

The Use of Linguistic Variables and the FMEA Analysis in Risk Assessment in Inland Navigation

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ABSTRACT: The paper continues the study of the same authors, who previously proposed a method of risk assessment in inland navigation.

In the literature there is a gap in the research area of a risk management of transportation systems, especially: inland navigation. The authors carried out interdisciplinary research and presented the results related to the identification of risk factors present in the systems of inland navigation.

The paper presents inland navigation risk analysis, conducted using the linguistic variables and the FMEA method, taking into account technical, economic and social aspects. The aim of the article is to present a procedure for the assessment of risk in inland waterways transport, and carry out risk analysis for transport companies. In paper the proposal of behavior scenarios, methods of preventing and minimizing effects of pointed risks are shown.

1 INTRODUCTION

Researchers around the world are increasingly pointing the need for a broader view of risk analysis in transport systems. Focused research, primarily aimed at assessing the safety of transport, are not sufficient anymore. Decision-making processes involving transport managers, require a holistic view of the risks associated with operations. Therefore, it is necessary to redefine a risk analysis frameworks, focusing on issues such as how to understand and describe risk, and how to use risk analysis in decision making (Aven&Zio 2014).

Inland navigation is seen as one of the safest transport systems for freight. The number of recorded accidents and breakdowns in this branch of transport is considerably lower than the others, which positively influences the safety assessment of

transport operations. However, this does not mean that the required reliability of the process is ensured.

This transport system is sensitive to other distortions that must be taken into account when organizing the carriage of goods. The specificity of inland waterway transport makes the models of risk assessment dedicated to maritime transport, unsuitable for the decision makers of inland navigation. For this reason it is necessary to prepare a holistic range of risk assessments, taking into account the specificity of this transport sector.

The aim of this article is to propose a scope of risk analysis for inland navigation and carry out a risk assessment for cargo transportation on the Oder. Therefore, in the first place, the most important definitions regarding the discussed research issues were presented. On the basis of literature review authors made a proposal for a procedure for risk assessment, taking into account the specificity of

inland waterways transport. At the end it was presented the analysis of the risks for the handling of a freight on the Oder River.

2 LITERATURE REVIEW

There are many different views on what risk is and how to define it (Aven 2012; Hampel 2006), how to measure and describe it (Aven 2010, Kaplan 1997), and how to use risk analysis in decision making (Apostolakis 2004, Aven 2009). Overview of the basic definition of the concept of risk can be found, among others, in (Aven 2016). According to this review, the proposed definitions generally refer level of uncertainty to the probability of an adverse event and its consequences. Therefore, in the research on risk assessment in inland waterways transport described in this paper the authors also adopted this point of view.

The way one understands and describes risk strongly influences the way risk is analysed and hence it may have serious implications for risk management and decision-making (Aven 2016). The authors in their study relied on the guidelines of ISO 31000. According to it (PN-ISO 2010) the risk assessment is defined as a holistic process that involves three stages of the procedure: (1) risk identification, (2) risk analysis, and (3) evaluation of risk. These stages are included in the proposed model of risk assessment for the transport process. Risk analysis may use various quantitative and qualitative techniques, which are also described in the above standard. In the proposed model of risk assessment the FMEA technique was used. It is one of the risk analysis techniques recommended by international standards (Wang et al. 2012). Linguistic variables were used to estimate the value of each parameter used for the risk assessment (Burduk 2012).

In the spotlight of the research conducted by the authors is primarily operational risk. It decides if the internal organizational processes are sufficiently effective, including immune to interference, that the organization is able to pursue their economic goals (Zawiła-Niedźwiecki 2012). Therefore since the early 2000s, there has been an increased focus on what has been defined as operational risk (Smallman 2000, King 2001, Ward 2001). Such risks relate to negative deviations of performance due to how the company is operated, rather than the way it finances its business (King 2001, Jorion 2006). It has been argued that there is a great need for improvement in the quality (as regards tools and formal processes to manage operational risk) and scope (such as identification of what risks to focus on) of Operational Risk Management. Companies frequently deal with operational risk issues as they occur, and often following a crisis or catastrophic event (King 2001). ORM is particularly important also for the organization involved in inland waterways transport processes.

Conducted by the authors analysis of publications in the EBSCO database from the years 2006-2016 dedicated to the risk management, indicates that for a water transportation, an extensive research are exclusively carried out in the field of maritime

transport [including: (Bubbico et al. 2009, Brown et al. 2016, Yuebo & Xuefen 2014, Langard et al. 2015). It is mostly a result of risk management has become a major part of operating decisions for companies in the maritime transportation sector and thus an important research domain (National Research Council 2000).

Special mention in this case deserves an article (Goerlandt & Montewka 2015), in which the authors presented a detailed review of the literature devoted to the analysis of risk for maritime transport. Overview publications of the period 2011-2014 allowed the authors to define current problems undertaken in research on risk in maritime transport. These among the others are:

- Determine the ship collision probability and frequency in a sea area (Goerlandt & Kujala 2011, Jeong et al. 2012, Rasmussen et al. 2012, Suman et al. 2012, Weng et al. 2012).
- Determine the risk of oil spill and hazardous substances in a sea area (Montewka et al. 2011, Goerlandt et al. 2011).
- Quantify effect of risk reduction measures on accident risk in a waterway area (van Dorp & Merrick 2011).

Literature analysis indicates that the main consideration of researchers in risk assessment in inland navigation is focused on the assessment of transport safety. Examined aspects of the experiments are mainly concerned with such threats as: accident, collision, contact (striking any fixed or floating objects other than those included under collision or grounding), grounding (being aground or hitting/touching shore or sea bottom or underwater objects), fire, explosion (Li et al. 2012). The frequency of these threats in inland navigation is limited. It should be a subject of risk analysis, but the main aspects of risk assessment should focus on the reliability of the whole process. To make this possible, the scope of the assessment should be subordinated to the decision-making process of participants in the freight transport process. For this reason it is necessary to define the area of analysis for risk assessment in inland waterways transport, taking into account the holistic approach proposed in ISO 31000. This means that the identification of potential hazards is done by the way of a process analysis, which includes the analysis of used resources (elements at the input to the process), the course of the process and the expected final result.

3 INLAND NAVIGATION ON ODRA WATERWAY

Odra Waterway links significant economic areas of the country with Szczecin-Swinoujście seaports. Although the inland navigation in Poland, for many decades, focused on the Oder, these connection not fully uses its potential.

The Odra has a dominant role of the inland navigation in Poland. One of factors of that domination is the fact that the Oder is connected to the Western Europe waterways. In the structure of the country's transport, inland waterway transport has a negligible share. This share in recent years does not exceed 0.2%.

The transportation on the Odra River is dominated by bulk cargo such as coal, ore, aggregates and oversized constructions. On the Polish waterways the transport of containers is not conducted. This kind of loads are starting to dominate the waterways of Europe. All branches of transportation reduce the supply of bulk cargo. Increases the importance of the containers transport. The transportation role of the Odra Waterway in recent years is further marginalized. Currently, transport on the Odra focuses on the Lower Odra, relations Szczecin - Western Europe. The regular transport in relation Gliwice - Szczecin disappeared, as well as on the canalized Odra. This is the result of degradation of waterways in Poland.

In recent years political environment in Poland has changed. The Ministry Of Maritime Economy And Inland Navigation has been initiated. Since that, Poland has joined the ANG agreement, many legal plans has been created and the inland navigation society has grown a lot. Thus it may be expected, that in a next few years some strategic investments will be made, and the potential of Polish waterways will be filled.

The future development of inland navigation in Poland should focus on the role of the authorities in modeling hydrotechnical conditions but the risk connected to ship owners is also important.

4 PROCESS OF RISK ASSESSMENT IN INLAND WATERWAYS TRANSPORT

Requirements of the waterways of the international importance (class IV and V) meets only 5,9 % of length of waterways in Poland (214km). Other waterways can be classified as regional (class I, II and II) (GUS 2015). The greater part of the inland waterway fleet is decapitalized and requires restoration. Its age far exceeds the standard period of use and further exploitation is possible only thanks to the constant modernization. According to data from the Central Statistical Office (GUS 2015) majority of used pusher tugs (73%), almost half of the pushed barges (48.7%) and all self-propelled barge were produced in the period 1949-1979. The products carried in inland waterways transport on Oder Waterway are mostly coal, aggregates and oversized goods.

Due to the fact, to collisions in inland navigation rarely ends with serious damages of a ship or health of people, they are almost never reported (to avoid a fine). For this reason authors decided not to take into account statistics devoted to reported inland navigation collisions. Authors defined the risks associated with transportation of cargo by inland waterways based on research on risk assessment in maritime transport and on the basis of cooperation with the Office of Inland Navigation in Wrocław. Authors analyzed both external and internal factors that could disrupt the correct implementation of the process. Based on the conducted analysis, authors defined 7 basic risk groups:

- Ship collisions;

- Poor navigation conditions;
- Poor condition of infrastructure and loading equipment;
- Poor condition of the fleet;
- Insufficient financial of both: the ship owners and authorities;
- Shortage of qualified HR;
- Lack of interest in this branch of transport.

It should be noted that only 3 identified groups remain under the control of ship owners. Other risks stem from the environment in which transportation is implemented.

The occurrence of the event belong to the one of the groups mentioned above may cause disturbances of varying strength of impact on the realization of the objective. The objective defined for inland waterways transport process is to unproblematically accomplish carriage by planned cost, quality and logistics parameters. The aim of Risk Management is to prevent the possibilities of accruing undesirable events or limit the consequences of their occurrence. Due to the lack of the performed control by ship owners over the majority of the factors generating the risk, the main action taken by them will, however, reduce potential effects of the event. Therefore, the proper identification of possible adverse events and assessment of accompanying risks is particularly important. The results of the proceedings constitute may then the basis for the planning scenario, allowing a flexible response to the disruption.

The risk assessment is carried out in three stages: (1) hazard identification; (2) an estimate of the likelihood and impact of hazards; (3) the identification of hazards, the level of risk is unacceptable by policy makers. Detailed course of the procedures is shown in Fig. 1.

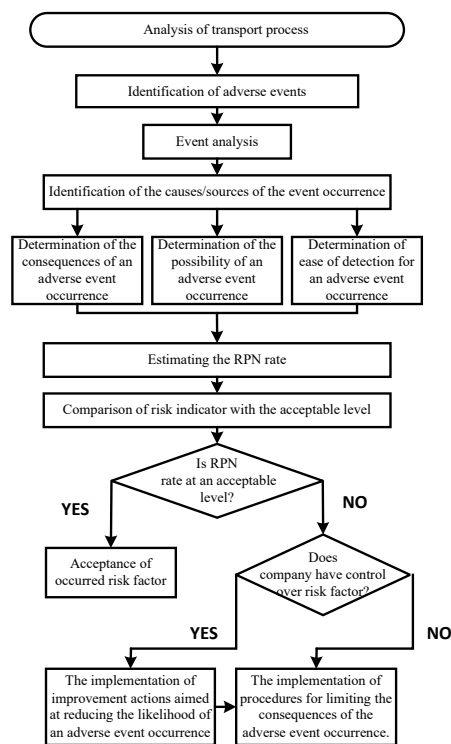


Figure 1. Risk assessment procedure

Due to the large diversity of the state of waterways in Poland, the presented risk assessment is illustrative.

5 ADVERSE EVENTS

On the basis of the 6 groups of risk, adverse events were defined. Table 1 shows those events.

Table 1. Adverse events in inland waterways transport

Ship collisions	
SC1	ship damaged due to the collision with other ship or tourists bout;
SC2	ship damaged and people wounded or killed due to the collision with other ship or tourists bout;
SC3	ship damaged due to the collision with infrastructure (bridge, river bank, lock gates, river bed);
SC4	ship damaged and people wounded or killed due to the collision with infrastructure (bridge, river bank, lock gates, river bed);
SC5	ship sinking due to the collision;
SC6	infrastructure damaged due to the collision;
SC7	oil spills due to the collision;
Poor navigation conditions	
NC1	closing of a navigation route due to too high depth of a waterway;
NC2	closing of a navigation route due to too low depth of a waterway;
NC3	closing of a navigation route due to ice cover on a waterway;
NC4	no possibility of full utilization of ships capacity due to too low depth of a waterway;
NC5	need of so-called wave support due to too low depth of a waterway;
Poor condition of infrastructure and loading equipment	
IC1	longer time of lockage;
IC2	closing of a lock;
IC3	longer time of loading;
IC4	no possibility of loading in a given place due to a lack of loading equipment;
IC5	no possibility of loading in a given place due to a condition of a loading equipment.
Poor condition of the fleet	
FC1	longer time of shipping;
FC2	no possibility of exploitation;
FC3	high costs needed service.
Insufficient financial of both: ship owners and authorities	
IF1	no possibility of ship exploitation;
IF2	no possibility of ship equipping in modern technology;
IF3	no possibility of infrastructure exploitation.
Shortage of qualified HR	
HR1	no possibility of sailing due to a lack of a crew;
HR2	greater probability of adverse events due to lack of experience of a crew members;
HR3	higher costs of crew.
Lack of interest in this branch of transport	
LI1	lack of shipping orders;
LI2	more inconvenience of inland waterway transportation development.

The risk index has been defined for all identified adverse events and expressed in accordance with the FMEA process, as a product of 3 parameters.

$$RPN_n = P_n \cdot E_n \cdot D_n \quad (1)$$

where:

RPN_n = risk index of appearance of n adverse event,

P_n = possibility of occurrence of n adverse event,

E_n = Effects of exposure on n adverse event,

D_n = Ease of detection of n adverse event.

Table 2. Possibility of occurrence level definition.

Possibility level	Estimated probability	Description of the probability level
1	High	The threat occurred in the last quarter
2-3	Medium	The threat occurred in the last year
4-5	Low	The threat occurred in the last two years or more

Table 3. Effects of exposure level definition.

Exposure level	Recovery time	Description of the effects of exposure
1	High	High financial losses
2-3	Medium	Financial losses, loss of reputation
4-5	Low	No financial loss, loss of confidence of clients

Table 4. Ease of detection level definition.

Detection level	Ease of detection	Description of the ease of detection
1	Low	Identification of a week or more
2-3	Medium	Identification within 2-5 days
4-5	High	Identification immediately after the occurrence

Table 5. Risk index evaluation.

Event	P_n	E_n	D_n	RPN_n
SC1	4	2	4	32
SC2	4	1	4	16
SC3	4	2	4	32
SC4	4	1	4	16
SC5	4	1	4	16
SC6	4	1	4	16
SC7	4	1	4	16
NC1	2	4	2	16
NC2	2	4	2	16
NC3	2	4	2	16
NC4	2	4	4	16
NC5	2	4	2	16
IC1	2	4	2	16
IC2	4	2	2	16
IC3	2	4	4	32
IC4	2	4	4	32
IC5	4	2	2	16
FC1	4	4	2	32
FC2	4	2	2	16
FC3	4	2	2	16
IF1	4	2	2	16
IF2	2	2	2	8
IF3	4	2	2	16
HR1	4	1	1	4
HR2	2	2	1	4
HR3	2	2	1	4
LI1	2	2	1	4
LI2	2	4	1	8

Based on a wide discussion of experts connected to inland navigation, present on gathering of Commission on Oder in Lower Silesian (functionary of administration of waterways, shipowners and other of interests group) the value of needed parameters were estimated with the use of the linguistic assessment.

The possibility of occurrence of the event was evaluated on a scale 1-5. This assessment was based on experts opinion. Effects of exposure for a company (a ship owner) were evaluated on a 1-5 scale, and ease of detection in a 1-5 scale. Detailed evaluation system is shown in Tables 2, 3 and 4.

Analysis of the results indicates that the ship owners particular attention should be focused on these events, which have the lowest RPN index. They are in fact events difficult to identify, which incidence is high, and at the same time are associated with significant financial consequences for the company. The acceptable level of risk determined on the basis of interviews with experts was set at $RPN > 16$. This is a product of the quarter of the scale adopted for the estimated three-pointers ($4 \times 4 \times 4$). With such a specific scale, only 5 of the 28 identified adverse events is indicator of risk at an acceptable level. The remaining 23 events requires further analysis. However, they all cannot be treated in the same way.

One can certainly distinguish among these two groups of threats that the proceedings should be varied. A first group of events, the events resulting from the environment to which the owners have no effect. In these cases, one can only take measures to reduce the consequences of this adverse events. The second group are the events on which the ship owner has a direct impact. In these cases it is necessary to take immediate preventive action. These events should also be subject to constant monitoring by management.

The adverse events, with unacceptable RPN, resulting from factors not associated with ship owners, from groups connected to navigation conditions (NC) and infrastructure conditions (IC) should be looked after by the authorities responsible for the maintenance of waterways. Groups of human resource (HR) and lack of interest (LI) could be influenced by the government, starting with affecting the education of children.

The other group of adverse events, with unacceptable RPN is connected with ship owners. Ship collisions (SC) can be prevented by training of a crew and mitigated by hull construction and also training. Problems with modern technology onboard mentioned in insufficient financial (IF) and condition of the fleet (FC) can be partly solved by looking for funds in European Projects.

All of the mentioned adverse events can be also divided into two groups, depending on the kind of actions that could be taken: i) adverse events that can be prevented, ii) adverse events that cannot be prevented, but the effects could be limited. The adverse events can also be divided into: j) preventing requires organizational changes, jj) preventing requires investments.

6 BEHAVIOR SCENARIOS

To describe above examples, one can use the behavioral scenario method. A few examples are presented further in the text.

To prevent the adverse event SC1 (ship damaged due to the collision with other ship or tourists boat), the captain or the shipowner can introduce safety procedures. This could be double checking the parameters of navigation, limiting the speed during maneuverings, the present of two crew members during high-risk maneuvering and so on.

The effects of the adverse event SC7 (oil spills due to the collision) can be limited by special onboard equipment, quick procedure to report an environmental accident or the crew training.

The adverse event NC2 (closing of a navigation route due to too low depth of a waterway) can be prevented by both organizational changes and investments. The low depth of a waterway is mostly caused by a drought and/or a lack of precipitation. It can be solved by a river cascading and construction of retention tanks. Both of this solution require legal actions – organizational changes and investments.

To prevent the adverse event HR1 (no possibility of sailing due to a lack of a crew), organizational changes are needed. A trained crew requires legal actions and time, so it is highly important to initiate proper actions in advance (proper training of students in high school lasts 4 years). It is lack of interests in inland navigation among young people, so specialized high schools are closing. Training more crew members would require advertising of sailors profession. The training can be conducted also on a ship. It does not take so much time, but that kind of training it does not give a solid background and professional knowledge, only practical skills.

7 CONCLUSIONS

Increasing competition in the freight market, the increase in congestion on the roads, make inland waterways transport companies increasingly interested in the techniques of risk analysis and management. Due to the lack of experience and good practices in this sector, the ship owners are looking for solutions model, which will be defined not only the risk assessment techniques, but also areas that should be analyzed.

In this paper, the authors presented inland navigation risk analysis, conducted using the linguistic variables and the FMEA method, taking into account technical, economic and social aspects. The proposed solution include the specific nature of inland navigation. Identification of the conditions of the process, existing limitations and analysis of actions taken in the next stages of the process, a source of information about potential adverse events and behavior scenarios were presented.

Next step in research on this topic will be to propose procedures to prevent the risk and minimize the scale of consequences for specific transportation.

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