navigation conditions; risk management; water transport

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NAVIGATION CONDITIONS AND THE RISK MANAGEMENT IN INLAND WATERWAY TRANSPORT ON THE MIDDLE DANUBE

Summary. Water transport could be the backbone of the future European combined transport system. The development of the cargo transport in river traffic depends directly on technical-exploitative characteristics of the network of inland waterways. Research of navigational abilities of inland waterways always comes before building ships or making a transport schedule. It is known that the size of the vessel's draught (*T*) is usually the limiting value in project tasks and it depend on the depth of the waterway or certain ports condition. This is the reason why navigation characteristics of rivers have to be determined as precise as possible, especially from the aspect of determination of the possible draught of vessels. Unfortunately, risks in water transport are perhaps an under researched area and consequently, this article outlines a rationale, why it is necessary to develop competence about risk in water transport. Climate changes require special attention and global monitoring. Current risk assessment methods for water transport just consider some dramatic events. We present a new method for the assessment of risk and vulnerability of water transport where river depth represents a crucial part. The analysis of water level changes in the middle Danube was done during the last sixty years.

STAN NAWIGACJI I ZARZĄDZANIE RYZYKIEM W ŚRÓDLĄDOWYM TRANSPORCIE WODNYM NA ŚRODKOWYM DUNAJU

Streszczenie. Transport wodny może być kręgosłupem przyszłości połączonego transportu europejskiego. Wynalezienie transportu towarowego w ruchu rzecznym zależy głównie od techniczno-eksploatacyjnego charakteru sieci śródlądowych dróg wodnych. Badanie nawigacyjnych możliwości śródlądowych dróg wodnych następuje zawsze przed budową statków lub przed wykonywaniem schematu transportu. Wiadomo, że rozmiar projektu statku (T) jest zwykle ograniczony wartością w projekcie i zależy on od głębokości drogi wodnej oraz od rzeczywistej kondycji portów. Jest to powodem tego, że charakterystyki nawigacyjne rzek muszą być określone tak precyzyjnie, jak to tylko możliwe, zwłaszcza w aspekcie tworzenia projektu statków. Niestety, ryzyko wodnego transportu stanowi przestrzeń prac badawczych i ten artykuł konsekwentnie zarysowuje racjonale uzasadnienie, dlaczego należy rozwijać znajomość ryzyka transportu wodnego. Zmiany klimatu wymagają specjalnej uwagi oraz globalnych obserwacji. Bieżące metody szacowania ryzyka dla transportu wodnego zawierają pewne dramatyczne elementy. My prezentujemy nową metodę szacowania ryzyka i słaby punkt transportu wodnego, w którym głębokość rzeki stanowi istotny element. Analizy zmian poziomu wody na środkowym Dunaju zostały przeprowadzone w ciągu ostatnich 60 lat.

1. INTRODUCTION

A logistic chain comprises all the entities and activities required to deliver final products to end customers – encompassing procurement, transportation, storage, conversation, packaging, etc. In recent years, due to increasing competition and tightening profit margins, companies have adopted a number of strategies to operate more efficiently and reduce transport and logistics costs. In general, lower cost and higher efficiencies are accomplished through a globalized logistic chain, higher capacity utilization, lower inventories, and just-in-time activities. However, there is always a trade-off between efficiency and some kind of vulnerabilities. Hence, there is a clear need for enterprises to manage logistic risks and reduce vulnerabilities so that they can respond and recover from interruptions promptly and efficiently [1]. According to this, we can conclude that risk management has become imperative for today's complex transport and logistics chain.

Inland water transport (IWT), as a crucial transport mode, could be the backbone of the future European intermodal transport chains, due to the fact that it can ship heavy as well as a large amount of commodities in combination with price advantages. Besides, inland waterways have still free shipment capacities. In Europe around 14,000 km of approximately 29,000 km of inland waterways are used for freight carrier. Also, IWT represents the only means of land transport which does not suffer congestion problems like that of rail or road within Europe. In general, inland waterways are underused, but inland navigation is not considered as a truly competitive alternative to other means of land transport. Estimates suggest that inland navigation would carry up to 425 million tons per year, including the accession countries, in the European inland waterway network, if the necessary action towards an integration of IWT into managed intermodal logistics chains were undertaken [15].

In order to develop and implement an advanced European concept to manage intermodal transport chains with IWT as a core transport mode, we need to develop effective risk management tool for proactive management of disruptive events in IWT. Unfortunately, risk in IWT are perhaps an under researched area and consequently, this article outlines a rationale for why it is necessary to develop competence about risk and risk management in IWT. Hence, in this research we examine inland waterways logistic chains with respect to risks and accordingly disruptive events which can occur at the nodes as well as at the links of the logistic chain. The aim is to develop framework for generating an extensive risk catalogue for all associated logistic chain members. Briefly, risk management framework proposed in this article consists of the following steps in sequence: risk identification, consequence analysis, risk estimation, risk mitigation, risk assessment, and risk monitoring. This article focuses on the risk identification and risk estimation steps. In addition to that, we estimate the risk of inappropriate river depth according to their probability of occurrence and their business impact.

2. COPING WITH RISK IN INLAND WATER TRANSPORT

There are many different definitions of risk in the literature, and we will not attempt to list them all. Some of those definitions assumed connections between risk and uncertainty, and their definition of risk is "the possibility of suffering harm or loss". From a more technical perspective, risk can be defined as the probability of an event multiplied by the (negative) consequences of the event. Kaplan [8] suggests that risk is defined by the answer to the three fundamental questions: (1) "What can go wrong?", (2) "How likely is that to happen?", and (3) "What are the consequences?". Also, risk can be defined as the potential negative impact that may arise from an adverse situation. In our context, IWT as part of intermodal logistic chain, the adverse situation is interruption to logistics operations. Interruption is defined as any event or situation that causes deviation from normal or planned logistic operations. Interruptions bring about adverse effects such as blockage of material and information flows, loss of ability to deliver the right quantity of the right product to the right place and at the right time, loss of cost efficiency, inability to meet quality requirements and process shutdown [1]. According to all above mentioned, we can conclude that risk represent exposure to circumstances with potentially damaging effects arising from an event that is not handled appropriately. So, risk is defined as product of probability of accidental event occurrence and its consequence, and risk management needs to address both sides of an accidental event, the sources leading up to it and the consequences arising from it [11].

$$\text{Risk (R)} = \text{Probability (P)} \times \text{Consequence (C)} \tag{1}$$

Generally, risks in supply chain can be “any risks for the information, material and product flows from original supplier to the delivery of the final product for the end user” [6]. In the inland waterway transport risks refer to the possibility and effect of a interruption of navigation between origin and destination port. ‘Risk sources’ are various variables which cannot be predicted with certainty and which impact on the inland waterway transport outcome variables. Risk consequences are the focused transport outcome variables and they are not subject of this analysis.

Risk management is the systematic approach to identifying, analyzing, and acting on risk. It incorporates all steps from the initial identification of risks to the final decision on risk-reducing actions and risk monitoring. The basic framework for risk management is illustrated in Figure 1 and follows a structure similar to [1].

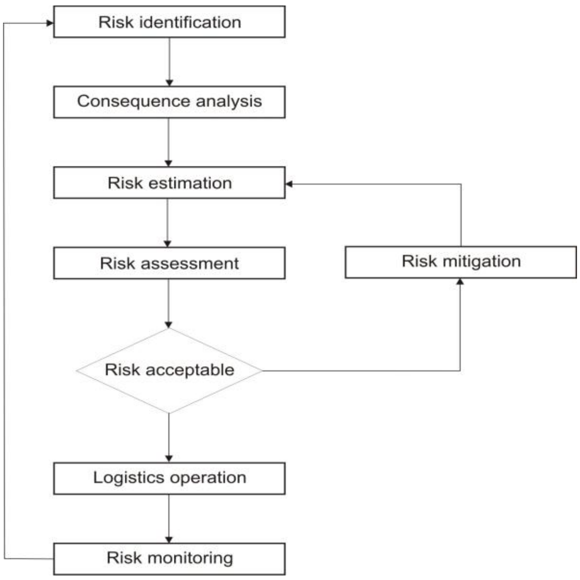

Fig. 1. Basic framework for risk management
Rys. 1. Podstawowa struktura zarządzania ryzykiem

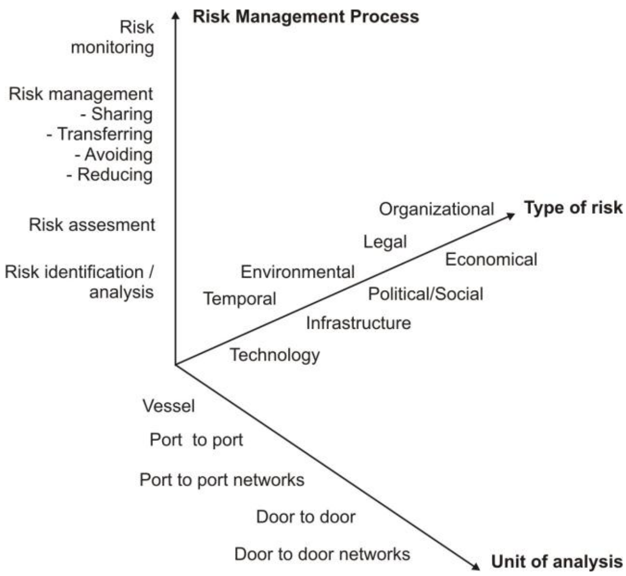

Fig. 2. The proposed framework for categorizing risk in IWT chains
Rys. 2. Proponowana struktura kategoryzacji ryzyka w łańcuchach IWT

The major steps are:

1. Risk identification: The first step is to recognize uncertainties and possible sources of interruption event. A wide array of methods exists for identifying sources of risk, e.g. comparative methods, fundamental methods, and logical diagram methods. Another way to identify potential risk factors is through historical analysis, which examines historical events to gain insight into potential future risk. Nevertheless, the identification or risk sources appear to be the least-mentioned risk technique, despite the fact that it is seen as the most important step.
2. Consequence analysis: Once the risks have been identified, their consequences have to be analyzed. The interruptions due to one particular risk or a combination can be simulated and consequences propagated through the business model to identify all likely effects.
3. Risk estimation: Risk is usually quantified in financial terms and/or ranked according to some pre-defined criteria. Two different dimensions need to be considered: its frequency/probability and its severity/consequences, taking into account the effects of mitigating actions and safeguards, if any.
4. Risk assessment: The risk management team decides whether the risk quantified in the previous step is acceptable based on experience, industry standards, benchmarks or business targets.

5. Risk mitigation: Mitigating actions and safeguards such as emergency procedures and redundancies have to be developed, based on both the business model and inputs from the risk management team or relevant personnel.
6. Risk monitoring: the business structure and operation do not remain stationary but change regularly, for example due to changes in suppliers, regulations, operating policies, products, etc.

The key research question in this paper was how to engineer this basic framework for risk management in IWT in general, given the different scope of different IWT chains. That is achieved by applying the framework for categorizing logistic risk and risk management used in [10], but adapted to an IWT setting, as the Figure 2 shows. This three-dimensional approach captures the different types of risks, the managerial context and the unit of analysis along three perpendicular axes.

In the next section we will use proposed framework for identification and estimation one kind of infrastructure risk – river depth as crucial navigation characteristics of river.

3. RIVER DEPTH AND OCCURRENCE OF ICE AS RISK FACTORS IN TRANSPORT PROCESS

The river depth risk is a product of the probability of the physical event occurrence as well as losses that include damage, loss of life and economic losses. Shallow water or restricted river depth can expose vessel owners and operators as well as the public to the possibility of vessel or cargo damage, injuries, environmental damage, etc. Complete risk modelling requires frequency estimation and consequence quantification. In the next section, based on proposed risk categorizing framework, through the appropriate case study, we will analyze frequency estimation of restricted river depth. Our case study covers only river depth risk, as one kind of infrastructure risks, and its identification in one part of IWT chain (unit of analysis is port to port), as is shown in the Figure 3.

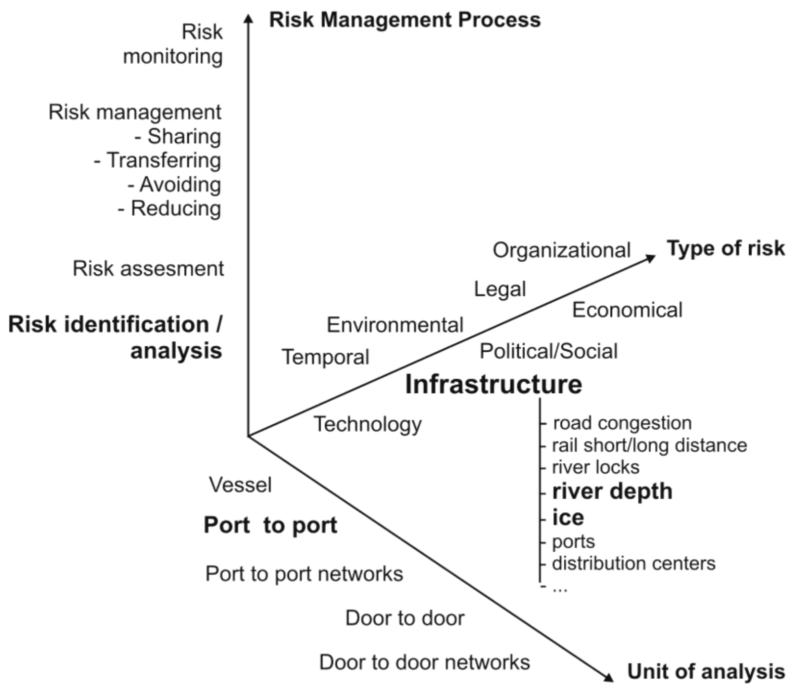

Fig. 3. Parts of the proposed framework for categorizing risk in IWT chains covered by the case study
Rys. 3. Części proponowanej struktury kategoryzacji ryzyka w łańcuchach IWT pokrytych studium przypadku

River depth is a variable in time and space and depends on multiple factors (climate area, basin characteristics, part of river flow, season). River depth is a variable factor with stochastic character, but it is possible to observe its seasonal disorders [5]. In land transport modes (rail and road) road infrastructure has standard dimensions, and climatic and weather conditions may cause interference or possible short delays. Unlike them, transport by inland waterways is not occurring under the same conditions, even on the same river. The dimensions of the waterway are variable in time and space, and depend on the water level of the river to the observed sector. In addition, a decrease in intensity and interruption of navigation can occur due to the presence of ice on the rivers. Ice on river is a phenomenon that occurs solely during winter months and causes interruption in navigation. In order for ice to form on a river, the air temperature needs to be low and lasting a period of time, so flowing water freezes. On all navigable rivers, there are sections with favourable and unfavourable navigational conditions.

The risk analysis first determines the critical sections, i.e. river sections with the most adverse navigational characteristics. According to the basic framework of risk management that is shown above (Fig. 1), the framework of analysis of risk caused by river depth is developed. The major steps are (Fig. 4):

1. Risk identification: The sources of interruption event are low river depth and ice occurrence. They are identified as risk factors through historical and empirical analysis. It is very important to emphasise that the technical and navigation characteristics of river sections must be determined before the risk identification.
2. Consequence analysis: The constraints and interruptions of navigation are the consequences of the identified risks.
3. Risk estimation: Two different dimensions are considered: risk probability and its consequence, taking into account the effects of mitigating actions.
4. Risk assessment: Making the mental map and decision making process: the risk quantified in the previous step is acceptable or not. A mental map is created by analyzing the changes over the period. In addition to the analysis of the entire period, it is necessary to compare results of analysis of sub periods with an overall average, thus providing another significant aspect of creating mental maps of the risks.
5. Risk mitigation: In observed problem, mitigation of the risk means change of the basic input - ship's draft, i.e. it's decreasing or choosing a ship with smaller draft than originally defined.
6. Planning and scheduling of navigation: Three levels of the navigation planning and scheduling are: short-term, mid-term and long-term.
7. Risk monitoring: Hydrologic, weather and navigation conditions and characteristic are variable it the time and space because the rivers are the part of nature. Their observation and analysis are the permanent tasks.

3.1. Case study: analysis of restricted river depths and ice occurrence on the Danube

Analysis of the water level oscillation on a critical section is used to plan the navigation because low navigation levels limit the size of draught of all vessels. It is known that the size of the vessel's draught (*T*) is usually the limiting value in project tasks and it is conditioned by the depth of the waterway or depths in certain ports. This is the reason why navigation characteristics of the Danube have to be determined as precise as possible, especially from the view point of determining in reality possible draught of vessels [7] [12].

Analysis of occurrence of unfavourable depths and ice on river was conducted with the goal of planning navigation period, i.e. to estimate the risk of navigation interruption due to ice. The research has been done for the period between 1 January 1951 and 31 December 2010. Duration of navigation period, i.e. determination of the risk of navigation interruption was based on analyses over many years and monitoring of the phenomenon trends. In order to follow the changes of a phenomenon over a period of time, the observed period was divided into three twenty-year sections (1951-1970, 1971-1990, 1991-2010). In that way, comparison of duration, i.e. probability of occurrence in the observed segments was conducted.

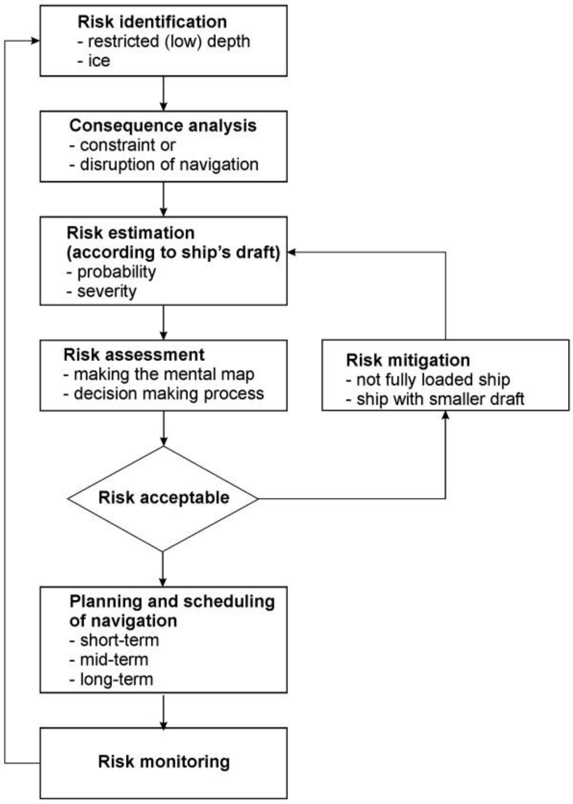

Fig. 4. The framework of analysis of risk caused by river depth and ice occurrence
Rys. 4. Struktura analiz ryzyka spowodowanego głębokością rzek oraz występowaniem lodu

3.1.1. *Results of analysis for water level station Novi Sad*

In this paper will analyze the oscillation of water level at the water level station in Novi Sad (Serbia). To get even more precise condition of waterway on this section of the Danube, during research it has been started from the assumption that the possible draught of vessels is T=250 cm when water level on station Novi Sad shows H=+80 cm (ENR – low navigation and regulation level). That means that, at that water level, in the zone of the water meter station, navigation is possible for vessels of up to 2.5 m draught. It has been confirmed in practice that very often, even at water level of +100 cm, there are moving shoals which can cause interference and navigation interruption. For that reason, probabilities of water level occurrence that are lower than the given values were determined [13] [14].

Basic navigation characteristics of importance for determining vessels' draughts in this period are:

- lowest water level determined in the observed period (1951-2010) is -48 cm;
- highest water level determined in the observed period (1951-2010) is +778 cm;
- average water level in the observed period (1951-2010) is $\overline{H} = 254$ cm with standard deviation from the average value $s = \pm 132$ cm, which gives an interval of possible values of navigation level H_{min}=+122 cm and H_{max}=+386 cm, or draughts of vessels, average $\overline{T} = 424$ cm, minimal T_{min}=292 cm and maximal T_{max}=556 cm.

Based on the analysis of the observed period (1951-2010) occurrence probability of the following water levels was determined:

- lower than +80 cm (ENR)
- lower than +100 cm (high occurrence of banks)
- higher than +700 cm (emerging flood defence)

Table 1 shows characteristic values of probability for the whole period and for parts. Table 2 shows mutual relationships among parameters from table 2, i.e. comparison and monitoring of parameter changes over the period. Comparison of results for sub periods in relation to the average for the entire period, and mutual comparison of results for sub periods (Table 2), was expressed by the percentage of increase or decrease of the probability value.

Table 1

Characteristic values of probability for the whole period and for parts

Probability	period			
	1951-1970 (t_1)	1971-1990 (t_2)	1991-2010 (t_3)	1951-2010 (Σt_i)
P(X<80)	0.0795	0.0921	0.0416	0.0711
P(X<100)	0.1177	0.1364	0.0879	0.1140
P(X>700)	0.0045	0.0005	0.0014	0.0021

Table 2

Comparison and monitoring of parameter changes over the period

Probability	P_i ratio (%)				
	$t_1/\Sigma t_i$	$t_2/\Sigma t_i$	$t_3/\Sigma t_i$	t_3/t_1	t_3/t_2
P(X<80)	+11.8	+29.6	-41.4	-47.6	-54.8
P(X<100)	+3.2	+19.7	-22.9	-25.3	-35.5
P(X>700)	+110.6	-74.5	-36.2	-69.7	+150.0

The period between 1951 and 2010 was analyzed (60 years) and the following parameters were monitored:

- hydrograph (figure 5)
- trends of maximum water level changes by months (figure 6)
- trends of average water level changes by months (figure 6)
- trends of minimum water level changes by months (figure 6)
- trends of changes of standard deviation from average water level by months (figure 6)

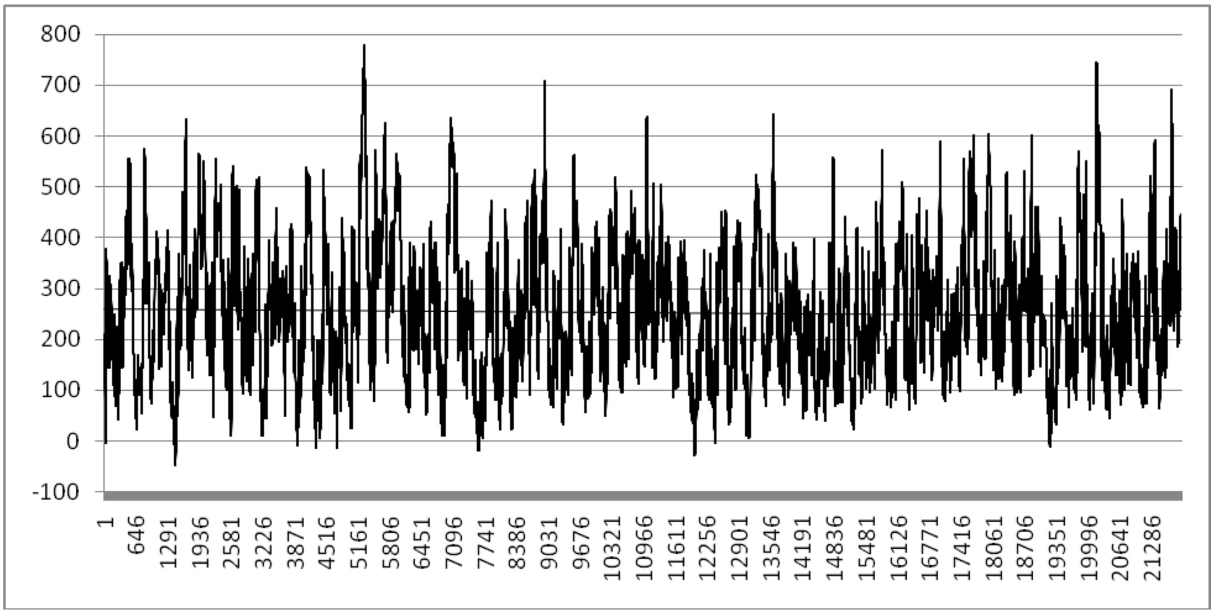

Fig. 5. Hydrograph
Rys. 5. Hydrograf

3.1.2. *Results of analysis of ice occurrence*

Analysis of occurrence of ice in the middle of the Danube was also conducted in the period of 1951-2010 and the following parameters were monitored:

- number of days with ice during winter (figure 7)
- probability of occurrence of days with ice (table 3)
- probability of occurrence of years with ice (table 4)

Table 3 shows characteristic values of probability for the whole period and for parts. Table 4 shows mutual relationships among parameters from table 3, i.e. comparison and monitoring of parameter changes over the period. Comparison of results for sub periods in relation to the average for the entire period, and mutual comparison of results for sub periods (Table 4), was expressed by the percentage of increase or decrease of the probability value.

Table 3

Characteristic values of probability for the whole period and for parts

Probability	period			
	1951-1970 (t_1)	1971-1990 (t_2)	1991-2010 (t_3)	1951-2010 (Σt_i)
P(per day)	0.0744	0.0282	0.0104	0.0377
P(per year)	0.900	0.750	0.450	0.700

Table 4

Comparison and monitoring of parameter changes over the period

Probability	P_i ratio (%)				
	$t_1/\Sigma t_i$	$t_2/\Sigma t_i$	$t_3/\Sigma t_i$	t_3/t_1	t_3/t_2
P(per day)	+97.5	-25.1	-72.4	-86.0	-63.1
P(per year)	+28.6	+7.1	-35.7	-50.0	-40.0

3.2. Discussion

Based on the presented data, the following rules can be defined:

- Average annual water levels tend to decrease, in other words, average depth of the waterway have a tendency to decrease.
- Moving of higher water levels to spring and autumn months.
- Significant decrease of average and extreme water levels (min and max) for May, June, July and August.
- Increase of average and extreme water levels (min and max) in March, April, November and December.
- Tendency of probability decrease of occurrence of water levels lower than +80 and +100 cm (significant decrease of occurrence of water levels lower than +80 cm).
- Standard deviation from average water level during the whole observed period, as well as for most months has the same value or has a tendency of slight decrease; except in August and September, where there is a tendency of increase.
- Significant decrease of the number of days with ice, as well as a significant decrease of probability of ice occurrence. The reason for this result is probably due to the fact that an increase of the average daily temperature in the second half of the twentieth century, in the world [4], Southern Europe [3] and Serbia [9].

- Reducing of discharge in the critical months is not too effective in prolonging the period, but on the decrease of unfavourable water levels anyway. On the other hand, reducing the probability of ice has resulted in the extension of the period of navigation, which allows proper planning and scheduling of navigation.

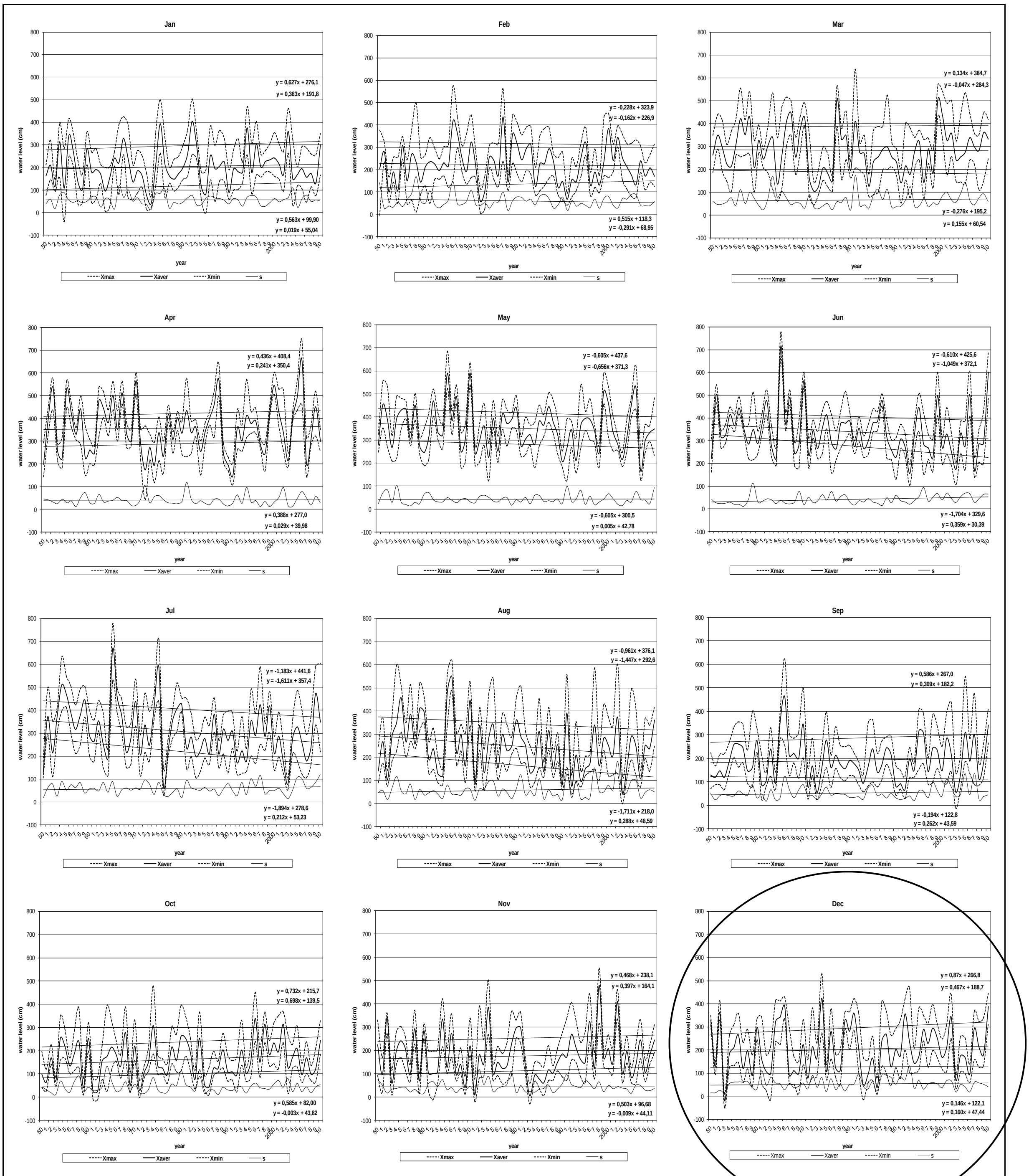

Fig. 6. Trends of changes of water level parameters by months
Rys. 6. Tendencje zmian parametrów poziomu wody w miesiącach

As an example, see Fig. 6a (next page)

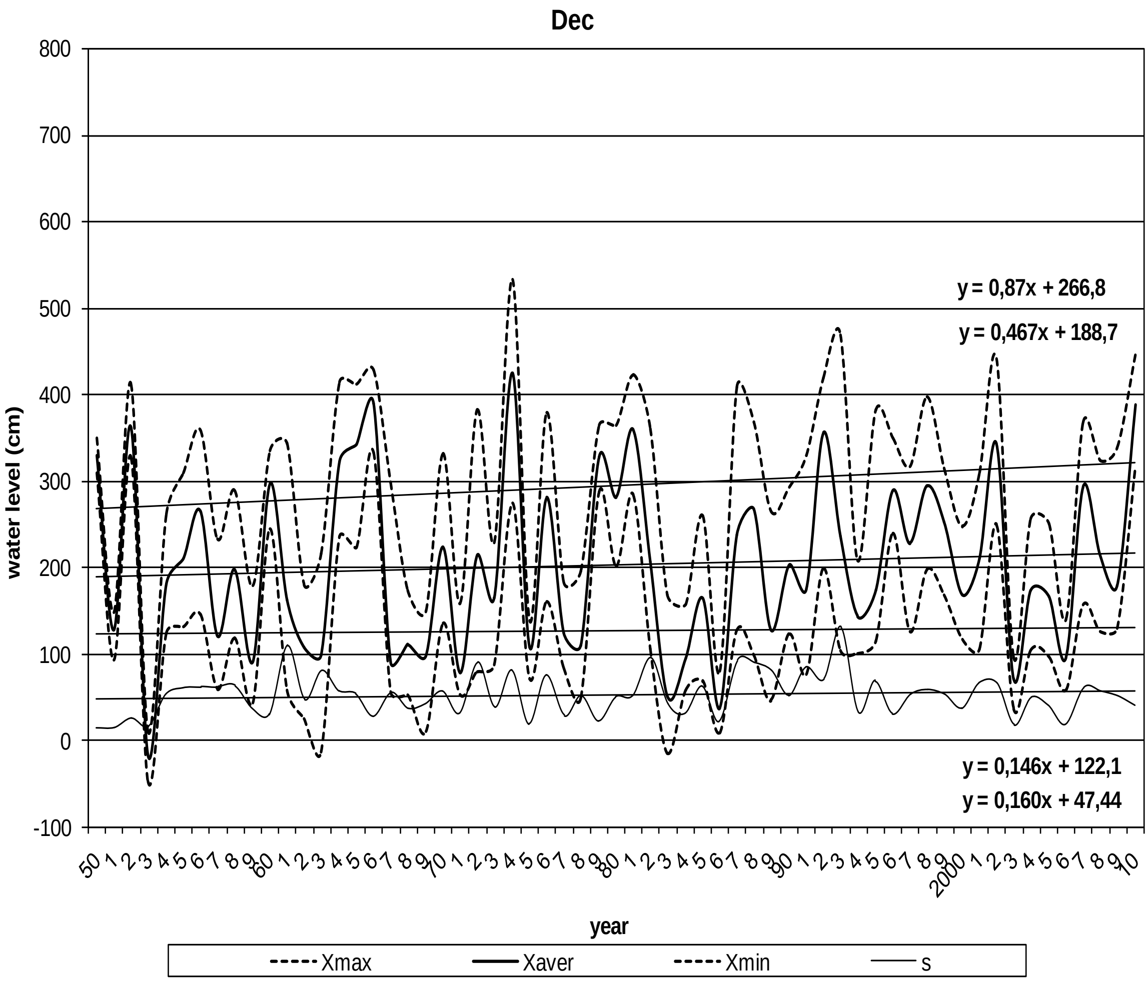

Fig. 6a. Trends of changes of water level parameters in December
Rys. 6a. Tendencje zmian parametrów poziomu wody w grudniu

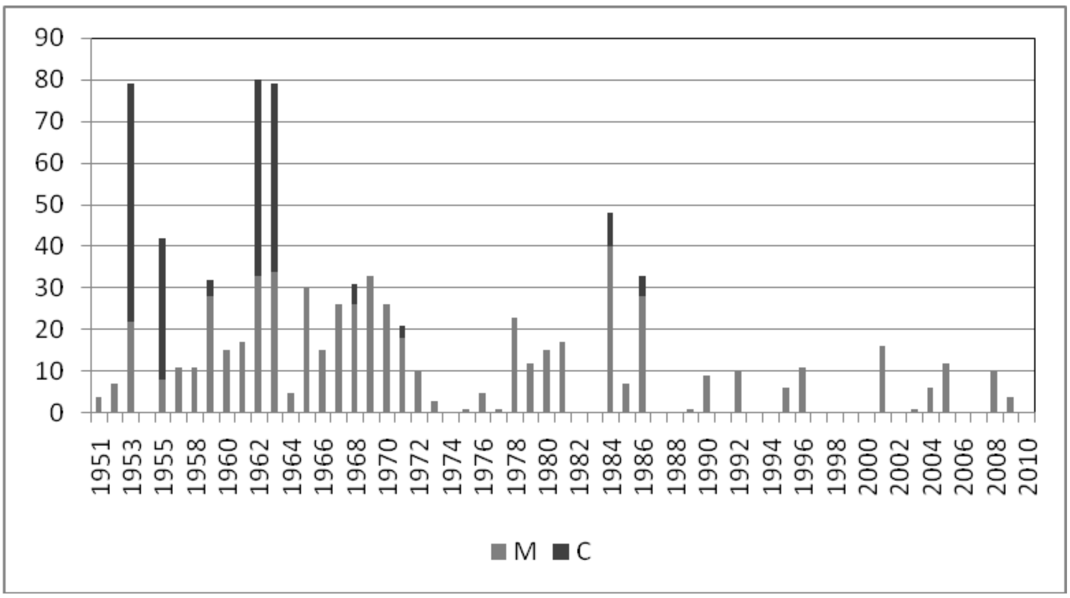

Fig. 7. Number of days with ice during winter (M – ice in movement, C – frozen surface)
Rys. 7. Liczba dni z lodem w czasie zimy (M – lód w ruchu, C – powierzchnia zamarznięta)

4. CONCLUSION

Risks are increasingly prevalent in complex transport and logistics chains. In addition to interruptions within each transport chain entity, the maze of interactions necessary for efficient logistic operations can also be the origin for interruptions. Currently, there are no systematic methods to identify logistic risks in complex logistic chains. This is especially the case in logistic chain where inland water transport presents one of the most crucial parts. Hence, in this paper, we propose a structured framework for characterizing risk in inland water transport chains. The first step of proposed risk management process is risk identification, and based on the proposed framework eight types of risks were identified in IWT chains: technology, infrastructure, political, economical, environmental, temporal, organizational, and legal. According to this, we analyze in detail river depth and ice occurrence as one of the infrastructure risks and crucial navigation characteristics of river.

The paper presented analysis of water level changes and occurrence of ice at one of the water meter stations in Serbia. The sequel to the paper requires further analysis of the given parameters at all water meter stations on the Danube, according to the suggested method. In that way, a complete picture of the influence of climate changes on the parameters that influence the navigation on the corridor VII will be obtained.

Decrease of average annual water levels, with the decrease of probability of water levels lower than +100 cm, i.e. +80 cm, points to the fact that the period of favourable water levels for vessels of up to 2.5 m draught has been extended. However, additional analyses, which would confirm the assumption that the probability of occurrence of unfavourable water levels, i.e. depths, has increased for vessels with draught of over 3.0 m are necessary. It should be also mentioned that, during the observed period, along the Danube over the 30 dams were built (especially on the upper Danube), so that the changes of water levels were mostly conditioned by the dam regimes.

On the other hand, decrease of number of days with ice, i.e. probability of occurrence of ice, dramatically decreased during the observed period. Even though, globally, the described phenomenon is negative, from navigation point of view it has a positive effect. Namely, fewer days with ice, i.e. low probability of occurrence of ice, extends navigation period, i.e. the period of possible exploitation of vessels.

Globally, climate changes increase risk and produce negative effects. From the aspect of navigation on mid-Danube, i.e. the part of Corridor VII that goes through Serbia, at the moment the share of positive effects is greater than the share of negative ones. Of course, constant and more detailed analyses are necessary, as well as connection between relevant climate and meteorological factors and discovery of mutual dependence and influence on hydrological phenomena.

The case study demonstrates the risk probability estimation of restricted river depth as a first part on risk assessment process. This work provides a good platform for further extensions of risk assessment and management process. In the next step we have to analyze possible consequence of restricted river depth and measures for managing and monitoring this kind of risk, and on that way we will have completed process of risk management.

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