DOI: 10.36163/aon-2021-0001

ESTIMATION OF MARINE TRANSPORT PERFORMANCE BASED ON HARMONISED DATASETS

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ABASTRACT

The production and analysis of transport statistics is an integral aspect of transport system management and monitoring. Updated and automated methods of generating statistics significantly improve the planning and execution of national transport policy. As part of the TransStat project, the authors developed a system of producing statistics describing transport performance, i.e. the carriage of cargo and passengers by sea, using harmonised sets of statistic data. The study presents the method of automatic estimation of transport performance related to cargo and passengers carried by sea, and statistics based on registered validation data.

The TransStat project is financed by the National Centre for Research and Development in the framework of the GospoStrateg programme, Agreement No Gospostrateg 1/383385/12/NCBR/2018.

Keywords – transport performance, harmonized dataset, maritime transport, statistics

1. INTRODUCTION

Statistical survey of each mode of transport is an important element of transport system development. The improvement of the process of such surveys, e.g. by using new technologies significantly enhances their quality and relieves respondents. Access to high quality statistics enables their comprehensive analysis, one of the factors leading to higher efficiency of transport. "A smart system for the production of road and maritime transport statistics using big data for shaping the country's transport policy - TranStat" provides tools optimising the production of statistical information. The project is implemented in the strategic programme of research and development "Social and economic development of Poland under the conditions of globalising markets" GOSPOSTRATEG.

One of the statistical indicators calculated in transport is transport performance. Transport performance is understood herein as a measure of the magnitude of cargo or passenger movements attributed to [7] specific:

- traffic flows – a set of passenger journeys, transport of cargo assigned to a specified transport vector described at the link of the directed graph in a transport network model,
- transport networks – a set of nodes and edges between them, which can be described as a directed graph.

Transport performance is the product of the number of kilometres travelled by a vehicle (vessel) and the number of persons or tons of goods carried. In passenger transport, the measurement unit is a passenger-kilometre (paskm) – 1 passenger-kilometre is the carriage of 1 passenger over a distance of 1 km.

$$PP_P[paskm] = p \cdot d \tag{1}$$

where: $PP_P[paskm]$ – transport performance in the carriage of people
$d\ [km]$ – distance
p – number of passengers

In cargo transport the unit of measurement is the ton-kilometre (tkm) – one ton-kilometre is the transport of 1 tonne of cargo over a distance of 1 km [8].

$$PP_T[tkm] = m \cdot d \tag{2}$$

where: $PP_T[tkm]$ – cargo transport performance,
$d\ [km]$ – distance,
$m\ [t]$ – cargo mass.

2. SOURCES OF DATA

The estimation of sea transport performance was based on the harmonisation of various sources of statistical and non-statistical data.

The source of statistical data is the survey of the Central Statistical Office (GUS) carried out under the Programme of the Statistical Research of the Public Statistics (PBSSP) 1.50 Maritime Economy and Inland Shipping, 1.0.01 Maritime and Coastal Transport. 'The objective of the survey is to provide information on the state of the maritime and coastal transport fleet, the state of the crews, sea-going ships flying the Polish flag, transport of goods and passengers by Polish sea carriers, goods turnover (goods in transit separately), movement of passengers and ships (including ship data) and berths in seaports [2]. The obligation to conduct statistical reports of that scope is set forth in Directive 2009/42/EC of the European Parliament and of the Council of 6 May 2009.

GUS (Central Statistical Office) collects data from mandatory forms – reports submitted by shipowners, maritime and coastal operators of transport ships. Reports are submitted via the GUS reporting portal and the dedicated TransMor program (Fig. 1), handling the Inventory System in Maritime Transport.

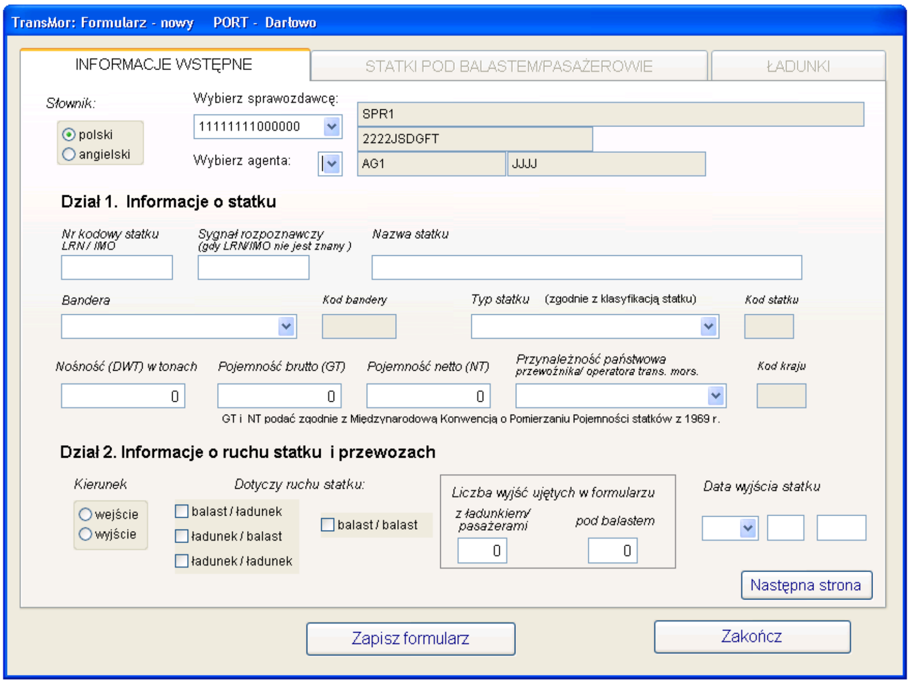

Fig. 1. View of the new form window of the TransMor program (source: [3]).

Data are aggregated in a Maritime Transport Dataset, which includes sea transport ships of 100 gross tons and above, which:

- arrived at or departed from a Polish seaport, hereinafter referred to as reporting port (port or offshore installation concerned),
- conducted or will conduct a journey wholly or partially at sea (includes sea-inland and inland-sea transport),
- called at a port due to unloading or loading of goods, disembarkation or embarkation of passengers,
- called at a port for disembarkation from a cruise ship of passengers for tourist purposes and their return onto the ship,
- called at a port under ballast,
- because of the draft or for other reasons they could not call at a port and where loading or unloading was done outside the port and the cargo was taken, respectively, from or to the reporting port.

Furthermore, the cargo included is that unloaded or loaded into ships, including goods shipped from or to offshore installations, such as oil rigs, goods reclaimed from the seabed and unloaded in port, if they are traded. The final statistical variable obtained from the survey is the number of passengers starting or finishing a journey in the reporting port, or those who during a journey on a cruise ship go on a short visit to a tourist attraction and return to the same ship before its departure from the reporting port.

The Maritime Transport Dataset contains total values referring to journeys during one month.

The Automatic Identification System (AIS) is a non-statistical source. AIS is the system of automatic identification of ships, which provides automatic exchange of data useful to avoid collision between ships and identifying the ship for land-based systems of traffic management and control. AIS transmits the following types of data:

- dynamic (ship's position, course, speed, information on course alteration, status of ships),
- static (name of the ship, call sign, flag state, IMO number, MMSI number, ship dimensions),

- concerning a particular journey (port of destination, draft, estimated time of arrival - ETA).

The scope of AIS data analysed at this study includes the content of message No 5 i.e. static data on the ship and voyage [6].

AIS equipment is installed on all ships with gross tonnage of 300 or more, engaged in international trade, on all ships of 500 or more gross tonnage, not engaged in international trade, and on all passenger ships, irrespective of size [5]. An example static AIS message in the NMEA format (National Marine Electronics Association) received by a base station has this form:
!BSVDM,2,1,3,B,53h;VCP279S1@H962208u8LPThB222222222221?4p:276T:N44nPnQ@jC`8,0*03
!BSVDM,2,2,3,B,88888888880,2*3D

Figure 2. presents decoded values of the above message.

id	: 5	Int32
repeat_indicator	: 0	Int32
mmsi	: 251848270	Int32
ais_version	: 0	Int32
imo_num	: 8857136	Int32
callsign	: "TFBQ "	String
name	: "BORGHILD "	String
type_and_cargo	: 79	Int32
dim_a	: 39	Int32
dim_b	: 10	Int32
dim_c	: 2	Int32
dim_d	: 7	Int32
fix_type	: 1	Int32
eta_month	: 10	Int32
eta_day	: 8	Int32
eta_hour	: 10	Int32
eta_minute	: 30	Int32
draught	: 1.6000000…	Double
destination	: "SZCZECIN "	String
dte	: 0	Int32
spare	: 0	Int32

Fig. 2. An example of a decoded static AIS message (Source: authors work).

Based on the sources described, information is collected on the characteristics of the ship, its cargo, ports of departure and destination. Another step necessary for the estimation of transport performance is to correctly define the route of the voyage travelled by the ship.

3. DETERMINATION OF THE DISTANCE BETWEEND PORTS

Ships are assumed to proceed along shipping routes, i.e. the safest and shortest tracks. Given that, the determination of most likely routes connecting foreign ports with the reporting port was based on the density map of vessel traffic in 2019, available in open access systems. The density map was created on the basis of position data of AIS, collected over the whole year and reflects the actual journeys made by ships. A fragment of the density map of the Southern Baltic and the North Sea is shown in Fig. 3.

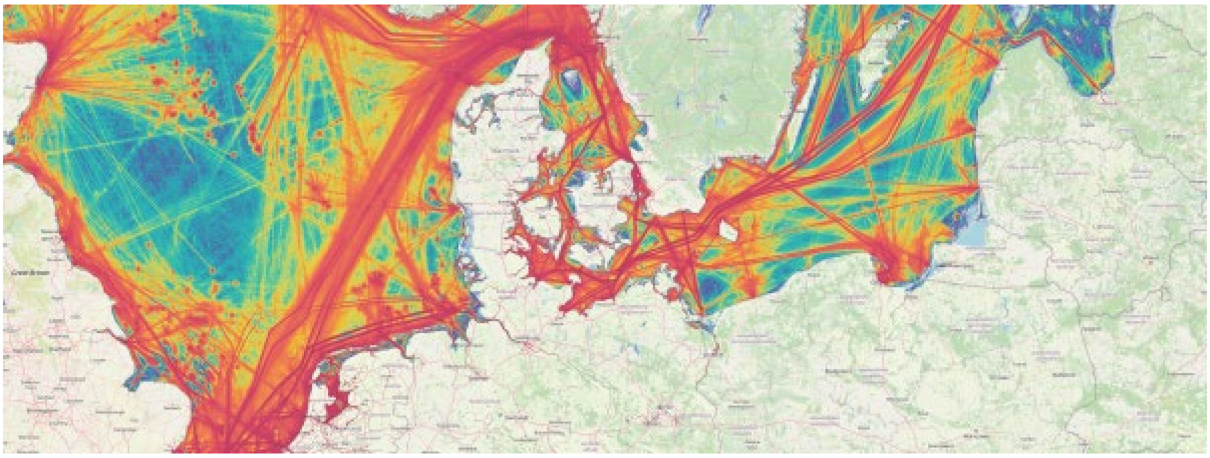

Fig. 3. Fragment of the density map of vessel traffic in 2019 for the region of the Southern Baltic and the North Sea (source: authors work, based on the marinetraffic.com].

The choice of a route between ports is primarily dictated by the economic factor (shortest distance) and the presence of traffic separation schemes (TSS). The distribution of the TSS is determined by the IMO (International Maritime Organisation), taking into account the safety and efficiency of shipping and environment protection [4]. Apart from random events, such as the blocking of an important shipping route or junction (canal, narrow passage), the routes shown are assumed to be unchanged. Ship routes run through subsequent waypoints, creating structures that can be presented in the form of edge-weighted directed graphs. The graph vertices (nodes) are waypoints, and the edges are straight sections connecting the vertices. A fragment of the graph is presented in Fig. 4.

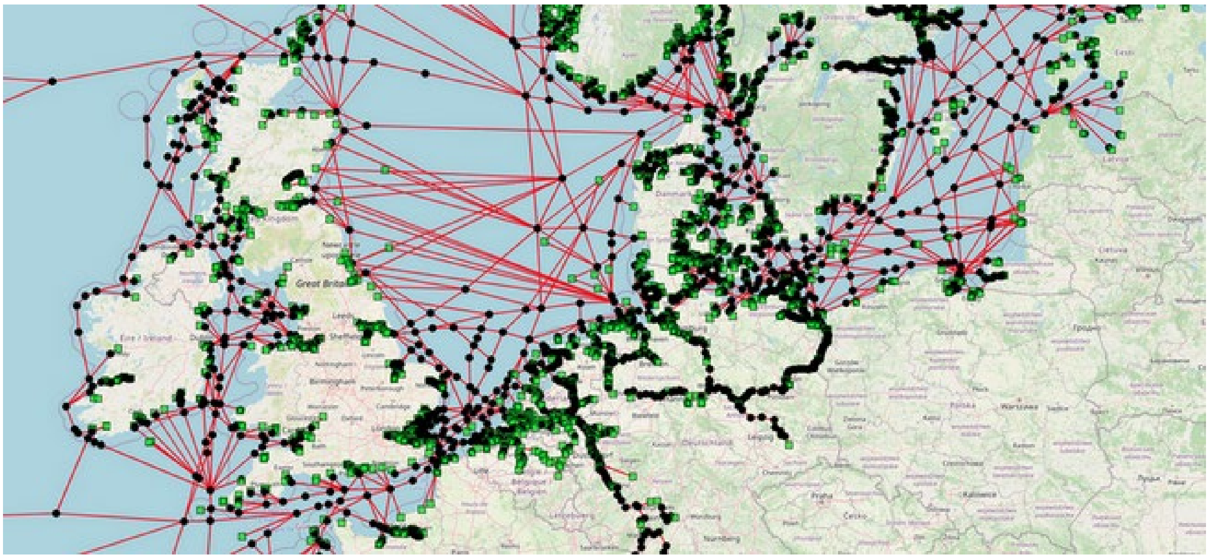

Fig. 4. Fragment of the graph for the area of the Southern Baltic and the North Sea (source: authors work).

Each edge contains the coordinates of the initial and final points and its weight is the length calculated by the haversine function (3).

$$d\,[m] = 2R \cdot \arcsin\left(\sqrt{\sin^2\left(\frac{\varphi_B - \varphi_A}{2}\right) + \cos(\varphi_A) \cdot \cos(\varphi_B) \cdot \sin^2\left(\frac{\lambda_B - \lambda_A}{2}\right)}\right) \quad (3)$$

where:
- $d\,[m]$ – orthodrome (great circle) route,
- $R\,[m]$ – mean radius of Earth,
- $\varphi_A\,[°]$ – geographical latitude of point A,
- $\lambda_A\,[°]$ – geographical longitude of point A,
- $\varphi_B\,[°]$ – geographical latitude of point B,
- $\lambda_B\,[°]$ – geographical longitude of point B.

The mean Earth radius $R = 6\,371\,008.7714\ [m]$ determined by the International Union of Geodesy and Geophysics (IUGG) was adopted for calculations [9]. To identify the shortest route, the Dijkstra algorithm was implemented in the graph.

The graph consists of 9859 vertices spanning the entire globe. 10731 links were established between the vertices. The vertices are ports identified by means of UNLOCODE (Unified Nations Code for Trade and Transport Logistics). The graph includes 3564 ports. The sum of edge weights equals 1088864 km.

To validate the determined values of sea routes, distances were calculated between randomly selected 70 destinations registered by the TransMor system and Szczecin. The calculation results were compiled and compared with three independent sources:

- Reed's Marine Table 2016,
- BP Port-to-port 2010,
- IHS Distance Table 2013.

The average difference of the distance was 2.82%.

4. HARMONISATION OF SOURCE DATA

It is possible to correctly determine statistics of transport performance in maritime transport over various trade routes if the following information is provided:

- mass of the cargo carried/number of passengers,
- AIS data (correctly entered, transmitted by the ship and received by the base station),
- distance travelled by the ship,
- time stamp.

The ship's identification data (IMO number, call signal) should be indicated, together with the relation (reporting port and port of arrival/departure) and the time stamp (time of voyage execution). These attributes allow maintaining full consistency and induce the integrity of the three sources of data, i.e. information from the Maritime Transport Dataset, AIS and the path-defining graph. The diagram depicting interrelations between the sources of data used in the harmonisation process is shown in Fig. 5.

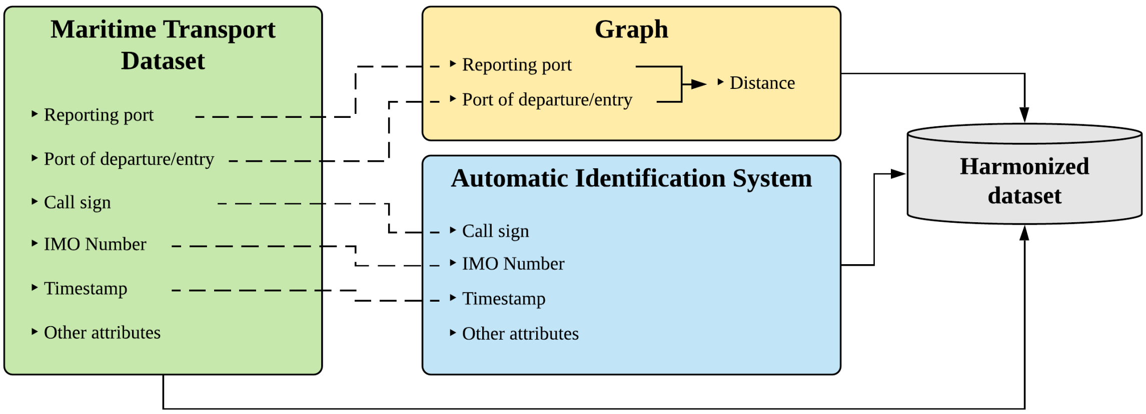

Fig. 5. The diagram showing interrelations between the sources of data used in the process of harmonization (source: authors work).

Table 1. contains selected attributes of harmonised sets and example values from three journeys:

P1) Klaipeda (LTKLJ) – Szczecin (PLZZ), general cargo/container ship (ship type 33 [1]) AZBURG, cargo of hard coal and brown coal (goods code 21 [2]),

P2) Argentina (AR888 [3]) – Szczecin (PLZZ), bulk carrier (type of ship 20) CHRYSANTHI S, cargo of cereals, starch and animal feed (code 46),

P3) Szczecin (PLZZ) – Marseille (FRMRS), ship serving offshore installations (type of ship 42) OCEAN VIKING carrying passengers.

Table 1. Selected attributes of the harmonized datasets and example value (source: authors work).

Source	Attribute	Voyage		
		P1)	P2)	P3)
Maritime Transport Dataset	Reporting port	PLSZZ	PLSZZ	PLSZZ
	Port of departure/entry	LTKLJ	AR888	FRMRS
	Direction of the journey	Entry	Entry	Departure
	Time tag	2019-07	2019-09	2019-07
	IMO Number	9102899	9527441	8506854
	Call sign	3EZK	D5CH5	JXIW3
	Name of the ship	AZBURG	CHRYSANTHI S	OCEAN VIKING
	Type of ship	33	20	42
	Flag state	Panama	Liberia	Norway
	DWT capacity	10 020 t	80 268 t	2 630 t
	Gross tonnage	6 353	43 950	2 090
	Net tonnage	3 387	27 013	627
	Goods code	21	46	-
	Weight of goods / Number of pas.	9 512 t	24 993 t	13 people
AIS	IMO Number	9102899	9527441	8506854
	Call sign	3EZK	D5CH5	JXIW3
	MMSI number	370236000	636015701	258479000
	Name of the ship	AZBURG	CHRYSANTHI S	OCEAN VIKING
	Ship length	130 m	229 m	70 m
	Breadth	16 m	32 m	16 m
	Type of ship [4]	70	79	90
	UTC time stamp	2019-0-08 19:02:41	2019-09-06 22:28:03	2019-07-04 09:08:25
Graph	Reporting port	PLSZZ	PLSZZ	PLSZZ
	Port of departure/arrival	LTKLJ	AR888	FRMRS
	Distance	583.45 km	13 528.20 km	4 853.59 km

[1] as per the directory attached to the Maritime Transport Dataset
[2] as per the directory attached to the Maritime Transport Dataset
[3] as per the directory attached to the Maritime Transport Dataset, known country, no indication of the port [1]
[4] as per the specification of AIS in [6]

A set of this kind can be created provided that at least one common attribute is present for each pair of harmonized sets. The proposed method of the harmonisation of sets was validated using the data from 1 July 2019 – 30 September 2019 for the port of Szczecin. The AIS data come from the base station located in the building of the Maritime University of Szczecin. The following problems arose:

Lack of consistency of the AIS and the Maritime Transport Dataset information,

Unclear position of the port assigned to the node in the graph.

Ad 1. Ships were found, registered in the Maritime Transport Dataset, that were not detected by the AIS. This may be caused by different times of reporting a ship's journey by respondents (e.g. delay resulting from customs procedures, agent's negligence) which does not need to coincide with the time of AIS registration. Besides, AIS equipment is installed on ships of minimum 300 gross tonnage, whereas the Maritime Transport Dataset comprises ships with gross tonnage of 100 and above. This problem does not exclude calculations of transport performance carried out by the ship, but limits the processing of certain statistics.

Ad 2. The ports directory provided with the Maritime Transport Dataset contains UNLOCODE, for which the exact position has not been unequivocally indicated. Example codes together with their description are summarised in the table below.

Table 2. Example UNLOCODE not including the clear geographical position (source: authors work).

UNLOCODE	**Country**	**Description**
AR888	Argentina	no indication of port
BE88P	Belgium	mining areas in the North Sea
BE88R	Belgium	ship-to-ship transfer - North Sea
CA88W	Canada	other ports - Western coast
SA88G	Saudi Arabia	ports in the Persian Gulf, Arabian Sea
RU88I	Russia	other European ports and the Caspian Sea
PL88Q	Poland	mining areas in the Baltic Sea

To identify geographical coordinates, the authors propose the method of arbitrary designation of a location (e.g. the country's main port, centroid of the coastal zone) or the optimization method in which the area's centre of gravity is determined.

The absence of a specific indication of the point of reference (geographical coordinates) prevents the estimation of track distance and consequently the calculation of the transport performance.

5. CALCULATION OF THE TRANSPORT PERFORMANCE

The structure of the harmonised set of data proposed in the article allows the calculation of the transport performance (Fig. 6):

- value of the attributes *Distance* and *Mass of cargo* are the factors of the product as per the formula (1),
- the value of attributes *Distance* and *Number of passengers* are the factors of the product as per the formula (2).

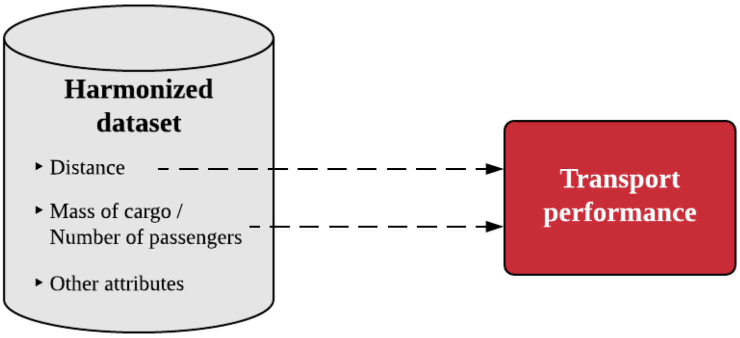

Fig. 6. Attributes of the harmonised set of data used in the calculations of transport performance (source: authors work).

The above relationships were used to estimate transport performance for three journeys: P1, P2, P3.

P1) $PP_T = 9\,512\,t \cdot 583.45\,km = 5\,549\,776{,}40\,tkm$

P2) $PP_T = 24\,993\,t \cdot 13\,528.20 km = 338\,110\,302.60\,tkm$

P3) $PP_P = 13\,pas \cdot 4\,853.59 km = 63\,096.67\,paskm$

The calculated values and the harmonised dataset are the core elements in the process of determining statistics related to transport performance of a sea-going ship.

6. TRANSPORT PERFORMANCE STATISTICS

The data from 3rd quarter of 2019 (1 July to 30 September 2019) were used to estimate transport performance for the port of Szczecin. AIS data were collected from the base station located in the building of the Maritime University of Szczecin, while the Maritime Transport Dataset from the *GUS* base. The distances were calculated on the basis of the created graph.

For each relation with the port of Szczecin the distance to the port of arrival/departure was determined in the Maritime Transport Dataset. In the next step, for each relation the transport performance was estimated in ton-kilometres or passenger-kilometres.

The following statistics were prepared from the cargo transport data:

1. Total transport performance in 3rd quarter for ships leaving/entering the port of Szczecin, (Fig. 7).

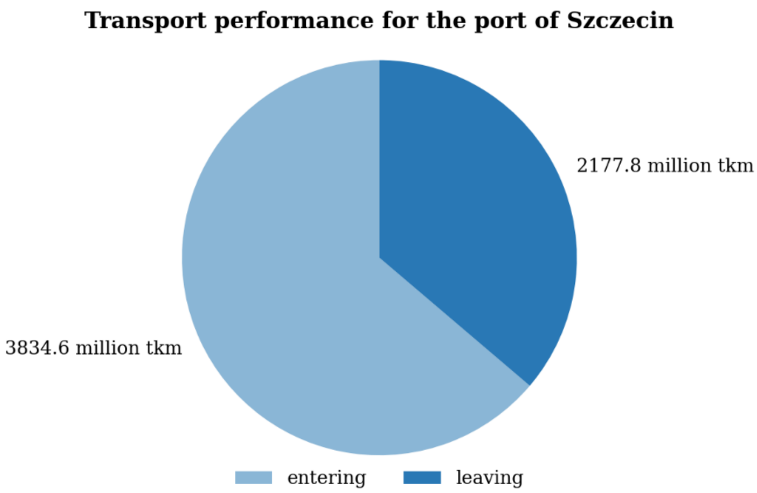

Fig. 7. Total cargo transport performance in 3rd quarter of 2019 for ships leaving/entering the port of Szczecin (source: authors work).

2. Total transport performance for ships leaving/entering the port of Szczecin in each month of 3rd quarter of 2019, Fig. 8.

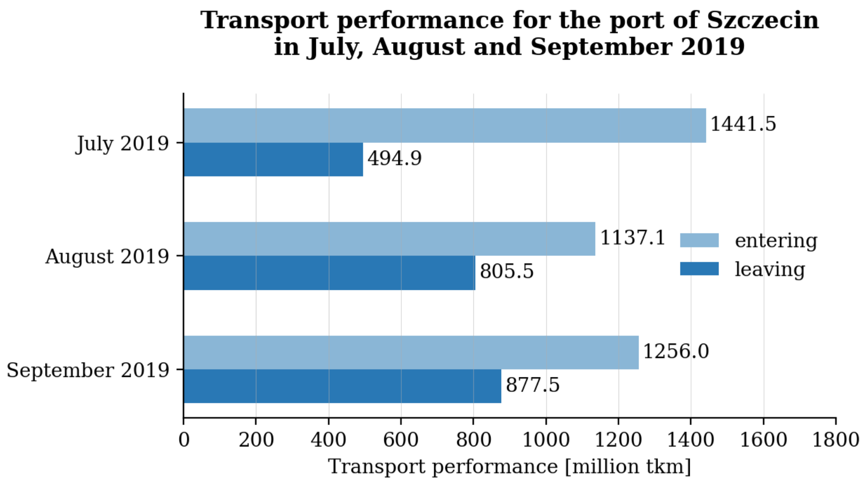

Fig. 2. Cargo transport performance in each month of 3rd quarter of 2019 for ships leaving/entering the port of Szczecin (source: authors work).

3. The largest unit transport performance recorded in Szczecin was 427.2 million ton-kilometres on a ship journey to a port in Saudi Arabia, Fig. 9.

Fig. 9. The suggested route of the ship linking the port of Szczecin with a port in Saudi Arabia in the Persian Gulf (source: authors work).

4. Total transport performance in 3rd quarter of 2019 by country, Table 3.

Table 3. Total cargo transport performance in 3rd quarter of 2019 by country for the port of Szczecin (source: authors work).

Country	Transport performance [million tkm]	Country	Transport performance [million tkm]
Argentina	1091.7	Turkey	94.8
Spain	664.0	Venezuela	93.2
Russia	495.8	Germany	90.0
Saudi Arabia	427.2	South Africa	82.3
Norway	258.5	Estonia	77.4
Finland	229.6	Mozambique	72.2
Brazil	207.9	India	65.2
Canada	207.0	Denmark	62.3
Namibia	177.0	France	59.6
Portugal	169.0	Romania	58.0
The Netherlands	146.3	Lithuania	52.7
Morocco	136.0	Italy	32.2
Egypt	135.8	Ireland	29.9
Algeria	134.8	Greece	26.7
Ivory Coast	130.7	Belgium	26.1
Sweden	114.8	Poland	19.1
USA	109.2	Latvia	17.1
Gabon	103.3	Iceland	13.4
Great Britain	99.8	Singapore	1.5

The tabular data are visualized in Figure 10.

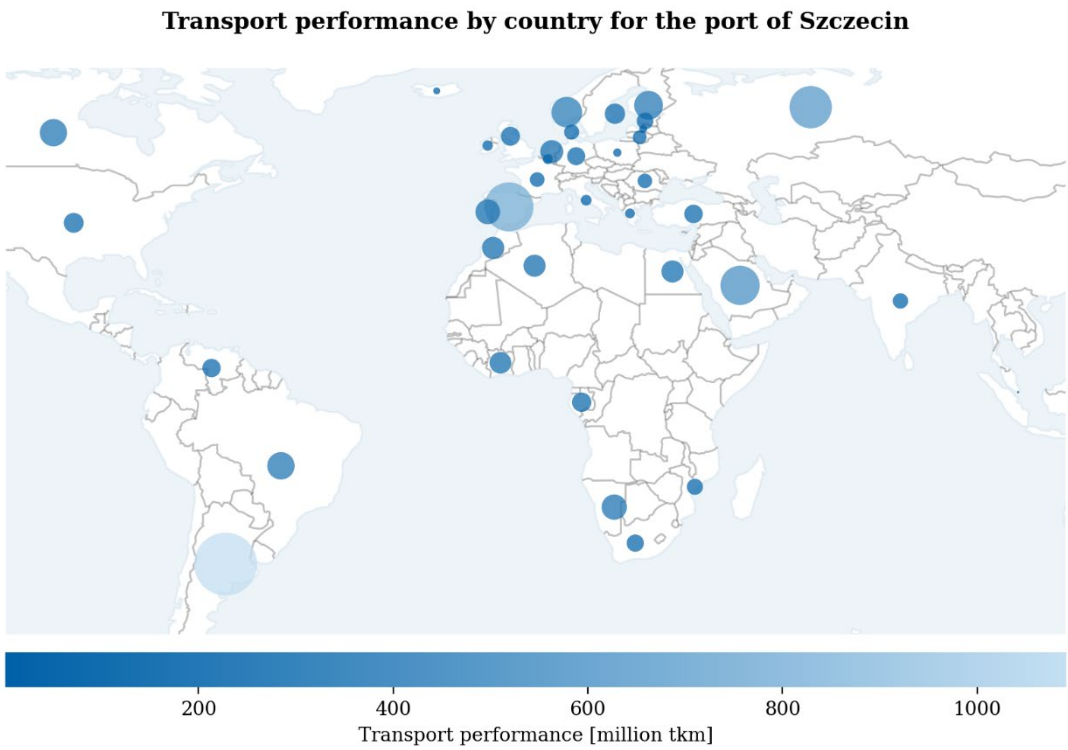

Fig. 10. Cargo transport performance in 3rd quarter of 2019 by country for the port of Szczecin (source: authors work).

5. Transport performance by ship length for the port of Szczecin, Fig. 11.

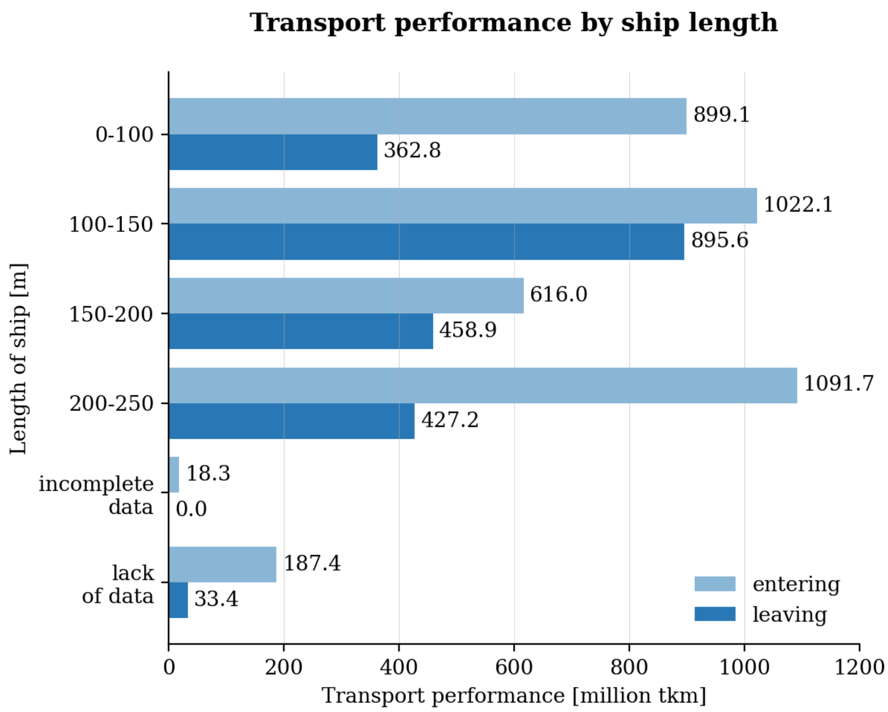

Fig. 11. Cargo transport performance in 3rd quarter of 2019 by ship length for the port of Szczecin (source: authors work).

6. Transport performance in 3rd quarter of 2019 by ship type, Fig. 12.

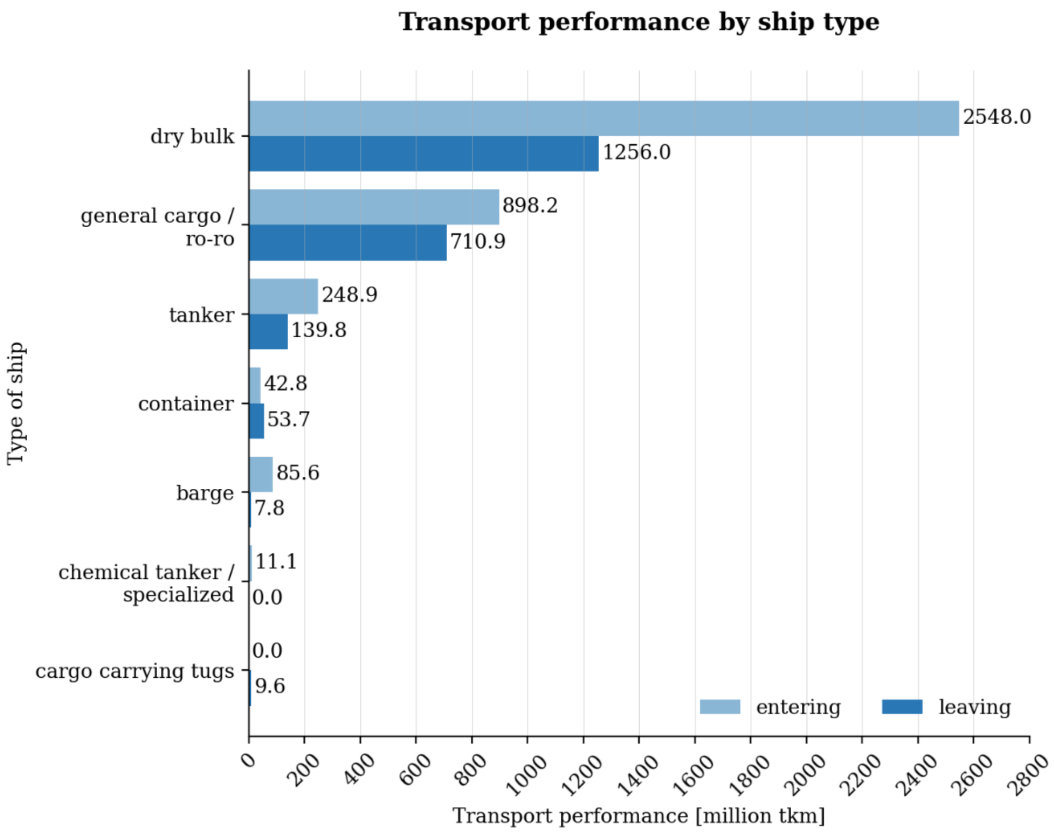

Fig. 12. Cargo transport performance in 3rd quarter of 2019 by ship type for the port of Szczecin (source: authors work).

The following statistics were prepared for passenger carriage by sea:

7. Total transport performance for ships leaving/entering the port of Szczecin in 3rd quarter of 2019, Fig. 13.

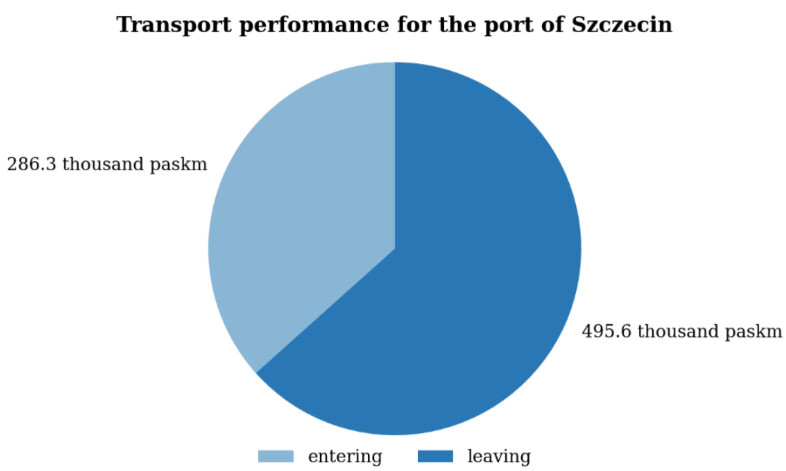

Fig. 13. Total passenger transport performance in 3rd quarter of 2019 of ships leaving/entering the port of Szczecin (source: authors work).

8. Total passenger transport performance for ships leaving/entering the port of Szczecin in each month of 3rd quarter of 2019, Fig. 14.

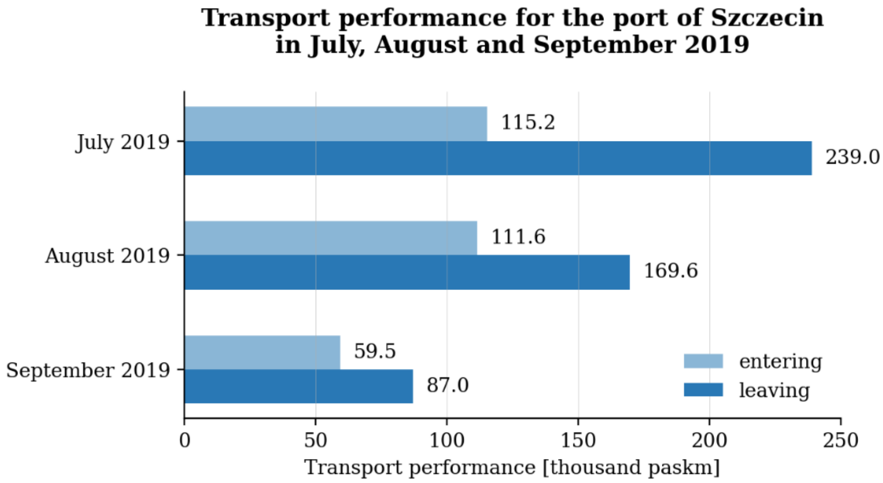

Fig. 14. Passenger transport performance in each month of 3rd quarter of 2019 for ships leaving/entering the port of Szczecin (source: authors study).

9. The largest unit transport performance recorded for the port of Szczecin was 76 119.41 passenger-kilometres, a journey to Świnoujście of the ship ODRA QUEEN.

7. Summary

The article aims to present the method of harmonising datasets and using them for determining statistics of a sea-going ship *transport performance*, understood as the carriage of cargo and/or passengers by sea, expressed in ton-kilometres and passenger-kilometres. The harmonisation process comprised sets of statistical data making up the Maritime Transport Dataset, distance between ports (graph) and non-statistical data – static information from the AIS.

The graph was built utilizing global historical data on ship movements in 2019. The distances between the ports on average differed by 2.82%, compared with three independent sources. In authors' opinion the results obtained were satisfactory. The actual distance travelled by a ship can be obtained from the AIS or other systems of traffic monitoring.

The structure of datasets was analysed to identify common parts. The attributes relevant in the process of harmonisation of datasets were separated: time stamp, reporting port, port of departure/arrival, IMO number, call sign. The outcome of harmonisation was a set of data containing factors of the product enabling the calculation of transport performance. The data thus prepared were the source of transport performance statistics.

Presented examples of calculated transport performance statistics referred to both goods and passengers. Szczecin was chosen as a reporting port. The research covered a period of three months, 3rd quarter of 2019. The subsequent analysis led to the following conclusions:

- total cargo transport performance amounted to 6012.4 million tkm, while the transport of passengers was 781.9 thousand paskm;
- cargo transport performed by entering ships was larger (1.7 times) than by departing ships; the transport performance for passengers was larger (1.73 times) by ships leaving the port;
- the largest cargo transport performance was noted in September (2133.5 million tkm), while the transport of passengers in July (354.2 thousand paskm);

- the lowest cargo transport performance was in July (1926.4 million tkm), the carriage of passengers was the lowest in September (146.5 000 paskm);
- transport performance in the longest journey was 38.2 million tkm, with the heaviest load the figure was 427.2 million tkm, (Table 4).

Table 4. Cargo transport performance in the longest journey and with the heaviest load (source: authors work).

Port of departure/arrival	Distance	Cargo mass	Transport performance
RUSAK	23 373.9 km	1 634 t	38 192 952.6 tkm
SA88G	13 225.4 km	32 300 t	427 189 420.0 tkm

- Passenger transport performance in the longest journey was about 9000 paskm, with the largest number of passengers - 76,100 paskm (Table 5);

Table 5. Passenger transport performance in the longest journey and with the largest number of passengers (source: authors work).

Port of departure/arrival	Distance	Number of passengers	Transport performance
BR888	9 007.0 km	1 pas	9 007.0 paskm
PLSWI	63.6 km	1 196 pas	76 065.6 paskm

- the largest total transport performance was to Argentina (1 091.7 million tkm), the smallest to Singapore (1.5 million tkm);
- the largest cargo transport performance (1917.7 million tkm) was done by ships of length ranging from 100 to 150 m;
- 239.1 million tkm were produced by ships with lengths unknown due to incomplete or lacking AIS data);
- the largest total cargo transport performance was carried out by bulk carriers (3804.0 million tkm); the performance of ships departing from a port made up 49% of the ingoing ships' performance.

The estimation of transport performance statistics has been improved. A tool has been provided for automatic calculations of the distances between ports. The content of the Dataset on Maritime Transport has been extended after the harmonisation of the sets. The method proposed by the authors was implemented under the TranStat project. The method will become part of the system of producing transport statistics used by the Central Statistical Office (GUS).

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