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Analysis of Possible Draught Size of Container Vessels on the Lower Danube

Todor Bačkalić, Marinko Maslarić, Milosav Georgijević, Sanja Bojić

***Abstract*—**Presented article outlines a rationale, why it is necessary to develop competence about infrastructure risk in water transport. Climate changes are evident and require special attention and global monitoring. Current risk assessment methods for Inland waterway transport just consider some dramatic events. We present a new method for the assessment of risk and vulnerability of inland waterway transport where river depth represents a crucial part. The analysis of water level changes in the lower Danube was done for two significant periods (1965-1979 and 1998-2012).

***Keywords*—**Container ship, draught, probability, the Danube.

I. Introduction

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. Inland waterway 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 [1]. 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 [2]. According to the EU Danube Strategy Action Plan [3], one of the crucial priority areas is connecting the Danube Region trough mobility and multimodality improvement. The future transport policy in landlocked countries from the Danube Region has to be based on inland waterway transport (IWT). Thus, the FP 7 funded project "NEWS" works on developing and validating a novel container inland vessel accompanied by an appropriate, special-designed and integrated logistics system. 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. In addition, IWT represents the only means of land transport that 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 [4], [5]. The development of the container transport on inland waterways depends directly on technical-exploitative characteristics of the network of inland waterways. Research of navigational abilities of inland waterways is the basic step in transport planning. The size of the vessel's draught (T) is the limiting value in project tasks and it depends on the depth of the waterway. Navigation characteristics of rivers have to be determined as precise as possible, especially from the aspect of determination of the possible draught of vessels [7].

The basic problems in the transport planning and risk management in IWT are probabilities of a disturbance occurrence and duration of period with restriction in navigation. This paper approaches determination of possible size of draught of vessels in the lower section of the Danube as one of their most important technical characteristics. According to this, it can be concluded that risk management has become imperative for today's complex transport and logistics chain.

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 that 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 risk analysis, risk estimation, risk mitigation, risk evaluation, and risk monitoring. This paper shows results of the possible ship's draught analysis concerning NEWS and focuses on the risk identification and risk estimation. In addition to that, the risk of inappropriate river depth was estimated according to

T. Bačkalić, is with the University of Novi Sad Faculty of Technical Sciences, Novi Sad, Serbia (corresponding author, phone: +381-21-485-2481; fax: +381-21-450-644; e-mail: tosa@uns.ac.rs).
M. Maslarić, M. Georgijević, and S. Bojić are with the University of Novi Sad Faculty of Technical Sciences, Novi Sad, Serbia (e-mail: marinko@uns.ac.rs, georgije@uns.ac.rs, s_bojic@uns.ac.rs).

their probability of occurrence and duration.

II. Risk in Inland Waterway Transport

There are many different definitions of risk in the literature and some of them 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 [6] 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 presented 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.

In the inland waterway transport, risks refer to the possibility and effect of an 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 Fig. 1 and follows a structure similar to [7] and [8].

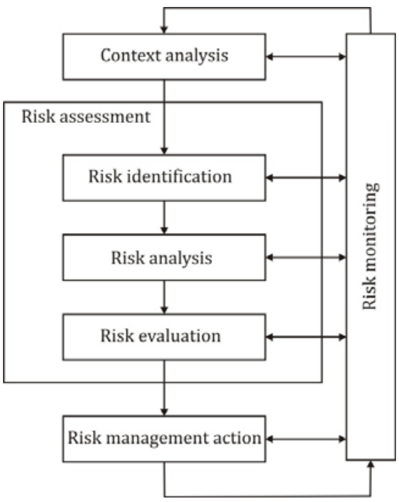

Fig. 1 Basic framework for risk management

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 [9], but adapted to an IWT setting, as the Fig. 2 shows. This three-dimensional approach captures the different types of risks, the managerial context and the unit of analysis along three perpendicular axes.

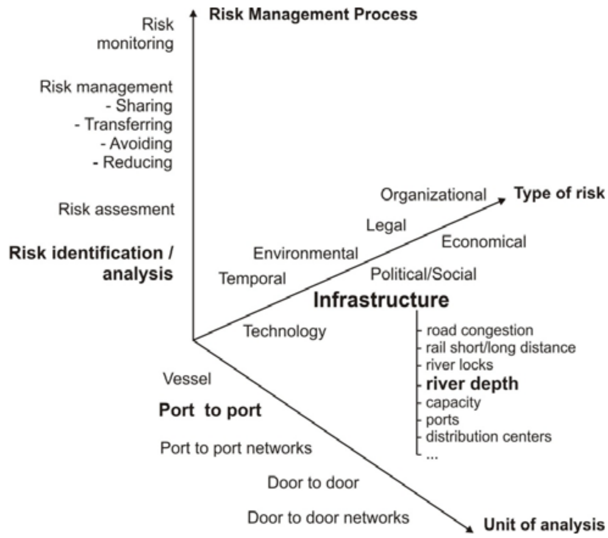

Fig. 2 Parts of the proposed framework for categorizing risk in IWT chains covered by the case study

In Section III, proposed framework is used for identification and estimation one kind of infrastructure risk – river depth as crucial navigation characteristics of river.

III. River Depth as Risk Factor in Inland Waterway 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. 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 [10]. In land transport modes, (rail and road) infrastructure has standard dimensions, and climatic and weather conditions may cause interference or possible short delays [11]. 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. On all navigable rivers, there are sections with favorable and unfavorable navigational conditions.

A. Basic Observations on the Lower Sections of the Danube

The lower section of the Danube from km 943 to its mouth is made up from three subsections: from km 943 (Sip) to km 493 (Giurgiu), from km 493 to km 170 (Braila) and from km 170 to its mouth (Sulina). According to the slope of the river bed and the regime of the waters the lower Danube is a typical lowland river and it is divided into lots of river branches with many islands, sandbars and shallow waters which have variable characters [12].

On the part of the lower Danube downstream from the mouth of the river Timok (km 845), there are a few shallow waters which can limit navigation considering vessel's draught. Those shallow waters are in positions: from km 767 to km 750, from km 633 to km 628, from km 568 to km 560 and from km 345 to km 315.

The lower Danube has a typical lowland river character, with a great amount of alluvium that forms sandbars and shallow waters. Navigation is regulated according to few water level measuring stations of which the most suitable is the one in Giurgiu. The norm of vessel's draught for this station is 250 cm when the water level is +44 cm. Characteristics of gauge station Giurgiu are: position km 493, left bank; +44 LNL; +707 HNL. Where LNL (Low Navigation and Regulation Level) is level determined with 94% accuracy based on observation of water flow during 40 years, and HNL (High Navigation Level) is level determined with 1% accuracy on observation of water flow during 40 years.

At km 307,5 from the Danube's main flow a big river branch separates and it is called Borcea. It is 104 km long and connects with the main flow of the Danube at km 248. At the Danube's km 345 this river branch meets with the Gura-Vai channel, which is at its 68-th km measuring from its downstream end. Gura-Vai channel is used for navigation on low water levels, together with Borcea river branch when it is not possible to navigate through shallow waters between km 345 and km 315.

Downstream from Braila to km 80 the Danube bed has big depths and is wide enough (between 350 m and 1200 m). From km 80 the river branches in two branches Kilia and Tulcea. Tulcea river branch from km 63 branches into Sulina and St. George's branches and the width of the waterways are significantly reduced.

IV. Analysis of Depths on the Lower Section of the Danube

River depths are analyzed using principle - each ship's draught corresponds to a certain depth or water level. The possible draught of vessels is T=250 cm when gauge station Giurgiu shows H=+44 (LNL) or $T\leq$250 cm when $H\leq$+44. The following draught values are analyzed: $T\leq$275 cm ($H\leq$+69); $T\leq$300 cm ($H\leq$+94); $T\leq$325 cm ($H\leq$+119); $T\leq$350 cm ($H\leq$+144). Research has been done for the two periods: the first from 1st January 1965 to 31st December 1979 and the second from 1st January 1998 to 31st December 2012.

The construction of the Iron Gate 1 dam was started in 1964, so the total period is divided into three intervals of approximately the same length (1965-1979, 1980-1997 and 1998-2012). The first and third intervals are selected for the analysis and comparison due to clarify the changes that have occurred.

A. Results for the First Period (from 1st January 1965 to 31st December 1979)

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

- lowest navigation level determined in the period 1965-1979 is -56;
- highest navigation level determined in the period 1965-1979 is +799
- Average navigation level in the period 1965-1979 is $\overline{H}$=293 cm with standard deviation from the average value s=±223 cm, which gives an interval of possible values of water level $\overline{H}$-s=+170 cm and $\overline{H}$+s=+516 cm, or draughts of vessels, average $\overline{T}$=543 cm, minimal $\overline{T}$-s=320 cm and maximal $\overline{T}$+s=766 cm.

Probabilities of occurrence of adopted navigation levels, possible draughts and expected number of days for navigation in a year according to adopted levels for gauge station Giurgiu in this period are shown in Table I. Results of additional analysis, which are necessary for evaluation of navigation characteristics of the lower Danube, are shown in Table II.

TABLE I
PROBABILITIES OF OCCURRENCE OF POSSIBLE DRAUGHTS OF VESSELS IN THE PERIOD 1965-1979

Probabilities of occurrence of possible draughts of vessels		Expected number of days for navigation
lower then adopted draught	higher than adopted draught	
P(T<250)=0,061	P($T\geq$250)=0,939	0,939 · 365=343
P(T<275)=0,087	P($T\geq$275)=0,913	0,913 · 365=333
P(T<300)=0,127	P($T\geq$300)=0,873	0,873 · 365=319
P(T<325)=0,178	P($T\geq$325)=0,822	0,822 · 365=300
P(T<350)=0,225	P($T\geq$350)=0,775	0,775 · 365=283

TABLE II
CHARACTERISTIC PARAMETERS OF ANALYSIS OF POSSIBLE DRAUGHTS OF VESSELS IN THE PERIOD 1965-1979

Draught	Characteristic parameter			
	number of years in which appeared depth which is lower than adopted	number of periods when possible draught was lower than adopted	average number of days in a year when possible draught was lower than adopted	average duration of the period when possible draught was lower than adopted (days)
T<250	7	12	47	28
T<275	12	17	40	26
T<300	13	25	53	24
T<325	14	26	69	32
T<350	15	35	82	35

B. Results for the Second Period (from 1st January 1998 to 31st December 2012)

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

- lowest navigation level determined in the period 1998-2012 is -142 cm;
- highest navigation level determined in the period 1998-2012 is +822 cm;
- Average navigation level in the period 1998-2012 is $\overline{H}$=222 cm with standard deviation from the average value s=±174 cm, which gives an interval of possible values of navigation level $\overline{H}$-s=+48 cm and $\overline{H}$+s=+396 cm, or

draughts of vessels, average $\overline{T}$=472 cm, minimal $\overline{T}$-s=298 cm and maximal $\overline{T}$+s=646 cm.

Probabilities of occurrence of adopted navigation levels, possible draughts and expected number of days for navigation in a year according to adopted levels for gauge station Giurgiu in this period are shown in Tables III and IV.

TABLE III
PROBABILITIES OF OCCURRENCE OF POSSIBLE DRAUGHTS OF VESSELS IN THE PERIOD 1998-2012

Probabilities of occurrence of possible draughts of vessels		Expected number of days for navigation
lower then adopted draught	higher than adopted draught	
P(T<250)=0,161	P(T≥250)=0,839	0,834 · 365=306
P(T<275)=0,211	P(T≥275)=0,789	0,786 · 365=288
P(T<300)=0,258	P(T≥300)=0,742	0,730 · 365=271
P(T<325)=0,320	P(T≥325)=0,680	0,676 · 365=248
P(T<350)=0,372	P(T≥350)=0,628	0,617 · 365=229

TABLE IV
CHARACTERISTIC PARAMETERS OF ANALYSIS OF POSSIBLE DRAUGHTS OF VESSELS IN THE PERIOD 1998-2012

Draught	Characteristic parameter			
	number of years in which appeared depth which is lower than adopted	number of periods when possible draught was lower than adopted	average number of days in a year when possible draught was lower than adopted	average duration of the period when possible draught was lower than adopted (days)
T<250	15	34	59	29
T<275	15	44	77	29
T<300	15	48	94	32
T<325	15	50	117	35
T<350	15	60	136	37

V. COMPARISON OF NAVIGATION CHARACTERISTICS ON THE LOWER DANUBE FOR PERIODS 1965-1979 AND 1998-2012

Besides the elementary and additional parameters, the probabilities of occurrence unfavorable navigational conditions by dates of the year were analyzed. Comparison of the observed periods was done for all values of vessel draught (Figs. 3-7). The expected start and end of the interval of possible occurrence of restricted navigation for certain ship's draught were determined for selected value of the occurrence probability (P≥0,2 and P≥0,4) (Tables V-VIII).

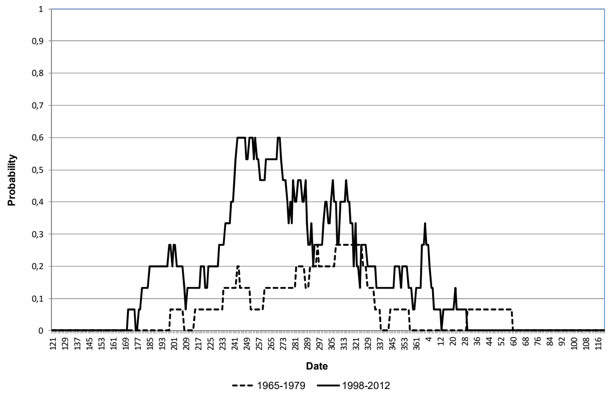

Fig. 3 Probabilities of occurrence of unfavorable navigational conditions (T<250) for both of observed periods (1 is 1st Jan, 365 is 31st Dec)

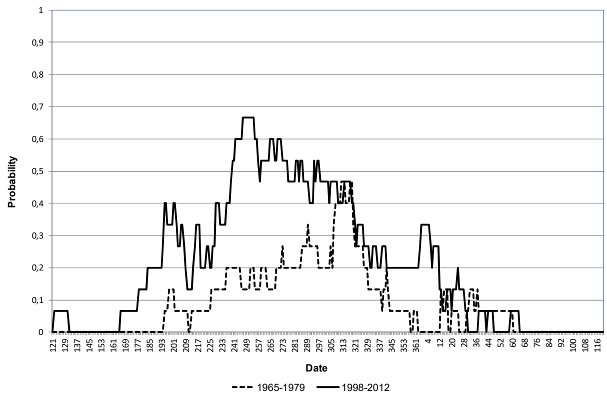

Fig. 4 Probabilities of occurrence of unfavorable navigational conditions (T<275) for both of observed periods (1 is 1st Jan, 365 is 31st Dec)

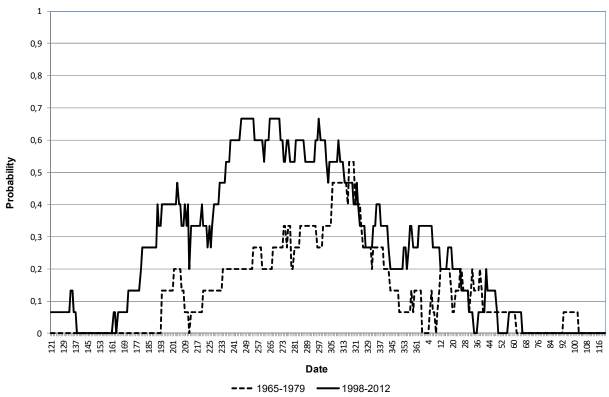

Fig. 5 Probabilities of occurrence of unfavorable navigational conditions (T<300) for both of observed periods (1 is 1st Jan, 365 is 31st Dec)

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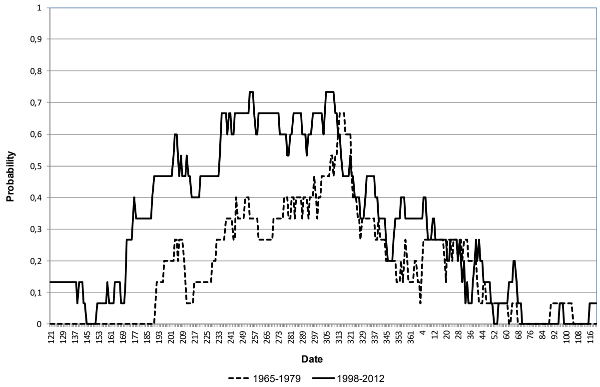

Fig. 6 Probabilities of occurrence of unfavorable navigational conditions (T<325) for both of observed periods (1 is 1st Jan, 365 is 31st Dec)

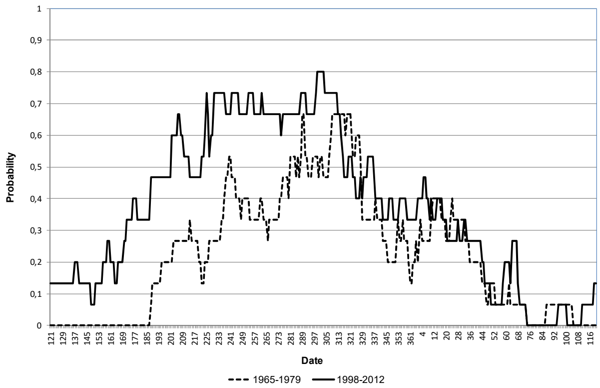

Fig. 7 Probabilities of occurrence of unfavorable navigational conditions (T<350) for both of observed periods (1 is 1st Jan, 365 is 31st Dec)

TABLE V
THE EXPECTED START, END AND DURATION OF THE INTERVAL OF POSSIBLE OCCURRENCE OF RESTRICTED NAVIGATION (P≥0,2) (1965-1979)

Draught	Expected					
	start-end	duration	start-end	duration	start-end	duration
T<250	9 Oct-24 Nov	47	-	-	-	-
T<275	26 Sep-25 Nov	61	-	-	-	-
T>300	22 Aug-9 Dec	110	-	-	-	-
T<325	4 Jan-9 Feb	37	16 Jul-29 Jul	14	18 Aug-17 Dec	122
T<350	14 Jul-12 Feb	214	-	-	-	-

TABLE VI
THE EXPECTED START, END AND DURATION OF THE INTERVAL OF POSSIBLE OCCURRENCE OF RESTRICTED NAVIGATION (P≥0,2) (1998-2012)

Draught	Expected			
	start-end	duration	start-end	duration
T<250	4 Jul-26 Jul	23	12 Aug-30 Nov	111
T<275	3 Jul-11 Jan	193	-	-
T>300	29 Jun-25 Jan	211	-	-
T<325	21 Jun-13 Feb	238	-	-
T<350	5 Jun-14 Feb	255	-	-

TABLE VII
THE EXPECTED START, END AND DURATION OF THE INTERVAL OF POSSIBLE OCCURRENCE OF RESTRICTED NAVIGATION (P≥0,4) (1965-1979)

Draught	Expected			
	start-end	duration	start-end	duration
T<250	-	-	-	-
T<275	4 Nov-15 Nov	12	-	-
T>300	2 Nov-20 Nov	19	-	-
T<325	7 Oct-21 Nov	46	-	-
T<350	23 Aug-11 Sep	21	1 Oct-24 Nov	55

TABLE VIII
THE EXPECTED START, END AND DURATION OF THE INTERVAL OF POSSIBLE OCCURRENCE OF RESTRICTED NAVIGATION (P≥0,4) (1998-2012)

Draught	Expected			
	start-end	duration	start-end	duration
T<250	27 Aug-15 Oct	50	28 Oct-13 Nov	17
T<275	17 Aug-16 Nov	92	-	-
T>300	13 Jul-25 Jul	13	16 Aug-19 Nov	96
T<325	8 Jul-5 Dec	151	-	-
T<350	7 Jul-8 Dec	155	1 Jan-17 Jan	17

With the goal of easier overview and analysis of navigational characteristics on the lower Danube, according to water levels at gauge station Giurgiu, in the Table IX comparison of most important characteristics has been presented.

TABLE IX
COMPARISON OF ANALYSIS RESULTS

Characteristic		Observed period	
		1965-1979	1998-2012
Lowest water level (cm)		- 56	- 142
Highest water level (cm)		+ 799	+ 822
Average water level and standard deviation (cm)		$\overline{H}$ =+293 (*s*=±223)	$\overline{H}$ =+222 (*s*=±174)
Average possible draught of vessels (cm)		$\overline{T}$ =543 ($\overline{T}$ -*s*=320 cm; $\overline{T}$ +*s*=766 cm)	$\overline{T}$ =472 ($\overline{T}$ -*s*=298 cm; $\overline{T}$ +*s*=646 cm)
Expected number of days for navigation according to the possible draught of vessels (days)	*T*≥250	343	306
	T≥275	333	288
	T≥300	319	271
	T≥325	300	248
	T≥350	283	229
Average number of days in a year when possible draught was lower than adopted (days)	*T*<250	47	59
	T<275	40	77
	T>300	53	94
	T<325	69	117
	T<350	82	136
Expected interval of occurrence of depths which are lower than adopted (*P*≥0,40) (days)	*T*<250	- -	27 Aug-15 Oct 28 Oct-13 Nov
	T<275	4 Nov-15 Nov -	17 Aug-16 Nov -
	T<300	2 Nov-20 Nov -	13 Jul-25 Jul 16 Aug-19 Nov
	T<325	7 Oct-21 Nov -	8 Jul-5 Dec -
	T<350	23 Aug-11 Sep 1 Oct-24 Nov	7 Jul-8 Dec 1 Jan-17 Jan

VI. Conclusion

By analyzing the values from the Table IX, it is obvious that in the period 1998-2012 there has been significant worsening of navigation conditions on the lower section of the Danube in comparison to the period 1965-1979. The fact that average daily water level in the second period is lower for 71 cm in comparison to the first period observed deserves special attention. In addition, analysis of number of periods when possible draught was lower than adopted, average number of days in a year when possible draught was lower than adopted and average duration of the period when possible draught was lower than adopted indicates their significant increase.

The trend of reduction in average annual water level, or flow, is evident in almost all the rivers in Central Europe. The results of the analysis lead to general conclusion on the conditions on the lower section of the Danube – determining the exact conditions demands more detailed analysis on every shallow that is stated which could be realized by careful measuring in the field. Only then based on such analysis the possible draught of container ships can be considered, which is, in great extent, limited.

Assuming the river depths as significant infrastructure risk factors in IWT, this analysis could be act then as the risk assessment stage. Output from this stage should lead to choosing the appropriate ways for making IWT more resilient regards to unfavorable navigational conditions, which means adequate decisions about container ship draught.

Acknowledgment

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Todor Bačkalić studied transport engineering at the University of Novi Sad (BSc, Dipl. Ing.) and University of Belgrade (MSc) and finished his doctoral thesis at the University of Novi Sad in 2001. His major field of interest is inland waterway transport.

He has worked at Department of Traffic Engineering of Faculty of Technical Sciences of University of Novi Sad since 1992.

Marinko Maslarić studied transport engineering at the University of Novi Sad (BSc Dipl. Ing., MSc) and finished his doctoral thesis at the University of Novi Sad in 2014. His major field of interest is supply chain management.

He has worked at Department of Traffic Engineering of Faculty of Technical Sciences of University of Novi Sad since 2004.

Milosav Georgijević studied mechanical engineering at the University of Novi Sad (BSc Dipl. Ing., MSc) and finished his doctoral thesis at the University of Novi Sad in 2014. His major field of interest is logistics.

He has worked at Department of Mechanical Engineering of Faculty of Technical Sciences of University of Novi Sad since 1979.

Sanja Bojić studied transport engineering at the University of Novi Sad (BSc Dipl. Ing., MSc) and finished her doctoral thesis at the University of Novi Sad in 2013. Her major field of interest is logistics.

She has worked at Department of Mechanical Engineering of Faculty of Technical Sciences of University of Novi Sad since 2006.