European Research Studies Journal
Volume XXV, Issue 1, 2022

pp. 917-937

Dimensions of Inland Ships in Relation to the Parameters of Waterways: The Case of Poland

Submitted 12/01/22, 1st revision 30/01/22, 2nd revision 22/02/22, accepted 25/03/22

Magdalena Kaup[1], Dorota Łozowicka[2], Wojciech Ślączka[3]

Abstract:

Purpose: *The article focuses on the analysis of the relation between the guaranteed parameters of the waterway and the dimensions of the inland ships. This article focuses on the consideration of how the change of the allowable ship draft affects the value of the efficiency index.*
Design/methodology/approach: *In this way, it was obtained that the transport efficiency is linearly dependent on the draft of the vessel, so if, despite the possibility of loading the vessel into allowable draft, it is impossible due to the parameters of the waterways, the overall transport efficiency may decrease to a greater extent. Changes in load capacity is another factor influencing the effectiveness of the use of inland ships in the conditions of their operation on Polish inland waterways.*
Findings: *The study analyzes the impact of this parameter on the shipowners decisions regarding investment in fleet maintenance.*
Practical implications: *The results of the research will help to achieve the means of water transport to the limited ones in the way of natural or technical parameters of the infrastructure of Polish waters.*
Originality value: *The results of the research complement the current knowledge on matching the parameters of specific inland vessels that provide services on a given route with the parameters of inland waterways, taking into account the dynamics of occurring negative changes on Polish waterways.*

Keywords: *Inland waterway transport, waterways parameters, transport efficiency, transport management.*

JEL classification: *L91, C100.*

Paper type: *Research article.*

Funding: *The publication was financed by a subsidy for the Faculty of Navigation of Maritime University of Szczecin for the maintenance and development of research potential.*

[1]*Maritime University of Szczecin, Faculty of Navigation, Szczecin, Poland, e-mail: m.kaup@am.szczecin.pl;*
[2]*Maritime University of Szczecin, Faculty of Navigation, Szczecin, Poland, e-mail: d.lozowicka@am.szczecin.pl;*
[3]*Maritime University of Szczecin, Faculty of Navigation, Szczecin, Poland, e-mail: w.slaczka@am.szczecin.pl;*

1. Introduction

The increasing number of vehicles used for the transport of passengers and freight causes more pollution and environmental degradation. Recognized as more environmentally friendly, carriage by inland waterways fits well in the concept of sustainable transport. One problem faced in Poland, however, is that waterways are not properly maintained. Inland fleet operators continue to cope with downgraded and insufficient infrastructure and unadjusted fleet of inland vessels. One of the essential issues is adapting the means of transport to the naturally or technically limited infrastructure parameters.

Creating appropriate transport infrastructure that fits technical and operational parameters of the existing fleet seems to be a priority, but raising waterways parameters requires large investment effort required for dredging fairways and reconstructing existing structures and facilities. Therefore, there is a need for matching specific vessels expected to provide services on a given route to the parameters of inland waterways, taking into account the dynamics of the adverse changes on these waterways. This problem was widely analyzed by Kaup and Łozowicka (Kaup, 2017; Kaup and Łozowicka, 2017).

The article aims to analyse the relationships between guaranteed waterway parameters and vessel dimensions. The technical parameters of inland vessels that navigate on specific waterways are essential for shipowners' operations. Provision of the proper difference between transit depth and vessel draft is an important aspect of navigational safety and efficiency of the operating vessels.

Problems related to the determination of main dimensions and technical-operational parameters of vessels addressed by scientific research mainly refer to restricted areas and port waters. The articles published by Panahi *et al.* (2018) and Radfar *et al.* (2017) describe the relationship between vessel parameters and those of port infrastructure including quays, breakwaters, turning basins, berthing structures and mooring facilities. Similar problems are dealt with in the publications (Takahashi *et al.*, 2026; Takahashi and Goto, 2007; Del Estado, 2007; Papanikolaou, 2014; Eyres and Bruce, 2012).

In the case of inland waterway vessels, the parameters are determined in reference to port infrastructure as well as inland waterways. Many publications are related to the characteristics of waterway networks in Europe and the world for example Prsic *et al.* (2011) and Sohngen *et al.* (2018). In the context of the studies discussed in this article the most relevant publications are those on inland waterways in Poland. The characteristics of inland waterways in Poland compared to Europe are presented in the publications of Polish scientists such as Urbanyi-Popiołek (2019), Stala-Szlugaj (2008), and Gołębiowski (2016).

The parameters of waterways are determined separately for each route, taking into account the morphology of river bed and technical and economic aspects of navigation. Examples of such analyses are presented by Prsic *et al.* (2011), Roldan *et al.* (2019), and Galor, (2017).

Climatic conditions are an essential factor affecting the navigability of inland waterways and thus, the efficiency of this mode of transport. The problem of increased operational costs caused by the changes in water level in rivers is raised in publications (Radojcic, 2010; Koetse and Rietveld, 2009; Skupień *et al.*, 2019). The increased frequency of low water levels may significantly raise the costs of inland waterway transport. The impact of climatic changes on total costs for different modes of transport has not been determined unequivocally so far, although it seems of vital importance for inland waterway shipping.

One of the areas of inland waterway transport studies is the assessment of its energy efficiency. The article published by Sun *et al.* (2013) examined the consumption of energy and greenhouse gas emissions in inland waterway navigation and compares these data to the performance of sea-going ships. It was found that the navigational environment could significantly affect the energy efficiency of inland river ships, which leads to varied transport costs.

Introduced a few years ago by the International Maritime Organization (IMO), the energy efficiency design indicator (EEDI), is an assessment tool that applies to sea-going ships. In Simic (2015) the EEDI was modified to adjust it better to self-propelled inland cargo vessels.

Since the share of inland ships in the global CO_2 emissions is only 0.6%, one might argue that the attempted reduction will not be significant. However, as shown in the publications (Hasan and Karim, 2017; 2020) from the commercial point of view the significance is very high, especially in poorly developed countries.

2. Research Methodology

In Poland today, all the standards related to the methodology and scope of measurements are set by the regulation of the Infrastructure Minister of 22 June 2010 on the measurement of inland vessels (The Convention on Tonnage Measurement of inland waterway vessels, 1966), based on the Convention on the measurement of inland navigation vessels, drawn up in 1966 in Geneva. The document includes all basic information, providing guidance for measurement. This allows for an unambiguous approach to Polish ships as suitable for recognition of their measurement certificates with analogous documents obtained by units in other states signing the Convention.

The first part of the document presents the purpose and measurement methods of vessels, divided by type and use. It is noted at the very beginning that the measurement consists in determining the volume of water displaced by a vessel as a function of its draft

Standards for marks and draft graduations, their number and location on a vessel's hull were also strictly specified. Properly placed signs on the vessel hull are essential for the shipowner and the person performing the measurement. Vessel measurement is aimed to determine its maximum displacement and possible displacement values corresponding to specific waterplanes. For cargo vessels, this also enables determining the cargo weight by the known draft level. For vessels not intended for the carriage of goods, measurement is limited to the determination of minimum and maximum displacement.

The results of the measurement made according to the procedure contained in (The Convention on Tonnage Measurement of inland waterway vessels, 1966) are used for calculating vessel deadweight. Information on the mean volume per one centimetre of draft of a measurement segment is assumed as increment of deadweight on each centimetre of draft in a given measurement segment. Zero load is always adopted for the draft of a light vessel, then, for maximum draft, the vessel deadweight is calculated, corresponding to the quantity of cargo the vessel is able to carry. For cargo vessels, properly placed draft graduation, and correctly calculated tables of deadweight are vital for the correct settlements of the ship in port or correct information on the quantity of cargo in the holds. The article attempts to answer the following research questions:

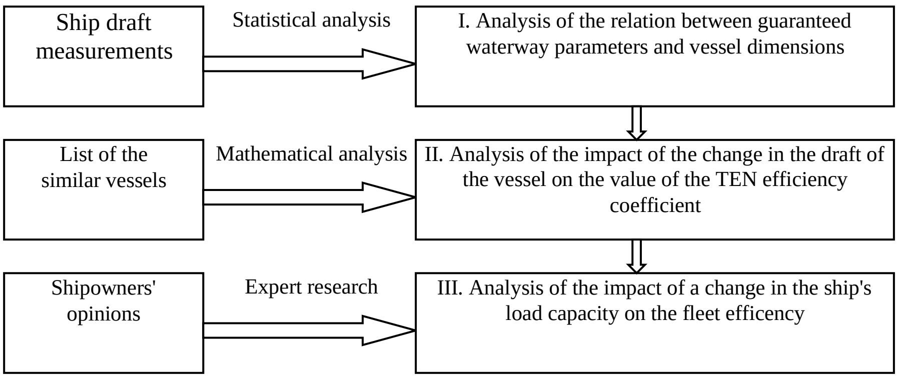
- *What is the impact of inland waterway parameters on the transport efficiency of an inland vessel?*
- *What percentage of inland vessels does not use full capacity due to low parameters of inland waterways?*
- *How do the structure and parameters of port and waterway infrastructure and the technical-operational parameters of the fleet affect the efficiency of inland waterway transport operations?*

In order to gather the necessary data, these authors used the results of inland vessels measurements conducted according to the described methodology.

The measurements brought information on allowable draft values, then enabled analysing the relationship between the values of transit depths and vessel drafts. This, in turn, made it possible to determine the impact of specific parameters of inland vessels on transport efficiency.

Currently, the development of inland waterway transport is focused on raising the quality of service and customized transport options. The exact range and scale of changes is different if we look into the full spectrum of ship operators. The reasons for large differences may be due to existing technical, technological, financial, or organisational and legal restrictions. Considering the possible decisions made by shipowners, we cannot regard them as a single uniform group. Each company differs significantly from each other in terms of the budget, management structure and the number of vessels in operation. The main factors for each shipowner operations include the position in the market, the manner of acquiring new customers and cooperation with the existing ones. Taking the above into account, the research was carried out in accordance with the scheme presented in Figure 1.

Figure 1. *Research methodology schema.*



Source: *Own study.*

In order to collect the necessary information and data for analyzes, a review of the scientific literature on the operation of inland vessels was performed. Based on the data obtained from entities fulfilling the supervision of inland navigation in Poland, a statistical analysis was carried out, which allowed to determine the relation between guaranteed waterway parameters and vessel dimensions and indicated bottlenecks in shipping. The aim of the statistical survey was to find out the distribution of the population in terms of the selected feature, i.e., allowable draft of vessels. All work related to the implementation of the statistical survey was divided into the following stages:

- Preparation of the study, including selection of ships for analysis, determination of parameters and scope of the study, selection of a unit with an appropriate source of data necessary for the study. The measurements used in the work were carried out in 2017-2018. The number of measured vessels is not large, which results from the local nature of the research. The data was obtained from the Inland Navigation Office in Szczecin. About 50-60 measurements are carried out by it throughout the year. There are only 3 offices of this type in Poland with separate delegations.
- Statistical observation, the purpose of which was to collect data on allowable draft of vessels. Due to the fact that the data were obtained from the institution that collected them for other reasons, they constitute secondary statistical material.

- Development of statistical material consisting in grouping data into a statistical series. In the research, a statistical series was created on the basis of a measurable step feature defining its variants in intervals.
- Statistical inference was made in the form of a visual presentation of statistical data (histogram).

The impact of some parameters of inland vessels was assessed to determine the measurable indicator of the effectiveness of inland water transport functioning. It was assumed that the effectiveness of inland water transport is the quotient of the useful effects and the expenditure directly incurred in this period, according to (Kaup, 2017; Kaup *et al.,* 2017). The main goal of the shipowner is to look for directions to achieve the highest possible profits with the lowest possible investment outlays.

However, it is difficult to forecast the costs and profits of inland vessels in the short and long term. Thus, a decision-making situation appears in which the shipowner is forced to decide on the organization of transport and further investments in the fleet. Completeness and reliability of information play an important role in this process. When selecting options, the possible actions are compared and assessed on the basis of defined indicators from among a number of alternatives. They can be described by means of mathematical relations in a certain permissible solution space between independent variables and their constraints.

The article focuses on the Transport Efficiency Number (TEN) because it takes into account the variable draft due to operating conditions. This draft depends on the length of the route, the type of cargo or the type of fleet. It is important to determine the transit depth on a given waterway for a specific time period.

Analysis of the impact of a change in the ship's load capacity on the fleet efficency was made on the basis of discussions with shipowners. Expert interviews were carried out, which, due to the small size of the research sample and different experiences of shipowners, took the form of non-standardized interviews. The questions concerned not only facts or attitudes towards them, but also attempts to explain and predict them. It was assumed that the shipowners are characterized by extensive professional achievements and professional knowledge on the subject.

Therefore, they can present interesting analytical propositions. Thanks to their expertise and good practice, they created valuable opinions used in the research. The study covered shipowners' enterprises divided into those with less than 20 ships and more than 20 ships in their fleet. The results of the analyzes made it possible to present the scale of the problem and directed the research to determine the factors limiting the activity of inland shipping companies.

3. Inland Waterway Parameters and Allowable Draft of Vessels

Despite a relatively dense inland waterway network, Poland ranks significantly lower than western countries in terms of appropriate management and use of inland waterways. These fall under one of five classes: Ia, Ib, II and III for regional waterways; and IV, Va and Vb for international waterways. The total length of inland waterway routes in Poland is 3 655 km, but only 5.9% (214 km) are waterways of class IV and V. Other inland networks consist of regional waterways of class I, II and III. Freight transport takes place mainly on local class III waterways (The Council of Minister, „On the Classification of Inland Waterways," The Council of Minister, Warszawa, 2002).

Restrictions caused by insufficient inland waterway parameters affect the parameters of inland vessels. For instance, vessels approved for operation on class III waterways may have the following parameters (Kaup *et al.,* 2017):

for self-propelled vessels and barges: L = 67-77 m, B = 8.2-9 m, T = 1.6 - 2 m.
for pushed barges: L=118-132 m, B = 8.2-9 m, T = 1.6 - 2 m.
where L, B, T denote principal dimensions of vessels (L - length overall, B- breadth, T- draft).

A transit depth of a navigable route of a specific waterway section directly affects allowable draft. An analysis of some water levels and transit depths observed in areas covered by the River Information Service (RIS) shows that monitored parameters are often much below the expected or even safe levels (Figure 2).

Such conditions critically influence transport possibilities in a given period. Inland vessel owners often have to dynamically respond by adjusting parameters of specific vessels intended to provide carriage services along a specific route. To complete a contract for transport of specific freight, operators have to use two barges of lower draft instead of one barge drawing deeper. Therefore, from shipowner's viewpoint, technical parameters of its vessels, including draft, are an extremely important aspect of the operations.

4. Analysis of Inland Vessel Draft Measurements

For cargo vessels, apart from measurement of principal hull dimensions, minimum freeboard, airdraft, the requirements include complete deadweight calculations for the whole draft scale. For vessels that do not carry freight, the requirements for a measurement certificate to be issued are substantially simplified. Besides basic ship dimensions, the procedure for calculating the maximum deadweight is aimed to determine displacement of a light vessel and maximum loaded vessel, or in one of these conditions (Kaup *et al.,* 2017).

Figure 2. *Daily report on navigational conditions and transit depths in the RIS centre monitored area of 16.07.2021.*

	name of the water station	river's name	symbol of water level status	the current state of the water level	date of measurement	trend of changing water level	water level warning level exceeded	water level alarm state exceeded
152140010	BIELINEK	Odra (1)	▼	206	pt 2018-08-31 10:50	↑	480	550
152140020	GOZDOWICE	Odra (1)	▼	205	pt 2018-08-31 10:50	→←	440	500
152140060	KOSTRZYN NAD ODRĄ	Odra (1)	▼	121	pt 2018-08-31 10:50	→←	420	470
153140010	ŚWINOUJŚCIE	Bałtyk (0)		527	pt 2018-08-31 10:50	→←	560	580
153140020	WIDUCHOWA	Odra (1)	▼	542	pt 2018-08-31 10:50	↓	630	650
153140030	GRYFINO	Odra (1)	▼	541	pt 2018-08-31 10:50	↓	570	600
153140040	TRZEBIEŻ	Zalew Szczeciński (319)		537	pt 2018-08-31 10:50	→←	540	560
153140050	SZCZECIN MOST DŁUGI	Odra (1)		540	pt 2018-08-31 10:50	→←	570	600
153140060	WOLIN	Cieśnina Dziwna (35)		536	pt 2018-08-31 10:50	↓	560	580
153140070	DZIWNÓW	Bałtyk (0)		531	pt 2018-08-31 10:50	↓	560	580

Source: *Own study.*

In the case of a cargo ship, where the basic measured hull dimensions include length, breadth, draft, minimum freeboard and airdraft, the calculations of deadweight capacity will cover the complete scale of draft. According to recommended survey requirements, the measurement includes light vessel draft as per all graduation on the vessel hull. The verification of the correct position of the scale is based on the freeboard determined by the classification society and its height above the water surface. This measurement is carried out by means of a sounding instrument that eliminates wave effect, ensuring maximum accuracy of readouts.

According to Ship measurement certificate (2021), the measurement includes the part of the ship between the basic waterlines corresponding to the light and maximum load ship. Pursuant to the technical documentation provided by the shipowner, the tested section of the ship is divided into measuring segments. Depending on the hull shape, the segment heights are so chosen that the volume of each segment can be represented as accurately as possible, reflecting all the irregularities of the theoretical lines, notches or hawsepipes.

Using the information available on ship's dimensions at particular heights, the areas of each waterplane are calculated. The determined quantities are used to calculate the volume of each of the measuring segments. The result of the volume of a section divided by its thickness represents the displacement per each centimetre of draft of the given section. Given below is an example table (Table 1) of the cargo vessel displacement calculation.

Table 1. *Displacement calculations for a cargo ship.*

Measuring segments limited by waterplanes	**1-2**	**2-3**	**3-4**	**4-5**	**5-6**
1. Height of measuring segments	0,465	0,500	0,500	0,500	0,500
2. Areas of waterplanes that limit the measuring segments	974,037	980,481	984,429	986,900	988,337
	980,481	984,429	986,900	988,337	989,265
3. Sum of waterplane section areas	1954,51	1964,91	1971,32	1975,23	1977,60
4. Half the sum of waterplane section areas	977,259	982,455	985,664	987,618	988,801
5. The volume of the measuring segment	454,425	491,227	492,832	493,809	494,400
6.Draft	1,00	1,50	2,00	2,50	3,00
7. Mean volume per 1 cm of the measuring segment draft	9,77259	9,82455	9,8664	9,87618	9,88801
8. Hull volume at draft	454,425	945,653	1438,485	1932,294	2426,695

Source: *Own study.*

The results obtained above provide a basis for the calculation of the vessel's deadweight capacity. Calculation result in item 7 (Table 1) is taken as the increment of the deadweight capacity from each centimetre of ship's draft in the given measuring segment. For the light ship's draft, zero load is always assumed, then the ship's deadweight capacity to the maximum draft level is calculated, corresponding to the quantity of cargo that a ship can carry.

In the case of cargo ships, properly fixed draft graduation, and correctly calculated deadweight tables are of utmost importance for such purposes as harbour fees and correct information on the quantity of customer's cargo that can be carried on one ship.

Based on data obtained from vessel measurements made by the Technical Inspection Commission (TKI) in Szczecin, the draft of allowable ships was examined to determine the level of inefficient use of vessel deadweight capacity, due to insufficient parameters of waterways in relation to transport efficiency. The data were collected during measurements of vessels by the TKI in 2019-2020 and include 80 measurements of maximum draft, light vessel draft and deadweight.

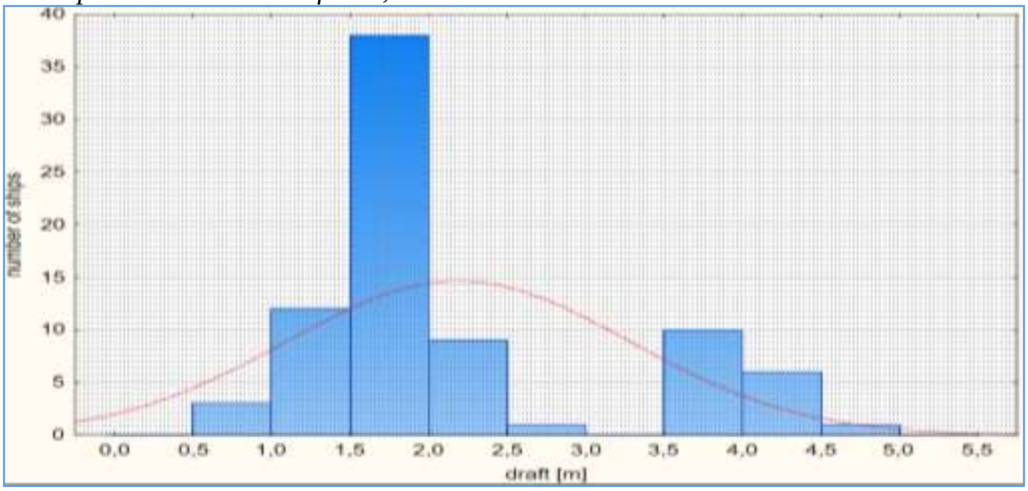
Table 2 presents allowable draft, grouped in interval series, belonging to a group of distribution series, considered as the simplest basic tool of breakdown analysis [28]. It depicts a division of a population by one measurable property, in this case allowable draft of a vessel. The histogram in Figure 3 presents the measurement results.

Table 2. *Allowable draft of inland vessels measured by TKI in the years 2019-2020.*

Vessel allowable draft [m]	**Number of vessels**
0.35-0.84	3
0.85-1.34	12
1.35-1.84	23
1.85-2.34	23
2.35-2.84	2
2.85-3.34	0
3.35-3.84	1
3.85-4.34	13
4.35-4.84	2
4.85-5.34	1

Source: *Authors' study based on Ship measurement certificate, 2021.*

Figure 3. *Histogram of inland vessel allowable drafts. Source: authors' study based on Ship measurement certificate, 2021*



Source: *Own study.*

The histogram (Figure 3) is a set of adjacent rectangles whose bases, equal to the class intervals, are presented on the abscissa on which the feature values are deposited, i.e. for the analyzed case it is the draft of the inland vessel. The number of feature variants, i.e. the number of inland vessels, is presented on the ordinate axis. Using a histogram, it was visualized which inland vessels (in relation to their draft) are the most common. Comparing the measurement results obtained and presented in the graph to the polish inland waterway parameters, it can be noted that a large part of the fleet will not be used effectively. The allowable draft above 3 meters does not increase the amount of transported cargo due to insufficient parameters of Polish waterways. The scale of this phenomenon is examined below using the statistical analysis.

For all tested vessels, the arithmetic mean $\bar{x}$ of the measured allowable draft was 2.2 m, and was calculated according to formula (1) for the distribution series.

$$\bar{x} = \frac{\sum_{i=1}^{k}(\dot{x}_i * n_i)}{N} = 2{,}2 \qquad (1)$$

where:
$\dot{x}$ – value of the middle of the range of vessel allowable draft,
n – the size of the range,
N – total number of ships,

The variance $S^2(x)$ was calculated according to the formula (2) and was 1.25 meters, while the standard deviation S(x) was calculated according to the formula (3) and amounted to 1.11 meters.

$$S^2(x) = \frac{\sum_{i=1}^{k}(\dot{x} - \bar{x})^2 * n_i}{N} = 1{,}25 \qquad (1)$$

$$S(x) = \sqrt{S^2(x)} = 1{,}11 \qquad (2)$$

Therefore, the allowable draft of the vessel was different from the arithmetic mean by approximately 1.11 metres.

After calculating the coefficient of variation $V_s(x)$ using formula (4), it was found that the proportion of standard deviation in the mean allowable draft of examined vessels is 50 %, which means that the allowable draft of those vessels is to some extent diversified.

$$V_s(x) = \frac{S(x)}{\bar{x}} * 100\% = 50\% \qquad (3)$$

An analysis of the typical area of variation x_{TYP} (according to classical measures of central tendency as per formula (5)), it was found that the typical allowable draft ranged from 1.09 to 3.31 m.

$$\bar{x} - S(x) < x_{TYP} < \bar{x} + S(x) \qquad (4)$$

The standard deviation was used to construct a typical area of variation of the studied feature, which is the allowable draft of the inland vessel. This area covers about 2/3 of the units of the analyzed statistical population, as it is contained within two standard deviations (formula 5). It can be assumed that typical units will fall within this area.

Given the parameters of inland waterways in Poland and the occurrence of some adverse phenomena discussed in the previous chapter, it can be seen that there is a risk of not using the potential of the existing fleet.

Assuming the allowable draft of two metres on class III waterways, we can estimate how many of the examined vessels cannot use fully their available capacity. To do this, we will calculate measures of the central tendency position. The central tendency in the statistical population is the indication of the value of the studied feature in the statistical community, around which the values of the features of all units included in this community are concentrated. The central tendency can be determined using measures of central tendency. These measures are commonly used because they are very simple to calculate.

The calculation of these measures allows for an accurate characterization of the level of a phenomenon occurring in the statistical population, using only one or a few numbers. Positional measures provide the values of a statistical feature occurring in a specific statistical unit, this unit is distinguished by its place in an ordered statistical series. The positional averages are extreme values, mode, median and quartiles.The median and quartiles were calculated to estimate the number of the analyzed vessels not using the full available deadweight.

To determine the median M, first quartile Q_1 and third quartile Q_3, the interval series was cumulated, then formulas (6), (7) and (8) were applied. The median range of draft values is (1.85-2.34), because half of the total set is contained in the cumulative size for this type interval as first. We similarly determine intervals for the first and third quartiles - these are, respectively, (1.35-1.84) and (1.85-2.34).

$$M = x_{0M} + \left[\frac{n}{2} - n_{sk-1}\right] * \frac{h_M}{n_M} = 1{,}89 \tag{5}$$

$$Q_1 = x_{0Q_1} + \left[\frac{n}{4} - n_{sk-1}\right] * \frac{h_{Q_1}}{n_{Q_1}} = 1{,}46 \tag{6}$$

$$Q_3 = x_{0Q_3} + \left[\frac{3n}{4} - n_{sk-1}\right] * \frac{h_{Q_3}}{n_{Q_3}} = 2{,}31 \tag{7}$$

where

$_{xo}$ – lower limit of the interval,

n_{sk-1} – cumulative size from the previous interval,

h – range,

n – interval size.

Interpretation of the above results indicates that half of the vessels measured had an allowable draft of not more than 1.89 metres, which qualifies them as fit for operation on class III waterways using the whole available dwt capacity. 25% of the examined vessels had allowable draft of not more than 1.46 metres, so these ships can be effectively used on waterways with lower parameters. However, 25% of vessels had allowable draft above 2.31 metres, which may considerably impact the efficient use of such vessels.

Summarizing the above calculation results, it can be concluded that from the examined population of inland ships in terms of effective use of their allowable draft:

- out of 80 analyzed ships, 40 have a draft not exceeding 1.89 meters, their operation is possible on Polish class III inland waterways with full load capacity,
- out of 80 analyzed ships, 20 have a draft not exceeding 1.46 meters, their operation is possible on Polish inland waterways lower than class III with the use of full load capacity,
- out of 80 analyzed ships, 20 have a draft greater than 2.31 meters, their operation is not possible on Polish class III inland waterways with full load capacity.

5. The Impact of some Parameters of Inland Vessels on Transport Efficiency

Different indicators may be used for assessment of inland waterway transport efficiency considered by (Kaup *et al.*, 2017; Simic, 2015; Radojcić and Simic, 2014):

- EEDI index, used for assessment of vessel energy efficiency,
- ODEX is an index showing the progress in energy efficiency relative to previous years,
- TEN indicator, referring to the size of the transport work done, (the larger the indicator, the transport work required less energy effort).

The TEN indicator will increase if the net deadweight of an inland vessel increases, propulsion power decreases, or vessel speed increases. Meeting these three conditions at the same time is not possible because the increase in the net deadweight or speed necessitates increase in power demand. The solution, i.e. the choice of the parameters, can be sought by tackling a multi-criteria optimization problem.

The value of the EEDI index for a specific vessel expresses its CO_2 emission in g/ton-mile of transported cargo. The structure of this index enables optimal selection of technical and operational parameters in the design of the vessel, maximisation of economic effects, so it may be used as one of the criteria in vessel design.

The ODEX index, to put it simply, is to be a ratio of the CO_2 emission (i.e., total carbon dioxide emission from fuel combustion) and transport work, dependent on vessel capacity and maximum speed.

This article analyses the impact of ship's allowable draft on transport efficiency using the TEN indicator, written by formula (9).

$$TEN = \frac{P_ł \cdot V}{P_B} \tag{8}$$

where
$P_ł$– net deadweight capacity of a vessel [t],
V – service speed [m/s],
P_B – propulsion power [kW].

It was assumed that the net deadweight $P_ł$ is 85% of the *DWT* capacity:

$$P_ł = 0.85 \cdot DWT \tag{9}$$

The deadweight capacity of a vessel as a function of displacement *D* was determined on the basis of a list of similar vessels (Kaup, 2017).

$$DWT = 0.626 \cdot D - 32.25 \tag{10}$$

According to the definition, the vessel displacement *D* is calculated as

$$D = L \cdot B \cdot T \cdot C_B \tag{11}$$

where: *L* - length [m],
B - breadth [m],
T - draft [m],
C_B - block coefficient [-].

In the above equation, water density γ is neglected because for inland waters the assumption is $\gamma_r = 1$.

The propulsion power is determined from the following relation:

$$P_B = \frac{D^{\frac{2}{3}} \cdot V^3}{20.02 - 0.003 \cdot \mathrm{V}} \tag{13}$$

This relation is obtained as the result:

$$TEN = \frac{0.85 \cdot (0.626 \cdot (L \cdot B \cdot T \cdot C_B) - 32.25) \cdot V}{\dfrac{(L \cdot B \cdot T \cdot C_B)^{\frac{2}{3}} \cdot V^3}{20.02 - 0.003 \cdot \mathrm{V}}} \tag{14}$$

The impact of inland vessel draft on the gained transport efficiency coefficient was analyzed by means of the determined formula (14).

Motor barges BM 500 and BM 700 with parameters as given in Table 3 were taken for calculations:

Table 3. *Parameters of barges BM 500 and BM 700.*

Parameters	**BM 500**	**BM 700**
Length - L [m]	57	67
Breadth - B [m]	7.54	8.20
Draft - T [m]	0.7 - 1.7	0.9 -2.12
Block coefficient - CB [-]	0.9	0.9
Speed - V [m/s]	3.06	4.17

Source: *Authors' study.*

We take into consideration a change in allowable draft of a vessel affecting the value of the TEN indicator. Increase in allowable draft raises the vessel net deadweight, which improves the TEN indicator. Table 4 presents the considered variants of vessels, for which specific values of length, breadth, block coefficient, and speed are adopted, with values of the TEN indicator calculated from formula (14). The results are shown in Figure 4.

Table 4. *Values of TEN indicator depending on vessel draft.*

BM 500		**BM 700**	
T	**TEN**	T	TEN
0.7	5.96	0,9	7.68
0.9	6.82	1.1	8.40
1.1	7.52	1.3	9.03
1.3	8.12	1.5	9.58
1.5	8.64	1.7	10.07
1.7	9.11	1.9	10.53
-	-	2.1	10.94

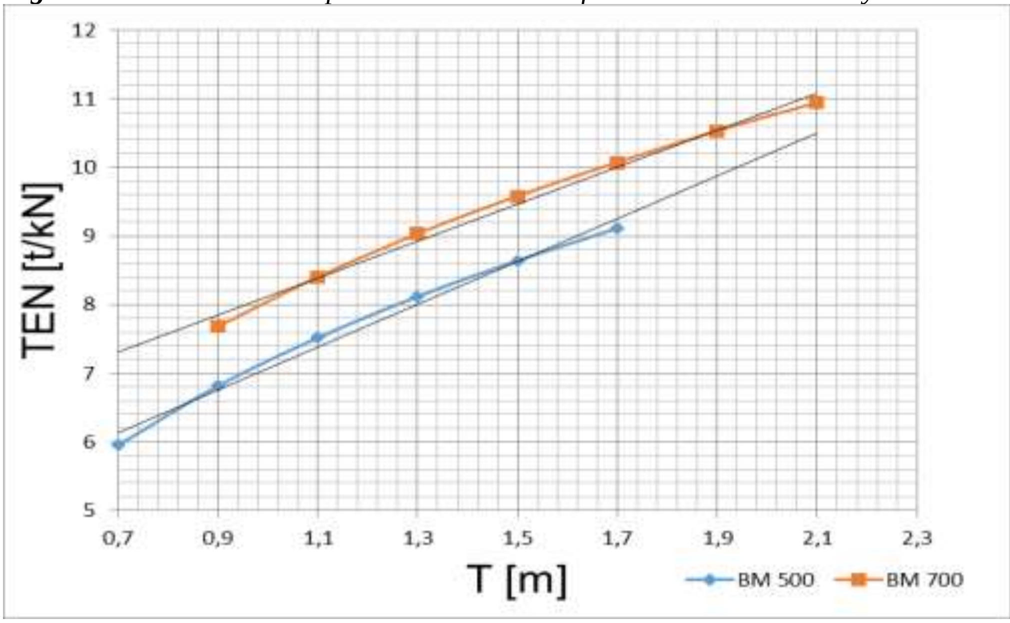
Source: *Authors' study.*

An almost linear impact of vessel draft change on the value of TEN, transport efficiency indicator, can be observed. We can indicate the most beneficial vessel draft, but the impact of this parameter on the vessel's transport efficiency should be analysed in conjunction with the other parameters included in formula (14).

6. Analysis of the Changes of the Light Ship Draft

The lack of adequately maintained waterways affects the utilization of the inland waterway transport capacity. However, the lack of waterways with desired parameters is not the only problem that eventually leads to low volumes of cargo carried on Polish rivers. The analysis of the results of the measurements carried out by the TKI in Szczecin revealed a decrease in overall deadweight capacity of inland vessels navigating along Polish waterways in the period between issuance of subsequent Measurement Certificates. Table 5 shows the deadweight changes observed during the measurement of the vessels by TKI Szczecin in the years 2019-2020 (Ship measurement certificate, 2021).

Figure 4. *TEN indicator dependent on vessel draft. Source: authors' study*



Source: *Authors' study.*

Table 5. *The changes of the deadweight capacities observed during measurement of vessels by TKI Szczecin in the years 2019-2020 [27]*

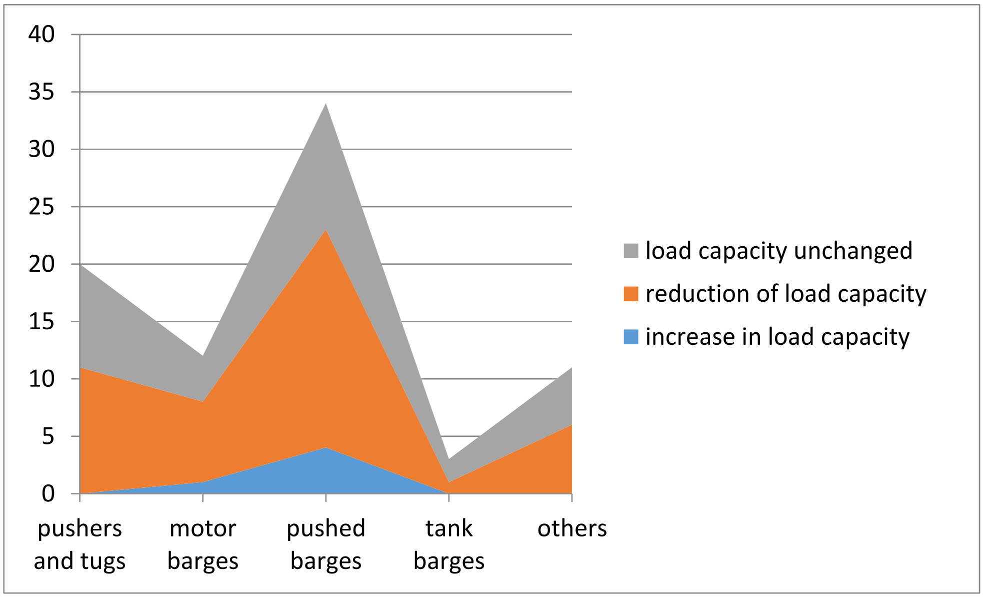
	Increase of the deadweight capacity	**Decrease of the deadweight capacity**	**No change in deadweight capacity**	**Total**
Pushers and tugs	0	11	9	20
Motor barges	1	7	4	12
Pushed barges	4	19	11	34
Tank barges	0	1	2	3
Other	0	6	5	11

Source: *Authors' study.*

Analyzing the data in the table, we can find the occurrences of the decrease in deadweight capacity of vessels navigating on Polish inland waterways in 10 to 15 years, in the period spanning issuance of the next Measurement Certificate. Undoubtedly, one of the significant reasons is insufficient maintenance and the age of the vessels (on average, Polish inland vessels are over 30 years old). Contrary to the degradation of the waterways due to negligence, shipowners themselves are those responsible for the fleet age and possible improvement of the current state of the fleet.

Further analysis was focused on groups of cargo vessels, as their deadweight capacity is a significant parameter from the shipowner's perspective. Cargo vessels constitute the most numerous group of vessels operated by Polish shipowners, and to put is simply, are the main source of income of their enterprises. In the Polish inland fleet, non-propelled vessels make up the largest group, in which pushed barges take the lead. Figure 5 shows the observed decrease in deadweight capacity, observed during ship measurements, divided by ship type.

Figure 5. *Changes in the load capacity observed in vessels surveyed in the years 2019-2020.*



Source: *Authors' study.*

The number of vessels in which load capacity decreased after the previous measurement is the largest in the group of pushed barges. It should be noted that the mean reduction was around 12 tonnes, the smallest about 2 tonnes, the largest recorded drop amounted to 23 tonnes. Unfortunately, few shipowners declared intention to improve the situation and take appropriate action, namely to overhaul of the ship. In the barge group for which no changes in load capacity were noted, the majority (seven vessels) were relatively young (under 20 years old).

All ships whose load capacity increased during the examined period have undergone a class repair. Of all the barges measured in the analysed period, the vessel with the greatest increase was one where the part of the bottom plating was renewed - a belt 2.5 m wide along the length of the barge. Besides, significant amount of sludge and deposits that gathered on the adjacent plating was also removed. The changes observed are most likely to have been related to inadequate ship preparation for the previous measurement (the vessel was not completely empty) or inadequate external conditions during the measurement. Nevertheless, that one particular ship is an excellent example of the benefits to be gained by bringing the ship to an appropriate technical condition. In that case, the increase in volume was over 43.5 tonnes.

Another type of vessel very often used by shipowners for cargo transport is a pushed tank barge. The fees for these barges are not settled based on their draft, but mostly by the measured flow of liquid cargo delivered on board or discharged. No significant differences in load capacity were observed between the subsequent measurements. This is undoubtedly related to the construction of tankers. These ships have numerous bulkheads, in most cases double sides and bottom. This structure facilitates the control of the technical condition and reduces the possibility of water and contaminants into the hull.

The use of such precautionary measures results from the types of cargo carried on tankers - often flammable, explosive or other hazardous materials that might pollute the water. The barges of this group often occur to be inspected at random, while the period between surveys for maintaining the ADN class is shorter. This effectively prevents ship degradation, and possible consequences such as reduced load capacity.

Motor barges are the second largest group of cargo ships owned by the Polish (inland) shipping firms. These ships have larger mass, resulting in lower capacity at given draft. The measurements showed that in more than 58% of the barges the load capacity was lower than previously, in 4 barges out of 12 no load capacity change was observed. Only one barge was found to have higher load capacity, an alarming fact.

Although motor barges are of lower average age than pushed barges, they are more vulnerable to ageing due to their construction. Such a low number of examined ships with improved condition may suggest that shipowners, if not forced by extreme factors, e.g. accident or negative results of the periodic hull survey, are unwilling to invest in overhauling this type of barges.

7. Conclusions

The best situation for the shipowner is the possibility of using the largest draft scale of a given vessel. It should be clearly indicated that the efficiency increases significantly along with increasing value of vessel draft.

One of the essential problems in the operation of inland vessels is a large technical diversity of the existing waterways, low parameters and small transit depths. As a result, shipowners cannot utilize the allowable maximum draft of their vessels.

It follows from the analysis that approximately half of the vessels measured can be operated on class III waterways, using their full capacity. 25% of the vessels under consideration can be efficiently used on waterways with lower parameters. The remaining 25% are vessels which due to the parameters of waterways cannot be efficiently used.

Efficiency assessment is undoubtedly much easier where the vessel operates with constant draft, defined as optimal on a given transport route. In Poland's hydro-engineering conditions, many components should additionally be considered, related to variable depths of waterways due to low water levels in some areas.

The article estimates the scale of failure to use the total available capacity of inland vessels resulting from insufficient parameters of inland waterways in Poland. Taking into account the fact that inland water transport is considered to be ecological, it would be necessary to improve its efficiency. One of the factors affecting transport efficiency is ship's allowable draft. section 5 assesses this impact. Transport efficiency is linearly dependent on the draft of the vessel, so if, despite the possibility of loading the vessel into an allowable draft, this is impossible due to the parameters of the waterways, overall transport efficiency may decrease to a greater extent.

According to the shipowners, the key factor influencing the increase in the efficiency and competitiveness of inland waterway transport is the provision of a constant transit depth unchanged in time, which will ensure punctuality and reliability for each inland carrier.

The maximum amount of transported cargo will be ensured by the maximum permissible design draft. In the opinion of carriers, this is the most important criterion. Taking into account the modern requirements for each carrier (timely deliveries and reliability), the main direction of modernization activities on the waterway should be to ensure a constant transit depth.The amount of transported cargo increases with increasing speed and design draft.

Research shows clear benefits of using the maximum acceptable design draft. It is also very advantageous to increase the length of the barges of the set for a predetermined width. The lengthening of the barges results in more favorable resistance relations as well as increased capacity of the barges.

References:

Czyżycki, R., Hundert, M., Klóska, R. 2006. Wybrane zagadnienia ze statystyki. Warszawa, Economicus.

Del Estado, P. 2007. Recomendations for designing the maritime confoguration of ports, approach channels and harbour basins. ROM 3.1, 99. Spain, Cedex.

Eyres, D.J., Bruce, G.J. 2012. Ship dimensions, form, size, or category. Ship Construction, pp. 11-16.

Galor, W. 2017. Sea-river shipping in Polish inland waterways. Scientific Journal of the Maritime University of Szczecin, 50(122), pp. 84-90.

Gołębiowski, C. 2016. Inland water transport in Poland. Transportation Research Procedia,

tom 14, pp. 223-232.
Hasan, S.M., Karim, M. 2017. Establishment of EEDI Baseline for Inland Ship of Bangladesh. Procedia Engineering, 194, pp. 370-377.
Hasan, S.M., Karim, M. 2020. Proposed Inland Oil Tanker Design in Bangladesh Focusing CO2 Emission Reduction Based on Revised EEDI Parameters. Journal of Marine Science and Engineering, 8(9).
Kaup, M. 2017. Wieloaspektowa ocena funkcjonowania jednostek śródlądowych i rzeczno-morskich. Warszawa, Oficyna Wydawnicza Politechniki Warszawskiej.
Kaup, M., Łozowicka, D. 2017. Wpływ innowacji na efektywność transportu wodnego śródlądowego, Prace Naukowe Politechniki Warszawskiej. Transport, tom 120.
Kaup, M., Łozowicka, D., Ślączka, W. 2017. A concept of an inland LNG barge designed for operation on the Odra waterway. Scientific Journal of Silesian University of Technology, Series Transport, nr 95.
Koetse, M.J., Rietveld, P. 2009. The impact of climate change and weather on transport: An overview of emiprical findings. Journal Transportaion Research Part D: Transport and Environment, pp. 205-211.
Panahi, R., Taherkhani, A., Radfar, S., Ghasemi, A. 2018. Standardization of the main dimensions of design ships for the Caspian Sea ports. Journal of Engineering for the Maritime Environment.
Panahi, R., Taherkhani, A., Radfar, S. 2017. Standarization of the Main Dimensions of Design Container Ships in Ports - A Case Study. World Journal of Engineering and Technology, tom 5, no 4B.
Papanikolaou, A. 2014. Ship Design: methodologies of preliminary design. Dordrecht.
Prsic, M., Carevic, C., Brcic, D. 2011. Determining inland waterway parameters with application on the Sava River. Promet-Traffic and Transportation, 23(2).
Radojcic, D. 2010. Environmentally friendly inland waterway ship design for the Danube River. World Wide Fund for Nature International Dunabe-Carpathian Programme (WWF-DCP).
Radojcic, D., Simic, A. 2014. Hydrodynamic Improvements- Energy Efficiency of IWW Self-propelled Ships. FP7-Move IT Project (WP2 Report), University of Belgrade.
Roldan, R.A., Moraes, H., Caprace, J.D. 2019. A Latin American inland waterways calssification assessement method as a strategy for economical region improvement. Brazil, Ship measurement certificate, 2021.
Simic, A. 2015. Energy Efficiency of Inland Waterway Self-Propelled Cargo Ships. Influence of EEDI on Ship Design. The Royal Institution of Naval Architects.
Skupień, E., Tubis, A., Bačkalić, T. 2019. The impact of the weather on inland navigation conditions. Scientific Journals of the Maritime University of Szczecin, 58.
Sohngen, B., Cordier, Y., Deplaix, J.M., Eloot, K., Iribarren, J., Pompee P.J., Rettemeier, K. 2018. Design guidelines for inland waterway dimensions. PIANC-World Congress Panama City.
Stala-Szlugaj, K. 2008. The inland waterways as a kind of coal transport in Europe. Energy Policy Journal, 11(1), pp. 477-486.
Sun, X., Yan, X.P., Wu, B., Song, X. 2013. Analysis of the operational energy efficiency for inland river ships. Transportation Research Part D: Transport and Environment, 22, 34-39.
Takahashi, H., Goto, A., Abe, M. 2006. Study on Standards for Main Dimensions of the Design Ship. Technical Note of National Institute for Land and Infrastructure Management Japan.
Takahashi, H., Goto, A. 2007. Study on Ship Height by Statistical Analysis. Report of

National Institute for Land and Infrasrtucture Management. Japan.
The Convention on Tonnage Measurement of inland waterway vessels. 1966.
The Council of Minister. 2002. On the Classification of Inland Waterways. The Council of Minister, Warszawa.
Urbanyi-Popiołek, I. 2019. The analyses of determinants affecting the river cruising in Poland in comparison with European tendencies. Scientific Journals of the Maritime University of Szczecin, 59.