćaju, CINS). Being one of 13 port authorities in Serbia, the Port Authority of Belgrade, strictly speaking, is in charge of accidents which happen on inland waterways in the relative vicinity of Belgrade (see Fig. 1 and Table 1). Nevertheless, the LKB records also contain the reports on accidents which took place in another part of the Serbian inland waterway network but were reported to the Port Authority of Belgrade. About 65% of accidents from the LKB records happened on the Danube.

Finally, it is important to note that BMVIT omitted the names and registration numbers of the vessels, as well as any other personal or sensitive information before providing the data to the University of Belgrade. On the other hand, the data from LKB records were anonymized for the purpose of analysis described in this paper upon extraction from the accident reports. The main features of the databases used in this analysis are summarized in Table 1.

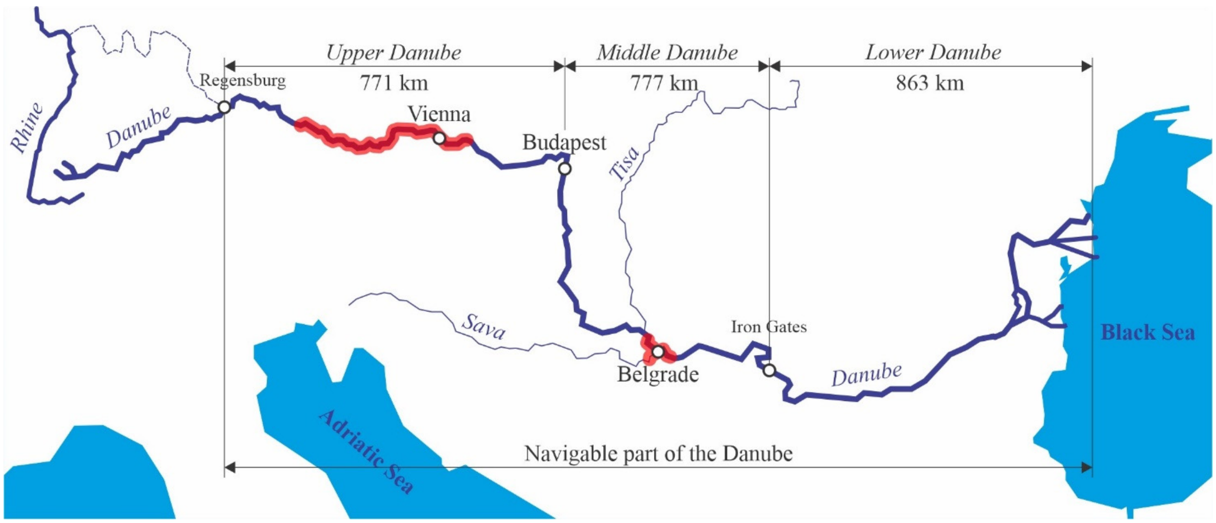

Figure 1. Inland waterways where the accidents analysed in this study occurred (highlighted in red)

Table 1. The main features of databases used in the analysis.

Country	Austria	Serbia
Database source	Federal Ministry of Transport, Innovation and Technology (BMVIT)	Port Authority of Belgrade (LKB)
Inland waterway	Danube 1870 – 2220 km	Danube 1136 – 1187 km (right bank) 1155 – 1205 km (left bank) Sava 0 – 80 km (right bank) 0 – 48 km (left bank)
Observed period	03/21/2002 – 10/04/2017	19/09/2001 – 08/26/2017
Total number of accidents	639	161
Number of selected accidents	584	118
Number of vessels involved in selected accidents	754	129
Database form	A spreadsheet with data extracted from accident reports	Full reports

2. METHODOLOGY AND DEFINITIONS

The primary goal of the investigation was to establish the frequency of different types of accidents as well as the frequency of causes of accidents, and to examine, as far as possible, the role of human operators in the accidents. To do so, it was necessary to adopt a common set of definitions and to identify the accidents which were of interest for the task specified within the project NOVIMAR.

3.1 Accident types

The following types of accidents were observed in the available data.

- Allision implies an accident which happens when a moving ship collides with a fixed object: a bridge, a riverbank, a structure such as berthing installation or a part of the waterway infrastructure, or even another ship that was not moving at the time of the accident.
- Collision is an accident which happens when two moving ships collide.
- Grounding comprises both the vessel running aground and the contact with waterway bed, as the available accident data often do not distinguish between the two events.
- Hull/machinery/equipment (HME) damage is an accident (typically involving one ship) which concluded with a malfunction of a system or a device, a structural collapse, or a component failure (e.g., breakdown of the main engine, loss of an anchor, crack in the hull, etc.). In some, more complex cases, this type of accident progressed into e.g. a collision or a grounding.
- Other accidents registered in the available databases comprised fire, capsize, shipwreck, foundering.

3.2 Causes of accidents

Upon the analysis of data, it was possible to establish the following causes of accidents.

- Human failures (HF) – different types of human failures were observed: fatigue (resulting in a brief sleep or a loss of concentration), failure to follow established procedures, abuse of alcohol, misunderstanding or lack of communication, misjudgement of navigational conditions or insufficient situation awareness.
- Technical faults (TF), e.g. a machinery or navigational equipment failure. Such event could progress into HME damage or another type of accident.
- Weather conditions (WEC) comprise the influence of gusty wind, fog, precipitation, ice, etc. as well as the water level fluctuations resulting in insufficient fairway depth (during the low-water periods) or strong river currents (during the high-water periods).
- Operational cause (OC) is attributed to the situations in which incident arose from circumstances encountered during the voyage, originating from inadequate waterway maintenance (floating debris, an unmarked underwater object or a sandbank that should have been removed) or interaction with other craft (waves of passing ships).

3.3 Ship types

The analysed accidents involved self-propelled cargo ships, push boats and barges, as well as various convoys consisted of the cargo vessels and other craft, passenger ships, special purpose ships (firefighting tugs, dredgers, floating cranes and workshops, etc.), pleasure craft and small craft (typically fishing boats). The accidents which included only pleasure craft or only small craft, or any combination thereof were excluded from the database and omitted from the analysis. Thus, the number of accidents which were taken into consideration was reduced from 639 to 584 accidents involving 754 vessels (in Austria) and from 161 to 118 accidents involving 129 vessels (in Serbia).

3.4 Consequences of accidents

Inland navigation is generally regarded as the safest transportation mode in Europe, in view of low number of casualties and fatalities in accidents on inland waterways. While this standpoint seemed to be confirmed by the available records on accidents, the actual extent of consequences was difficult to capture. Such difficulties are caused by the absence of data relevant for estimation of environmental damage, and direct and indirect economic consequences of navigation suspension and waterway infrastructure damage, which are often set off by the accidents. Inability to accurately assess consequences of accidents on inland waterways based on available data makes it difficult to evaluate the risks borne by inland navigation.

4. ANALYSIS OF THE AVAILABLE DATA ON ACCIDENTS

The most frequent accidents on the Austrian part of the Danube in the examined period were the allisions (46% of the accidents) see Table A1 and Figure A1 in the Appendix. On the other hand, the most frequent accidents on the Serbian inland waterways were the HME damages which formed more than a half of the total number of accidents (54%). Quite the opposite, the HME damages were the least frequent accidents on the Austrian Danube (only 2% of the accidents). Among the least frequent accidents on the Serbian inland waterways were groundings and fires (3% each), but also the catastrophic events such as capsizes (2% of the total number of accidents) which typically concluded with the loss of ship and/or the loss of life.

With respect to the causes of accident, up to 58% of accidents on the Austrian part of the Danube were attributed to human failures, while the least frequent were the operational causes (4%), see Table A2 and Figure A2 in the Appendix. On the other hand, human failures were behind just 19% of accidents on the Serbian inland waterways representing the least frequent cause of accidents. The most frequent causes of accidents in Serbia were technical faults and operational causes (29% each).

Most of the allisions on the Austrian part of the Danube could be attributed to human failures (59% of allisions), while the operational causes were found to be the least frequent cause of allisions (2%). The most decisive factor in allisions which took place on Serbian inland waterways were weather conditions (37%). The influence of technical faults and human failures was not insignificant either (each contributed to 24% of allisions). Just as in Austria, the least frequent cause of allisions recorded by LKB were the operational causes, see Table A3 and Figure A3 in the Appendix.

The analysis of causes of collisions reveals that the human failures were the most frequent cause of this type of accident on both the Austrian and the Serbian inland waterways (77% and 56% of collisions respectively). Similarly, operational causes were the least frequent cause of collisions in both Austria and Serbia, even though it should be noted that the frequency of collisions due to operational causes is by an order of magnitude greater in Serbia than in Austria (11% vs. 2%), see Table A4 and Figure A4 in the Appendix.

Regarding the causes of groundings, 67% of such cases on the Austrian section of the Danube could be ascribed to human failures. Weather conditions and operational causes were the least frequent causes of groundings in Austria (5% each). On the other hand, all groundings on Serbian inland waterways, registered by Port Authority of Belgrade, could have been attributed to operational causes, see Table A5 and Figure A5 in the Appendix.

In Austria, HME damages were caused mostly by operational causes (39%) and weather conditions (31%). Operational causes played a significant role in HME damages in Serbia too

(39%), but most accidents of this type were caused by technical faults (42%). Interestingly, the influence of human failures on HME damages was negligible, both in Austria and in Serbia, see Table A6 and Figure A6 in the Appendix.

5. DISCUSSION

The comparison on data on accidents on Austrian and Serbian inland waterways reveals that the available records differ considerably with respect to both the frequency of accident types and the frequency of causes of accidents. Herein, an effort will be made to explain some of the most striking differences.

One of the most obvious differences is the disparity with respect to frequency of accident types in Austria and Serbia. Groundings and collisions were found to be more frequent in Austria (27% and 25% respectively) than in Serbia (3% and 9% respectively). On the other hand, HME damages were much more frequent in Serbia (54% of accidents) than in Austria (only 2%). Allisions make a large share of accidents in both Austria and Serbia (46% and 29% respectively). Lower frequency of collisions in Serbia could be explained by a lower traffic density, generally wider fairway, and lower stream velocities. Even lower frequency of groundings in Serbia could be explained by the greater fairway depth of the Danube in Serbia than in Austria; in fact, groundings in Serbia represent contacts with unmarked underwater objects and obstacles rather than ships running aground in shallow water. Considering that 89% of vessels which were involved in the accidents on the Serbian inland waterways had the Serbian flag, the high frequency of HME damages in Serbia seems to indicate the poor technical state of the ships, and an inadequate maintenance of the Serbian fleet.

Considerable discrepancies could be observed with respect to the distribution of causes of accidents, too. Within the context of autonomous shipping, the impact of human failures on safety of inland vessels is probably the most interesting factor. The findings of the analysis presented in this paper, however, did not confirm that human failures had an excessive impact on safety in inland navigation, as pointed out by some studies. Furthermore, in some more complex accidents the human action was decisive in mitigation of consequences or even avoiding of an incident (the event thus resulted in a near miss, instead of an accident).

While the human failures represent the most important cause of accidents in Austria, they seem to be the least frequent cause overall on Serbian inland waterways (58% in Austria vs. 19% in Serbia). Human failures were the most frequent cause of allisions, collisions, and groundings in Austria. In Serbia, however, the human failures were the main cause of collisions only. On the other hand, the weather conditions and the operational causes combined were responsible for only 10% of accidents in Austria, while they constituted as much as 52% of accident causes in Serbia. These figures suggest that the weather conditions on the Middle Danube are harsher than on the Upper Danube in Austria, which raises the question whether the present status of the Danube as a single navigation zone in European technical standards for inland vessels (see CESNI, 2019) should be reconsidered. Furthermore, the results seem to indicate inadequate waterway maintenance in Serbia. Indeed, drifting wood, unmarked underwater objects, sandbanks which should have been removed as a part of the regular fairway maintenance, etc. were described in many accident reports in the LKB records.

None of the HME damages was caused by human failures in Austria, while human failures contributed to not more than 4% of HME damages in Serbia. Technical faults seem to be a cause of accidents which was of almost equal importance both in Austria and in Serbia (20% and 29% of all accidents respectively). However, the nature of the technical faults seems to be quite different in the two examined waterways. On Serbian inland waterways, the technical faults caused as much as 42% of HME damages. On the Austrian Danube, however, the majority of HME damages (70%) was due to "external" factors (operational causes and weather conditions). This finding may also indicate an improper technical state of ships in Serbia.

5.1 Missing data

The data provided by BMVIT did not contain information on main particulars, displacement, and age of the vessels involved in accidents. On the other hand, although the main particulars of ships are generally given in the reports of the Port Authority of Belgrade, the overall dimensions of convoys or the actual draught of the ship at the time of accident were not recorded.

Neither BMVIT nor LKB records contain the data on the location and the extent of hull damages. The lack of such historical data hampers the development of more rational subdivision and damage stability regulations for inland vessels. The present regulations are deterministic and partially based on SOLAS 74 rules for seagoing ships (see Bačkalov & Vidić, 2020).

In the statistical analyses of maritime accidents, it is common to relate the number of accidents to "operational fleet at risk" (see e.g. Eliopoulou et al, 2016). In inland navigation, however, it could be challenging to determine the size of the operational fleet at risk. Namely, the question arises whether e.g. "the Danube fleet" is comprised of the vessels registered in the Danube riparian states or the vessels which sailed along the Danube in the observed period, regardless of their flag.[2] Even though the latter seems to make more sense, it is also a figure which is much more difficult to estimate.

5.2 Deficiencies of the analysis

The analysis presented in the paper has some inherent deficiencies. The Austrian BMVIT records comprise the data on accidents on the complete Austrian section of the Danube, while the records available from the Port Authority of Belgrade correspond to the sections of the Danube and the Sava in the vicinity of Belgrade.

Another potential source of disparity between the findings from the accidents in Austria and Serbia is related to the fact that the data corresponding to the Austrian Danube were already extracted from the accident reports, while the authors had access to full reports of accidents in Serbian inland waterways and extracted the data by themselves. Had the authors have the access to the full accident reports from the BMVIT records, it is possible that the outcome of the analysis could have been somewhat different.

6. CONCLUSIONS

The Danube is the second-longest European river: some 2400 km of the navigable waterway, consisted of three major sectors (Upper, Middle, and Lower Danube), connect 10 countries with different climates, economic backgrounds, and safety culture profiles. Such differences may result in diverse safety issues, as well as in dissimilarities in typical causes of accidents and in different distributions of the major types of accidents. This seems to be confirmed by the comparative analysis of accidents that occurred on the Upper Danube (Austria) and the Middle Danube and Sava (Serbia) in the same period, between 2001/2002 and 2017.

With respect to the prospects for introduction of an inland navigation concept that would imply a reduced human involvement (such as the Vessel Train) on the Danube, the analysis seems to confirm that a system which would replace the crew in regular navigation tasks (thus diminishing the possibility of a human failure) would be beneficial for ship safety. However, this is valid as long as both the waterway and the ship are in a fair condition and properly main-

[2] For instance, most of the river cruise ships in Europe sail under the Swiss flag.

tained. Otherwise, the conditions that could trigger an accident become much less predictable and, therefore, less likely to be successfully resolved by an unmanned system. In fact, in some cases, the human involvement (which typically includes a rapid experience-based risk assessment) becomes a decisive factor in turning a potential accident into a near-miss.

Contrary to what is often cited, the analysis presented in this paper did not confirm that the human failures could be responsible for as much as e.g. 80% of accidents. Considering that human failures caused less than 60% of accidents in Austria, and less than 20% of accidents in Serbia, it seems that the influence of human failures may be exaggerated, at least in case of inland navigation on the Danube and the Sava, and that it could well depend on the navigational conditions on a specific waterway and the level of safety attained by the design and maintenance of ships in a specific fleet. This conclusion is consistent with the arguments presented by Heraghty et al (2018): human errors are merely the symptoms – not the cause of accidents which, in fact, come as a consequence of complex system problems.

Any analysis of influence of human operators on ship safety may be considered as incomplete unless it takes into consideration the records of near-misses. Since by default near-misses are not recorded, it follows that the current understanding of the actual role of human operators in safety of inland navigation remains deficient and deserves more research. On the other hand, research into the classification and the causes of human failures (see, e.g. Hasanspahić et al, 2021), could provide a better insight into this topic and facilitate the introduction of adequate measures aimed at the human error reduction.

A relatively high share of technical faults in analysed accidents both in Austria (where technical faults were the second most frequent cause of all accidents) and in Serbia (where technical faults, together with operational causes, were the most frequent cause of accidents) indicates that the technical reliability of vessels should be improved even if the present level of manning is maintained. The first step towards this would be certainly a thorough examination and revision of the current requirements for systems and equipment contained in technical standards for European inland cargo vessels.

Additionally, when considering the reduced manning, it seems that a particular attention should be paid to the weather conditions on the Danube which, even in a standard, manned model of sailing may require more crew than e.g. on the Rhine.

7. ACKNOWLEDMENTS

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8. REFERENCES

Bačkalov, I., 2020, “Safety of autonomous inland vessels: An analysis of regulatory barriers in the present technical standards in Europe”, Safety Science, Vol. 128, article 104763.

Bačkalov, I., Bulian, G., Rosén, A., Shigunov, V., Themelis, N., 2016, “Improvement of ship stability and safety in intact condition through operational measures: challenges and opportunities”, Ocean Engineering, Vol. 120, pp. 353-361.

Bačkalov, I., Vidić, M., 2020, “Damage stability of river cruisers: a case for harmonization of international regulations”, Proceedings of the International Conference on the Sustainable and Safe Passenger Ships, Athens, pp. 119-132.

CESNI (European Committee for drawing up Standards in the field of Inland Navigation), 2019, "European Standard laying down technical requirements for Inland Navigation vessels (ES-TRIN)", Strasbourg.

Eliopoulou, E., Papanikolaou, A., Voulgarellis, M., 2016, "Statistical analysis of ship accidents and review of safety level", Safety Science, Vol. 85, pp. 282-292.

Endrina, N., Konovessis, D., Sourina, O., Krishnan, G., 2019, "Influence of ship design and operational factors on human performance and evaluation of effects and sensitivity using risk models", Ocean Engineering, Vol. 184, pp. 143-158.

Hasanspahić, N., Vujičić, S., Frančić, V., Čampara, L., 2021, "The Role of the Human Factor in Marine Accidents", Journal of Marine Science and Engineering, Vol. 9, Issue 3, Article 261.

Heraghty, D., Dekker, S., Rae, A., 2018, "Accident Report Interpretation", Safety, Vol. 4, Issue 4, Article 46.

Klotwijk-de Vries, F., Espenhahn, A., 2020, "Data collection on accidents in inland navigation – Zoom on the current situation", CESNI Workshop Data collection on accidents in inland navigation, Strasbourg.

van der Weide, R., Schreibers, K., 2020, "Human factors root causes of accidents in inland navigation, Phase 1: data and expert analysis", INTERGO (International Centre for Safety Ergonomics & Human Factors), Amersfoort.

APPENDIX: COMPARISON OF THE RECORDS OF ACCIDENTS ON INLAND WATERWAYS IN AUSTRIA AND SERBIA

Table A1. Breakdown of accident types on inland waterways in Austria and Serbia

Type of accident	Austria	Serbia
Allision	46%	29%
Collision	25%	9%
Grounding	27%	3%
HME damage	2%	54%
Capsize	-	2%
Fire	-	3%

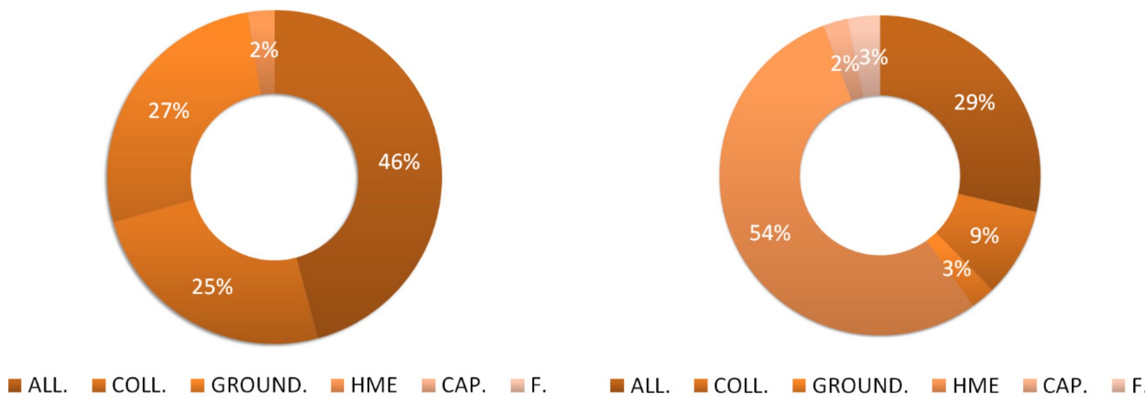

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Figure A1. Breakdown of accident types on inland waterways in a) Austria and b) Serbia

Table A2. Breakdown of causes of accidents on inland waterways in Austria and Serbia

Cause of accident	Austria	Serbia
Human failure	58%	19%
Technical fault	20%	29%
Weather conditions	6%	23%
Operational cause	4%	29%
Other	12%	-

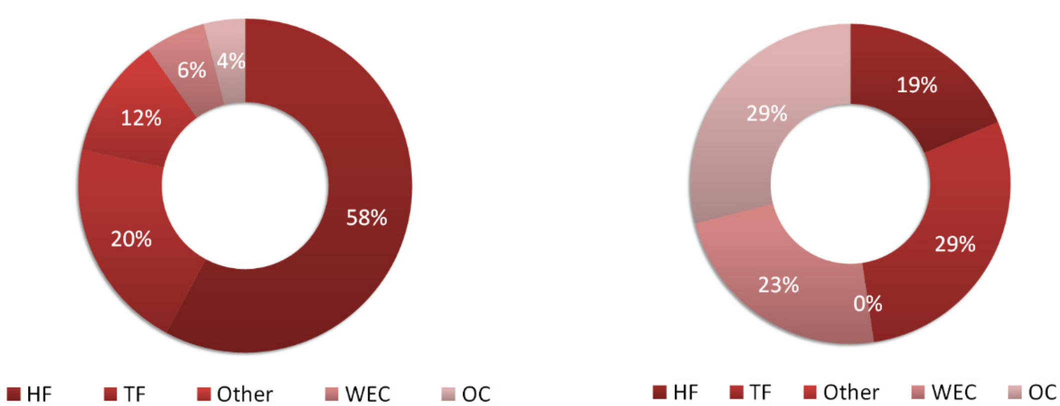

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Figure A2. Breakdown of causes of accidents on inland waterways in a) Austria and b) Serbia

Table A3. Breakdown of causes of allisions on inland waterways in Austria and Serbia

Cause of accident	Austria	Serbia
Human failure	59%	24%
Technical fault	20%	24%
Weather conditions	6%	37%
Operational cause	2%	15%
Other	13%	-

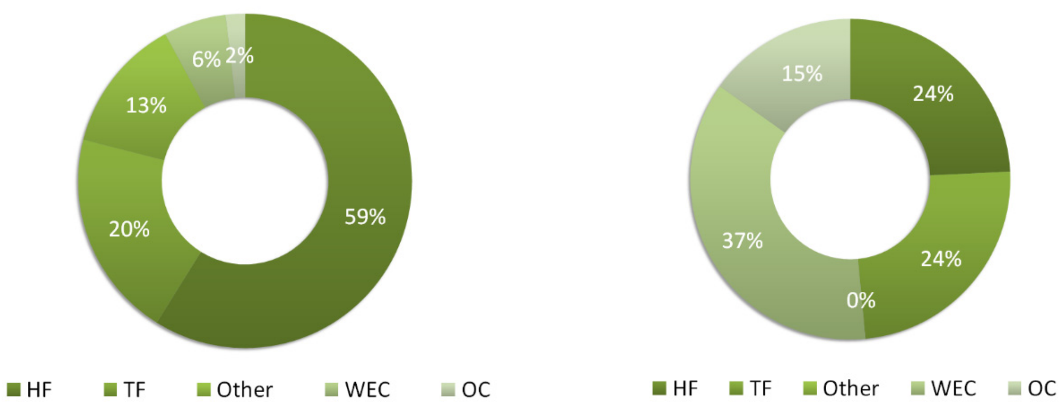

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Figure A3. Breakdown of causes of allisions on inland waterways in a) Austria and b) Serbia

Table A4. Breakdown of causes of collisions on inland waterways in Austria and Serbia

Cause of accident	Austria	Serbia
Human failure	77%	56%
Technical fault	9%	33%
Weather conditions	3%	-
Operational cause	2%	11%
Other	9%	-

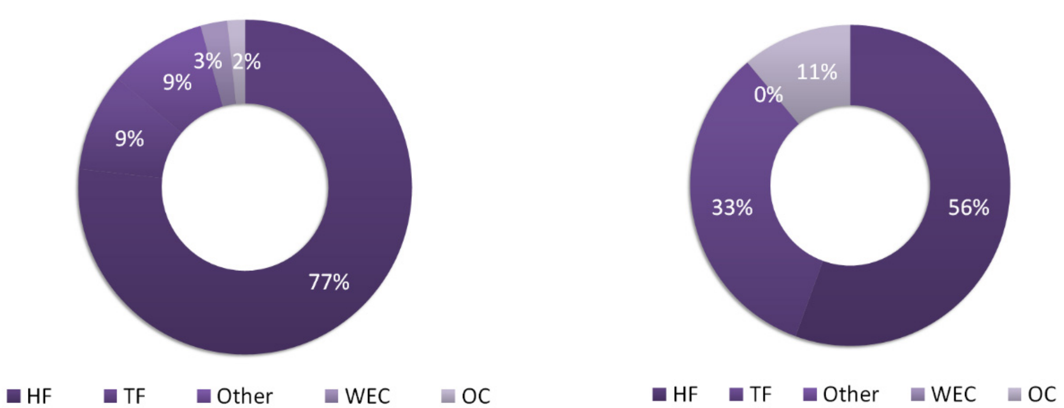

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Figure A4. Breakdown of causes of collisions on inland waterways in a) Austria and b) Serbia

Table A5. Breakdown of causes of groundings on inland waterways in Austria and Serbia

Cause of accident	Austria	Serbia
Human failure	67%	-
Technical fault	15%	-
Weather conditions	5%	-
Operational cause	5%	100%
Other	8%	-

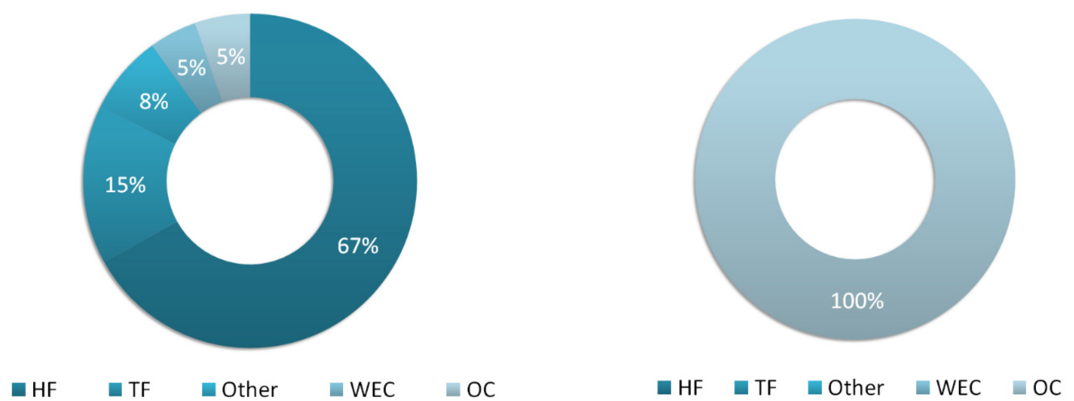

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Figure A5. Breakdown of causes of groundings on inland waterways in a) Austria and b) Serbia

Table A6. Breakdown of causes of HME damages on inland waterways in Austria and Serbia

Cause of accident	Austria	Serbia
Human failure	-	4%
Technical fault	15%	42%
Weather conditions	31%	15%
Operational cause	39%	39%
Other	15%	-

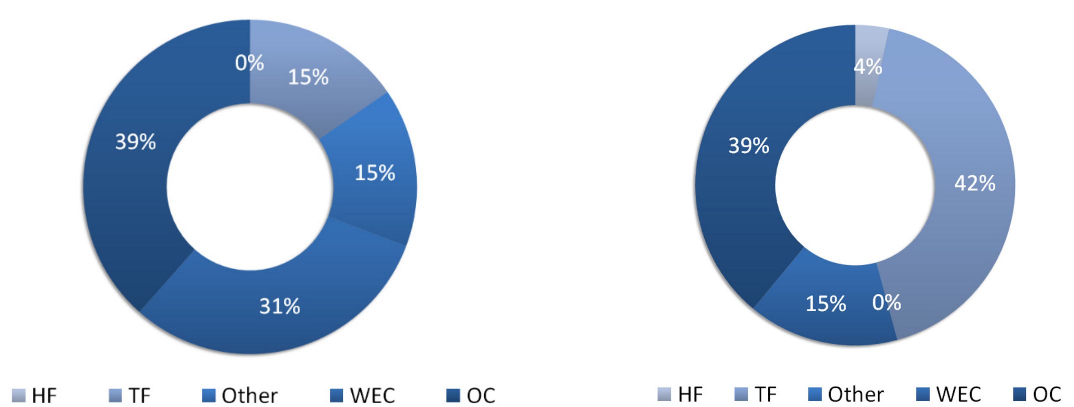

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Figure A6. Breakdown of causes of HME damages on inland waterways in a) Austria and b) Serbia