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Forecasting the Cargo Throughput for Small and Medium-sized Ports: Multi-stage Approach with Reference to the Multi-port System

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Abstract:

Purpose: *The paper aims to elaborate on long-term throughput forecasts in Small and Medium-Sized ports (SMPs). The research problem relates to determining a method that is relevant for the long-term transhipment forecasting in SMPs.*
Design/Methodology/Approach: *Research was applied to the Polish ports system consisting of three major ports (Gdańsk, Gdynia, and Świnoujście) and the minor port of Szczecin. Forecasts for the cargo groups in the major ports were produced using regression models where the model parameters were estimated with the Ordinary Least Squares Method. The obtained forecasts of the throughput of cargo groups in major Polish seaports were converted into dynamics indices. The resulting matrices of the cargo throughput dynamics indices established for the leading Polish seaports were used to prepare cargo throughput forecasts for the port of Szczecin.*
Findings: *Elaborated throughput forecasts indicate that, in the future, the port in Szczecin will retain its universal character, and a moderate increase in the cargo volumes confirms that it will serve as a complementary port to the major ports in the range. The forecasted modal split of hinterland transport indicates the increasing importance of road transport, and a decreased rail and inland waterway transport to/from the hinterland. That is likely due to a lower cargo throughput and difficulties in organizing the rail and inland waterway corridors based on smaller freight volumes.*
Practical implications: *The study provides a practical tool for long-term throughput and hinterland traffic forecasting in SMPs. It is addressed to port authorities as the method may be used in decision-making on capacity expansion and academics exploring the phenomenon of predictions in maritime transport.*
Originality/Values: *The novel method of demand forecasting in SMPs includes relations between major and minor ports in the range and multi-staged validation of results. Research advances studies on the dynamics of multi-port systems.*

Keywords: *Forecast, throughput, minor seaports, multi-port system.*
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1. Introduction

Capacity planning is a complex and vital aspect of seaport development. If the port capacity is higher than the demand for its services, this results in inefficient use of port infrastructure and superstructure and, thus, higher costs of port services. On the other hand, when the demand for port services exceeds the production capacity of the port, the time of ship and cargo handling lasts longer, which, in turn, increases the delivery costs and losses for cargo receivers. Port services cannot be stored; therefore, their supply is determined by the port's transhipment capacity, and the increase in their volume is incremental, time-consuming, and requires costly investment. Therefore, to avoid the consequences of non-compliance of port supply and demand and to create a basis for sizing supply, there is a need for demand forecasting of port services (Jarrett, 2015). Before making any decisions on capacity development, it is necessary to establish the level of long-term demand for port facilities and services, i.e., to prepare port traffic volume forecasts. There is no universally accepted terminology for classifying seaports. The literature refers to smaller ports as minor, secondary, peripheral, regional, local, or feeder ports, while more oversized ports are often named major, primary, large, or hub ports, as well as load centres or gateways (Bichou and Gray, 2005; Bichou, 2009). In a work by Abdul Rahman *et al.* (2018), a thorough critical comparative study of the port typology was presented.

For this paper, smaller ports are referred to as small and medium-sized ports (SMPs) and will be defined as ports that are not as big in size, capacity, or throughput volumes as major national seaports (Khalid *et al.*, 2011). In terms of the annual cargo volumes, Verhoeven (2010) defined small ports as those with an annual volume of goods handled less or equal to 10 million tonnes, while *medium ports* were defined as those handling more than 10 million tonnes but not exceeding 50 million tonnes of goods. In the Baltic Sea region, small and medium-sized ports are that ports whose handling capacity is less than 10 million tonnes annually (Rozmarynowska and Oldakowski, 2013).

The main differences between SMPs and major ports relate to the scale and scope of port activity. Major ports host the largest oceangoing vessels and obtain high cargo throughput while serving a vast international hinterland. Minor seaports accommodate smaller vessels in short- and medium-range shipping, have a smaller and typically more diversified cargo throughput, and serve their regional hinterland. The main problems in developing large ports are the growing transport congestion and insufficient land resources for expansion. In small ports, the transport congestion is less critical, and the land resources are typically more considerable (de Langen,1998). According to Hayuth (1981), the port system concentration will eventually reach its limits and then invert, leading to a process of de-concentration. As a port system develops, diseconomies of scale in some large load centres emerge in the form of insufficient space for expansion and port congestion. This encourages smaller ports or even new ports to attract cargo. The phenomenon is referred to as the peripheral port challenge (Hayuth and Fleming, 1994). In recent models of port system development, SMPs were seen to be instrumental to the peripheral port challenge and, thus, to the port system de-concentration (Slack and Wang, 2002, Wang *et al.*, 2012, Wilmsmeier and Monios, 2013, Wilmsmeier, Monios, and Perez-Salas, 2014).

Notteboom (2005) analysed the concentration and de-concentration processes on the examples of two-port systems located in the Rhine-Scheldt delta port cluster and the port system located in the West Mediterranean port range. Both port systems consist of several small and medium-sized ports as well as major ports. They argued that de-concentration within a port system occurs when some of the cargo is shifted from large ports to smaller and new ports or when the large load centres only absorb a small portion of the container traffic growth in the whole port system. Seaports are becoming increasingly interrelated with other ports and inland ports. The question arises about finding the right balance between competition and cooperation to achieve a sustainable competitive advantage for both the individual load centres in a port system and the system (Notteboom, 2005).

Feng and Notteboom (2011) examined the empirical case of Yingkou port in the logistics system of the Bohai Sea of China, which places Yingkou port into a more competitive position in contrast to the dominant ports in that area. SMPs often look for cost advantage in specific niche markets. They might also secure growth by serving the dominant ports in a multi-port gateway region. Such a strategy demands close cooperation between ports. In another work by Feng and Notteboom (2013) the role of SMPs in the multi-gateway regions was studied in the context of five variables: (a) the handled cargo volume and market share; (b) the international connectivity; (c) a cluster's relative position; (d) the port city and hinterland connections; and (e) the logistics and distribution function. In conclusion, they stated that SMPs develop independently, which requires ports to find their specific competitive advantage or cooperate when they seek cooperation with neighbouring more oversized ports.

The existing studies on cargo throughput forecasting focus on major seaports but ignore this issue for smaller ports. In this paper, we address this niche in the literature and propose a method of cargo throughput forecasting focusing on supporting smaller port authorities in their expansion decisions. The presented research process was based on studies on the development of port systems and the relationships taking place between the major and minor ports located within a specific port range.

2. Brief Outline of the Polish Port System

The system of Polish seaports includes Gdańsk, Gdynia, Świnoujście, and Szczecin, the four most critical Baltic ports in terms of the volume of handled cargo. These are seaports of fundamental importance for the national economy, and they are located within the range of 500 km.

From 2007 to 2019, the highest dynamics of cargo throughput growth were recorded in the port in Gdańsk. Transshipments in the port of Gdańsk more than doubled in that period and rose on average by 8.39% per year. Compared to 2007, in 2019, the port of Świnoujście saw the cargo throughput increased by 64.8%, i.e., by an average of 4.25% annually, while in the port of Gdynia, it grew by 41.1%, i.e., by an average of 2.91% annually. Against that background, only the port in Szczecin did not record an increase in cargo throughput. In 2007, the cargo handled by the port of Szczecin amounted to 9487 thousand tonnes and in 2019 to 9305 thousand tonnes, which decreased the cargo throughput by 1.92% over the analyzed period. As a result, the role of the port in Szczecin as a load center decreased compared to other Polish seaports.

Table 1. *Cargo transshipment volume in Polish seaports in 2007-2019 (tonnes)*

Year	Port				Total
	Szczecin	Świnoujście	Gdańsk	Gdynia	
2007	9,486,600	9,238,000	19,826,332	16,989,000	55,539,932
2010	8,755,900	12,086,900	27,182,097	14,692,000	62,716,897
2013	8,714,700	14,035,300	30,259,295	17,564,000	70,573,295
2016	9,264,149	14,841,558	37,288,969	19,563,000	80,957,676
2019	9,304,833	15,226,975	52,154,098	23,965,000	100,650,906

Source: *Port authorities.*

The share of the port in Szczecin in the total cargo throughput in Polish ports decreased from 17.1% in 2007 to 9.2% in 2019 (a fall by 7.9 percentage points). Based on data about transshipments in major Polish ports in the years 2007–2019 and the Polish GDP in current prices, the relationship between the volume of cargo flow in Polish seaports and the gross domestic product (GDP) was measured using Pearson correlation coefficients.

The calculation formula of Pearson's correlation coefficient is as follows:

$$r_{C,GDP} = \frac{cov(C, GDP)}{S(C) \cdot S(GDP)} = \frac{\overline{C \cdot GDP} - \bar{C} \cdot \overline{GDP}}{S(C) \cdot S(GDP)} \quad (1)$$

where:

$r_{C,GDP}$—the Pearson coefficient of correlation between the seaport cargo throughput in seaports (C) and the gross domestic product (GDP) in 2007–2019,

cov (*C*, *GDP*)—the covariance (measure of strength and direction of correlation) of seaport cargo throughput (C) and the gross domestic product (GDP) in 2007–2019,

$\overline{C \cdot GDP}$—the average product of the seaport cargo throughput (C) and gross domestic product (GDP) calculated based on data from 2007–2019,

$\bar{C}$—the average seaport cargo throughput in 2007–2019,

$\overline{GDP}$—the average Polish GDP in 2007–2019,
$S(C)$—the standard deviation (measure of variability) of seaport cargo throughput in 2007–2019, and
$S(GDP)$ — the standard deviation (measure of variability) of the Polish GDP in 2007–2019.

Table 2. *Matrix of Pearson coefficients of correlation between cargo throughput in Polish seaports and the development of Gross Domestic Product in 2007-2019*

Port	Szczecin	Świnoujście	Gdańsk	Gdynia
GDP at current prices	0.339	0.907	0.977	0.886

Source: *Own study.*

The overall volume of cargo throughput in Polish ports is strongly linked to the country's economic development. The exception is the port of Szczecin, where the transshipment dynamics were much lower than the dynamics of economic growth in Poland. The coefficient of correlation between the volume of cargo transshipments in the port of Szczecin and the GDP rate was low and amounted to a mere 0.34.

The port of Szczecin is located 65 km south of the Baltic Sea and is connected to it by a waterway. The quality of the fairway determines the access to the port from the sea. The current depth of the fairway of 10.5 m allows for safe navigation and seagoing service ships with a draught of 9.15 m and a carrying capacity of up to 20,000 tonnes. At the present stage of the development of sea trade and shipping, the accessibility of the port of Szczecin from the seaside is low. All other significant ports located on the southern coast of the Baltic Sea have navigational conditions allowing them to serve larger sea vessels than the port of Szczecin. The volumes of cargo throughput in the port of Szczecin in 2007–2019 are presented in Table 3.

Table 3. *Cargo throughput by groups of cargo in port of Szczecin in 2007–2019 (tonnes)*

Year	Coal	Iron ore	Other bulk	Grain	General cargo	Containerized cargo	Oil and oil products	Total
2007	2,014,600	525,200	2,761,400	1,451,800	1,830,418	601,382	301,800	9,486,600
2010	2,595,300	311,100	2,009,100	1,309,000	1,753,116	580,784	197,500	8,755,900
2013	1,907,800	311,400	2,704,100	1,121,500	1,840,143	587,257	242,500	8,714,700
2016	1,388,541	486,298	2,842,526	1,271,102	2,461,840	643,443	170,400	9,264,149
2019	1,252,234	472,431	3,218,197	875,204	2,551,695	704,230	230,842	9,304,833

Source: *Port authorities.*

The port in Szczecin also handles transit cargo transported along the north-south European routes. The most significant shares in cargo flow are held by the Czech Republic, Slovakia, Germany, Hungary, and Austria. Annual transit volumes in the Port of Szczecin amounted to 1,491,467 tonnes on average in 2016–2018. The modal structure of the hinterland transport in the port of Szczecin was determined solely for the years 2009–2014 since detailed data were available for that period only.

Excluding periodical and minor fluctuations in the shipments by transport modes, rail transport constituted 50% of the total cargo volume on average, the share of road transport reached 40%. In comparison, inland waterway transport retained its share at 11% of total hinterland transport.

In summary, as concerns, the port of Szczecin, the adverse trends in the growth rate of cargo throughput were mainly due to the limited port's accessibility from the sea. In the system of Polish seaports, the port in Szczecin plays the role of a small and medium-sized port (SMP) and is marginalized because the competing and major neighboring ports in Gdańsk, Gdynia, and Świnoujście have deeper waterways, canals, and basins as well as deep-water quays, thus, being able to serve larger vessels and increase their cost advantage in handling trade.

3. Literature Review

A review of research works on the port transshipment quantitative forecasting revealed that: (1) the subject has not received much attention and, most likely, an accepted guide on port throughput forecasting does not exist, (2) in practice, forecasts are usually based on casual relationships between port transshipments and demographic, economic, or industrial growth, (3) the majority of articles dealing with the subject do not relate to casual models applied in practice, but instead they refer to methods that are based on mere trend extrapolation from historical data and trend-based models (Dorsser, Wolters, and Wee, 2011). By definition, models based on mere trend extrapolation are not suitable for long-term predictions.

Almost all the academic works on port throughput projections deal with container traffic only and take a pure modeling approach. The most common are: Univariate Autoregressive Moving Average Models (ARIMA) (Jarret, 2015; Klein, 1966); Vector Autoregressive Models (Veenstra and Haralambides, 2001); Seasonal Autoregressive Integrated Moving Average (SARIMA) (Chen and Chen, 2010); the neural network (Liu and Zang, 2007); the classical decomposition model; the trigonometric regression model; the regression model with seasonal dummy variables; the grey model (Sun and Zheng, 2007); the hybrid gray model and the SARIMA model (Peng and Chu, 2009); and error-correction models (Fung, 2002; Hui *et al.*, 2004) — these authors created a projection model of container transshipments for Hong Kong. A system dynamics model was developed to fit the trend of greater accuracy in forecasting container volumes and account for the port′s properties (Xu, Yan, and Zhang, 2006; Wang, Chou, and Yeo, 2013).

The purpose of the casual models is to determine a relationship between several variables and cargo transshipment in the ports. The most popular variables are the GDP and the size of the population. The GDP is a good indicator of port transshipments because it is determined by imports and exports, a function of the GDP. The demand for port services is an outcome of the demand for imports and exports. Economic textbooks indicate the presence of a correlation between economic activity (measured in GDP) and freight transport (measured in tonnes or tonne-kilometers (Meersman and Van de Voorde, 2008).

In a paper by Van Dorsser *et al.* (2012), a forecast was made with a very long-time horizon (the year 2100), based on a model that relates port transshipments to GDP growth. Another paper (De Lange, Meijeren, and Tavasszy, 2012) proposed a long-term forecasting approach that used a freight transport model combined with expert judgment and commodity-specific research.

The classical regression models are commonly used in practice. In a previous paper (Wang, 2009), the correlation coefficient between the GDP and container volume was estimated to be 0.97. Thus the GDP is a representative variable in forecasting. Wang constructed a one-dimensional linear regression equation to study the relationship between sports and the economy. In another paper (Chou *et al.*, 2008), a modified regression model to forecast the import container volume of Taiwan was developed. Applying a classical regression model to forecasting can be problematic because the outcomes are only valid if the variables are stationary. The variables that follow the same trend over time are closely related, while this is not necessarily true.

To avoid this problem, the error correction model (ECM) can be used. ECM is only valid if the variables have a genuine relationship over time (Van Dorsser *et al.*, 2011). A cointegration test can be used to check whether such a relationship exists (Hui *et al.*, 2004). The error correction models (ECM) and ordinary least squares (OLS) models have been used in the port of Antwerp for forecasting general and bulk cargo volumes as well as iron ore transshipments (Meersman, Moglia, and Van de Voorde, 2002).

Thus far, the research related to turnover forecasts has concerned major seaports and focused primarily on the container throughput forecasts. The issue of throughput forecasting in small and medium-sized ports has been omitted in the research. In contrast to major ports, cargo throughput projections in smaller ports cover many groups of cargo (not just containers) and are primarily determined by the relationships that arise between major and minor ports located in the given range.

4. Research Methodology

The present study aimed to prepare long-term forecasts of traffic and freight flows in SMPs. The research problem relates to determining a method that is relevant for the long-term transhipment forecasting in SMPs. We assumed that the SMP throughput forecasts should consider the development of essential ports and competition within the port system. The future demand for SMP services results from changes in the port system, with the development of smaller ports being determined by the development of large ports.

The relationships that emerge between major and minor ports located in a given range stem from competition and cooperation: (1) it is the essential ports that play a predominant role in shaping these relationships, (2) SMPs improve competitiveness against major ports by expanding their quantitative and qualitative capacity.

The proposed method of forecasting the SMPs' demand is, therefore, relative, as it refers to the estimation of the demand for services in major ports, and multi-stage, as the elaborated forecast for large ports is later revised and subsequently adapted to SMPs. In the first stage, the demand forecast for neighbouring major ports was made. It was necessary to estimate how much demand can be met by a given SMP in the second stage. Finally, the forecast should be validated for the constraints of SMPs to meet the demand.

The research focuses on the Polish port system to forecast the cargo throughput in the SMP of Szczecin. Recently, large-scale investments were made in the port of Szczecin to improve access to the port of Szczecin. The investments included the deepening to 12.5 m (+2.5 m) of a 67 km long waterway leading from the Baltic Sea to the port of Szczecin and the reconstruction of quays in the areas of general cargo handling and bulk cargo handling. This will enable the port to handle sea-going vessels with up to 40,000 tonnes and increase the handling capacity for the container, grain, and dry bulk cargo (coal, iron ore, and other bulk cargo) in the port of Szczecin.

The investment projects carried out in the period 2019–2023 are intended to contribute to the increased efficiency of sea transport (scale effects determined by the size of sea vessels) and the improved competitiveness of the port of Szczecin. Investment decisions require forecasts for 25 years ahead as ports generally have a long technical and economic life, and investments made in port infrastructure have a long pay-back period (De Lange, Van Meijeren, and Tavasszy, 2012).

The proposed research method involves three stages of prognostic works. In the first stage, forecasts of cargo throughput in the nation's major seaports Gdańsk, Gdynia, and Świnoujście were made. In the second stage, the obtained results were used to prepare the forecast of cargo throughput in the port of Szczecin. In the final stage, the forecast was validated considering the capacity limitations faced by the port of Szczecin and the expert judgments concerning the expected throughput of selected cargo groups.

To prepare forecasts of the cargo throughput in Polish seaports, regression models of the cargo throughput about the GDP were applied in the following general form (Bernacki and Lis 2019):

$$C_{tj} = \alpha_{1j} \cdot GDP_t + \alpha_{0j} + \xi_{tj} \tag{2}$$

where:

C_{ti}—the cargo throughput of the *j*-th group over period *t*;

GDP_t—the observations of the GDP over period t;

α_{1i}, α_{0i} —the structural parameters of the regression model for the j-th cargo group;

and

ξ_{ti}—the random component of the model over period t for the j-th cargo group.

The calculations were based on the Ministry of Development and Finance's long-term GDP forecast for long-term forecasts for the Polish transport sector. The GDP growth forecasts were expressed in the form of GDP growth indicators (year-on-year, the previous year = 100) and in PLN millions in constant average annual prices (Appendix A).

Initially, a reloading forecast was produced for major Polish seaports (Świnoujście, Gdynia, and Gdańsk), excluding the port in Szczecin, which resulted from the historical constraints to its development caused by inadequate transport accessibility. Pearson's correlation between cargo throughput in Polish seaports (excluding the port of Szczecin) and the Polish GDP was calculated. Transit cargoes were excluded from the calculations, as they are independent of the national GDP, as well as ro-ro cargoes, which, in turn, have no commercial significance for the port of Szczecin.

The resulting Pearson's correlation coefficients for groups of cargo, including bulk (coal + iron ore + other bulk), grain, conventional general cargo, container cargo, and oil and oil products, were found to be statistically significant, which made them useful for forecasting the cargo throughput in the important Polish ports of Gdańsk, Gdynia, and Świnoujście. Forecasts for the distinguished cargo groups were produced using regression models where the model parameters were estimated with the Ordinary Least Squares Method. The obtained forecasts of the total cargo throughput in major Polish seaports (without the port of Szczecin, transit, and ro-ro cargo) and the volumes of throughput of cargo groups were converted into dynamics indices. The resulting matrices of the cargo throughput dynamics indices established for the leading Polish seaports were used to prepare cargo throughput forecasts for the port of Szczecin.

The demand for transshipment services in the port of Szczecin was calculated as a product of the average volume of the domestic cargo throughput for cargo groups handled in the port of Szczecin between 2007 and 2019 and the indices of the demand dynamics for transshipments of individual cargo groups in the Polish seaports. In the following years, the forecast of the cargo throughput in the port of Szczecin was obtained by multiplying the volume of the domestic cargo throughput in the previous year by the index of demand dynamics for transshipment services in the current year.

In each subsequent year, the average volume of transit cargo for the years 2017–2019 was added to the predicted volume of the cargo throughput. At the final stage, the forecasted throughput volume in the port of Szczecin was validated using an expert method. The forecasted throughput volume was also verified against the existing and planned capacity of the port. As a result, the forecast of effective demand for transshipments in the port of Szczecin was obtained.

5. Research Results

5.1 Forecasted Demand for Transhipments in Major Ports

The size and generic structure of transshipments in the ports of Świnoujście, Gdynia, and Gdańsk, excluding Szczecin, transit cargo, and ro-ro cargo, are presented in the table below[1].

***Table 4**. Volume of cargo throughput in Polish seaports (tonnes) and GDP in current prices (PLN million) in years 2007-2019*

Year	Bulk (coal + iron ore + other bulk)	Grain	General cargo	Container cargo	Oil and oil products	Total	GDP at current prices (Millions of PLN)
2007	11,173,398	2,291,024	3,853,493	6,983,932	6,321,425	30,623,272	1,187,605
2010	14,131,874	2,479,052	4,680,855	7,602,173	6,140,243	35,034,197	1,445,298
2013	15,013,932	4,157,243	5,061,008	11,130,229	10,644,183	46,006,595	1,656,895
2016	13,646,050	5,875,588	7,016,536	13,941,782	13,804,260	54,284,216	1,861,112
2019	16,936,371	4,125,780	10,075,065	22,637,976	22,988,627	76,763,819	2,273,556

***Source:** Port authorities and the Central Statistical Office (GUS).*

To assess the usefulness of statistical-econometric tools for forecasting the cargo throughput, the strength of correlation between the cargo throughput of the Polish ports (excluding Szczecin, transit, and ro-ro cargo) and Poland's GDP was examined. Pearson's product-moment correlation coefficients were used. The list of correlation coefficients is included in the table.

***Table 5.** Pearson's linear correlation coefficients between GDP and cargo throughput of Polish ports by cargo groups in 2007-2019*

Year	Bulk (coal + iron ore + other bulk)	Grain	General cargo	Container cargo	Oil and oil products	Total
GDP	0.737	0.658	0.924	0.972	0.968	0.979

***Source:** Own study.*

The correlation coefficients for all cargo groups confirmed the high positive correlation between import and export transshipments in Polish seaports and the Polish GDP. This justified applying regression models of demand for transshipments of primary cargo groups against the GDP. The necessary condition was to obtain the statistical significance for the correlation coefficients. To this end, a significance test for the correlation coefficients was run on a small sample ($n = 13$). The value of the test statistics for the student's t-distribution was determined:

$$t = \frac{r_{xy}}{\sqrt{1 - r_{xy}^2}}\sqrt{n-2} \tag{3}$$

where:
r_{xy}—the coefficients of correlation among basic cargo group and GDP; and
n—the number of observations.

Then, the values of the test statistics were compared with the critical value of the test determined based on the student's t-distribution (a one-sample) for a predetermined level of significance and the number of degrees of freedom $df = n$-2. The null hypothesis of no statistical significance of the correlation was rejected in favor of the alternative hypothesis, assuming the statistical significance of the correlation if the value of the test statistic was more significant than the critical value. The statistics used to verify the statistical hypotheses and statistical significance of the correlation are presented below.

***Table 6**. Summary of statistics used for the statistical significance test of correlation coefficients between transshipments in export/import in Polish seaports and GDP*

Correlation coefficient	Bulk (coal + iron ore + other bulk)	Grain	General cargo	Container cargo	Oil and oil products	Total
GDP	0.737	0.658	0.924	0.972	0.968	0.979
n	13	13	13	13	13	13
test statistic t	3.616	2.900	7.985	13.745	12.844	15.842
significance level	0.05	0.05	0.05	0.05	0.05	0.05
t_a *(test critical value)*	1.796	1.796	1.796	1.796	1.796	1.796
Statistical significance of linear correlation coeff.	statistically significant					

***Source:** Own study.*

All the basic groups of transshipments in Polish ports of major economic importance were characterized by a statistically significant correlation with the Polish GDP.

The regression equations used to prepare the forecasts for groups of cargo in Polish ports are presented below:

- bulk (coal + iron ore + other bulk):

$$\hat{C}_{tm} = \underset{(1{,}538)}{4{,}562} \cdot GDP_t + \underset{(2\ 635\ 857)}{4\ 629\ 908}; \tag{4}$$

- grain:

$$\hat{C}_{tz} = \underset{(0{,}944)}{2{,}736} \cdot GDP_t - \underset{(1\ 617\ 218)}{852\ 475} \tag{5}$$

- conventional general cargo:

$$\hat{C}_{td} = \underset{(0{,}808)}{6{,}452} \cdot GDP_t - \underset{(1\ 384\ 597)}{4\ 881\ 745} \tag{6}$$

- container general cargo:

$$\hat{C}_{tk} = \underset{(1{,}106)}{15{,}207} \cdot GDP_t - \underset{(1\ 896\ 007)}{13\ 329\ 651} \tag{7}$$

- oil and oil products:

$$\hat{C}_{tr} = \underset{(1,277)}{16{,}408} \cdot GDP_t - \underset{(2\ 189\ 250)}{15\ 436\ 507}. \qquad (8)$$

Using the GDP growth forecast prepared by the Ministry of Development and Finance in 2019[2] and applying the extrapolation of cargo throughput models, the throughput forecasts for individual cargo groups for the years 2020–2043 were produced. The forecasts are summarized in the table below[3].

Table 7. *Forecasted throughput of cargo groups in major Polish seaports (tonnes)*

Year	Bulk (coal + iron ore + other bulk)	Grain	General cargo	Container cargo	Oil and oil products	Total
2019*	16,936,371	4,125,780	10,075,065	22,637,976	22,988,627	76,763,819
2020	17,744,480	5,598,758	10,329,167	22,523,594	23,249,139	79,445,138
2025	19,951,649	6,684,494	12,889,147	28,557,656	29,759,891	97,842,837
2030	22,237,287	7,808,830	15,540,141	34,806,243	36,502,115	116,894,616
2035	24,453,960	8,899,241	18,111,145	40,866,289	43,040,904	135,371,538
2040	26,581,680	9,945,894	20,578,977	46,683,152	49,317,297	153,107,000
2043	27,879,649	10,584,383	22,084,424	50,231,602	53,146,074	163,926,132

Note: ** The starting year for the preparation of forecasts was the actual throughput volumes in 2019.*
Source: *Own study.*

The highest expected dynamics in the forecast period were shown by such cargoes, as grain (+156.5%), oil and oil products (+131.2%), and container general cargo (+121.9%). The smallest increases were projected for conventional general cargo (+119.2%) and bulk cargo (coal, iron ore and other bulk) (+64.6%).

Next, chain indices were calculated, thus informing about expected increases in the throughput of cargo groups year on year. Table 8 presents the projected volumes of the cargo group throughput in Polish seaports, converted into dynamics indices.

Table 8. *Matrix of indices of demand dynamics for transshipments of individual cargo groups in Polish seaports in years 2020-2043 ($I_{i,t+1}$)*

Year	Bulk (coal + iron ore + other bulk)	Grain	General cargo	Container cargo	Oil and oil products	Total
2020	1.048	1.357	1.025	0.995	1.011	1.035
2025	1.023	1.034	1.042	1.045	1.046	1.040
2030	1.021	1.030	1.036	1.038	1.039	1.034
2035	1.018	1.024	1.028	1.029	1.030	1.027
2040	1.016	1.022	1.025	1.026	1.026	1.024
2043	1.016	1.021	1.023	1.024	1.025	1.023

Note: ** The starting year for the preparation of forecasts was the actual transshipment volumes in 2019.*
Source: *Own study.*

The matrix of indices of the demand dynamics for transshipments of individual cargo groups, as established for major Polish ports, was used to predict the demand for services of the SMP of Szczecin.

5.2 Forecasted Demand for Transhipment in Small and Medium Sized Port of Szczecin

Given the knowledge of transshipments in the port of Szczecin in 2019 and the chain indices of the forecasted increases in the cargo throughput in major Polish ports in the years 2020–2043, the following recursive equation was used to produce cargo throughput forecasts in the port of Szczecin:

$$C_{t,j}^{*} = C_{t-1,j}^{*} \cdot i_{t/t-1,j} + \bar{T}_{t-k-1,j} \tag{9}$$

where:
$C_{t,j}^{*}$—forecasts for *j*-th cargo group in time *t*;
$C_{t-1,j}^{*}$—forecasts for *j*-th cargo group in time *t*-1*;*
$i_{t/t-1,j}$—the annual chain indexes of dynamics of cargo throughput growth in *j*-th cargo group in major ports;
and
$\bar{T}_{t-k-1,j}$—the average level of transit in *j*-th cargo group determined from *k* time periods.

The fairway depth does not prevent multi-purpose ships and tankers from calling at the port in Szczecin. According to the information provided by forwarders in the port of Szczecin, the carriage of general cargo, chemical products, and oil products is performed by ships with a maximum carrying capacity of 12,000 tonnes and a draught not exceeding 9.15 m. Regarding sea relations to/from the port of Szczecin, no increase in the shipment size of these cargoes is expected in the future and, consequently, no increase in the size of the ships.

Therefore, we assumed for forecasting that the transshipments of general cargo and oil would not change. Therefore, we assumed for forecasting that general cargo and oil transshipments would remain at the average throughput volumes from 2007 to 2019. Table 9 shows the forecasted throughput volumes of individual groups of cargo. The predicted cargo throughput volumes were additionally limited by the handling capacity of the port of Szczecin.

Table 9. *Throughput forecast by cargo groups in port of Szczecin (tonnes)*

Year	Coal	Iron ore + other bulk	Grain	General cargo	Container cargo	Oil and oil products	Total
2020	1,630,214	4,022,226	1,188,335	2,037,224	700,672	228, 883	9,807,554
2025	1,793,407	4,503,193	1,418,652	2,037,224	888,382	228,883	10,869,741
2030	1,962,402	5,001,260	1,657,158	2,037,224	1,082,765	228,883	11,969,692
2035	2,126,297	5,484,298	1,888,468	2,037,224	1,271,283	228,883	13,036,453

2040	2,283,615	5,947,952	2,110,495	2,037,224	1,452,236	228,883	14,060,406
2043	2,379,584	6,230,795	2,245,938	2,037,224	1,562,623	228,883	14,685,046

Source: *Own study.*

Elaborated cargo throughput forecasts of the SMP of Szczecin predicted the long-term increase in transshipments by 4.9 million tonnes, from 9.8 million tonnes in 2020, to 14.7 million tonnes in 2043.

5.3 Forecasted Traffic and Freight Flows in Port–Hinterland Relations

The forecast of cargo throughput is the basis for the development of the forecast of the freight and traffic flow in the port of Szczecin–hinterland relation. The starting point was the modal split of cargo flow in the port–hinterland relation. Table 10 shows the average volume of freight flow for each cargo group in the years 2009–2014.

Table 10. *Average modal split of hinterland transport by cargo groups in port of Szczecin (in percent)*

2009-2014	Coal			Iron ore			Other bulk			Grain			General cargo			Containers		
	b	t	r	b	t	r	b	t	r	b	t	r	b	t	r	b	t	r
Average	23.5	12.3	64.1	0.98	17.6	81.4	8.5	46.	45.5	3.7	90.3	6.1	8.2	45.7	46.1	0.0	97.0	3.0

Note: *abbreviations: b – barges; t – trucks; r – railway.*
Source: *Own study based on data from port authority.*

The forecast of hinterland cargo traffic from/to the port of Szczecin was obtained by multiplying the forecasted volumes of individual cargo groups by the determined proportions of the traffic by transport modes according to the formula:

$$T^*_{t,m} = C^*_t \cdot p_{09-14,m} \tag{10}$$

where:
$T^*_{t,m}$—forecast of traffic by *m*-th mode of hinterland transport in *t*-th year;
C^*_t—forecast of total freight flow in the port in *t*-th year; and
$p_{09-14,m}$—the average share of traffic by *m*-th mode of hinterland transport in 2009–2014.

Table 11*. Forecasted freight flow by means of hinterland transport in port of Szczecin*

Year	Freight (tonnes) barges	trucks	rail	Total	Structure (%) barges	trucks	rail	Total
2020	851,190	4,318,980	3,705,205	8,875,376	9.59%	48.66%	41.75%	100.00%
2025	979,926	5,427,747	4,462,069	10,869,741	9.02%	49.93%	41.05%	100.00%
2030	1,065,951	6,063,016	4,840,724	11,969,692	8.91%	50.65%	40.44%	100.00%
2035	1,149,381	6,679,118	5,207,954	13,036,453	8.82%	51.23%	39.10%	100.00%
2040	1,229,463	7,270,496	5,560,448	14,060,406	8.74%	51.71%	39.55%	100.00%
2043	1,278,315	7,631,253	5,775,478	14,685,046	8.70%	51.97%	39.33%	100.00%

Source: *Own study.*

When forecasting the traffic flow by modes of hinterland transport, the following transport means typical for shipping cargo groups were considered: trucks, rail cars, and sets of barges, as presented in Appendix B.

Due to the organizational and commercial conditions of land freight transport to/from seaports, cargo shipments are destined for specific consignees, and each freight transport is organized specifically for a given shipment. This means that the transport is one-way, i.e., the transport modes (trucks, barges, and trains) deliver goods exported from the hinterland or import goods to the hinterland (therefore, there are no cargo transports in two directions). This translates into the movement of transport modes to/from the port. The transport modes arrive at the port with cargo and leave without cargo or arrive at the port without cargo and leave the port with cargo. Therefore, the predicted number of transport modes on the access routes to port reloading areas should be doubled.

The forecasted truck, train, and barge traffic to/from the port of Szczecin were obtained by dividing the size of the forecasted throughput of cargo groups by the load capacity of trucks, trains, and barges, thus, obtaining the annual number of trucks, trains, and barge sets on routes leading directly to the port transshipment areas. The forecasted traffic flow of transport modes was determined according to the formula:

$$N_{t,m} = \sum_{j=1}^{n} \frac{C_{t,j}^{*}}{L_m} \tag{11}$$

where:
$N_{t,m}$—the traffic intensity of the *m*-th transport mode in time *t*;
$C_{t,j}^{*}$—forecasted traffic of *j*-th cargo group in time *t*; and
L_m—the load capacity of the *m*-th transport mode.

Detailed results of the calculations related to the projected traffic of trucks, trains, and barges (multiplied by two: entry and exit) serving the berths of the port of Szczecin are presented in an excel spreadsheet, while the summarized results are presented in Table 12.

The traffic forecast for roads leading directly to the port reloading areas can be produced using statistical data on the truck distribution at the entry gates to the port areas. By multiplying the forecasted volume of total truck traffic to the port by the shares of the truck traffic at the port entrance gates, we obtained the annual number of trucks on roads leading directly to the port loading areas. The forecast of the truck traffic flow was obtained according to the formula:

$$N_{t,vehicles,g} = N_{t,vehicles} \cdot s_g, \tag{12}$$

where:

$N_{t,vehicles,g}$—the truck traffic flow at the g-th port gate at the t-th time;
$N_{t,vehicles}$—the truck traffic flow in the port at the t-th time; and
s_g—the share of truck traffic flow at the g-th port gate.

Table 12. *Forecasted traffic flow by trucks, trains and barge sets to/from port of Szczecin*

Year	Means of transport (units)		
	barges	trucks	trains
2020	1,298	757,178	3,222
2025	1,452	920,982	3,558
2030	1,616	1,090,606	3,906
2035	1,772	1,255,112	4,244
2040	1,922	1,413,020	4,567
2043	2,014	1,509,348	4,765

Source: *Own study.*

The above equation makes it possible to distribute the projected truck traffic by the port entrance gates. Thus, it helps to determine the predicted intensity of truck traffic on the roads leading to reloading areas of the port.

6. Conclusions and Discussion

To our knowledge, there are no studies available forecasting the demand in small and medium-sized seaports. In this paper, the method, and results of the long-term forecasting of cargo throughput in a small and medium-sized port were elaborated concerning the Polish port system. Because of structural constraints related to poor transport accessibility, the port in Szczecin encounters barriers to development and loses its transport importance. The major neighboring ports of Gdańsk, Gdynia, and Świnoujście are capable of handling larger vessels and, thus, have a competitive advantage over the port of Szczecin. They are constantly increasing their cargo throughput.

When throughput forecasts are produced with direct reference to the trends and internal conditions in the port of Szczecin, they are burdened with structural limitations to the port's growth and ignore its relations with the major ports. Numerous studies confirm that their relations with essential ports determine the cargo throughput growth in smaller ports.

These relations, in turn, depend on competition and complementarity in handling the growing demand for services by essential ports. In our case, these are the relations within a group consisting of three major Polish ports (i.e., Świnoujście, Gdańsk, and Gdynia) and the SMP of Szczecin. The proposed method to forecast the demand for SMPs' services is, therefore, relative, as it refers to the estimated demand for transshipments in essential ports, and it uses the obtained indices of transshipment dynamics in important ports to develop forecasts of the cargo throughput in SMPs. The demand forecast is subject to verification concerning the capacity per individual cargo group and is adapted to the SMPs' operation and growth conditions.

Forecasts for the individual cargo groups in large Polish ports were developed using estimated regression models. The forecasts made for large ports excluded the port of Szczecin, transit cargoes (that are independent of the national GDP), and ro-ro cargoes that, in turn, are of no commercial significance at the port of Szczecin. The resulting forecasts of the throughput of cargo groups in important ports were converted into dynamics indices, which were then used to prepare the preliminary forecast of the cargo throughput in the port of Szczecin. At the next stage, the forecast was verified against the existing and planned (due to the ongoing investments) capacity of the port and concerning expert evaluations for the predicted transshipments of individual cargo groups. The latter was based on questionnaire-based surveys and interviews with shippers and forwarders.

The cargo throughput forecast can be used to develop a forecast of the freight flow in the hinterland traffic and project the traffic flow of transport modes to/from the port's hinterland. However, the direct attribution of the cargo and traffic flow of transport modes requires detailed data on the proportion of transport modes in the flow of each cargo group. It is also necessary to know the distribution of the transport modes at the port's entrance gates and reloading areas. These issues cannot be overestimated when ensuring efficient cargo handling in the port, planning the capacity of last-mile transport connections, and creating an efficient port-city interface.

Elaborated cargo throughput forecasts indicate that, in the future, the port in Szczecin will retain its universal character, and a moderate increase in the cargo throughput confirms that it will serve as a complementary port to the major ports in the range. The forecasted modal split of hinterland transport indicates the increasing importance of road transport, and a decreased rail and inland waterway transport to/from the hinterland. That is likely due to a lower cargo throughput and difficulties in organizing the rail and inland waterway corridors based on smaller freight volumes. The presented computations show that the number of trucks serving the forecasted cargo transshipments will increase, which should be considered when designing and expanding the road system in the port vicinity.

The limitations of the study result from the adopted assumptions and the prognostic data used in the research. The forecasting of the cargo throughput in smaller ports covers many cargo groups and is primarily determined by the relationships that arise amongst major and minor ports located in the range. It is difficult to determine to what extent the forecasted throughput volumes in SMPs result from their cooperation with large ports in handling the growing demand, and to what extent is the improvement of the competitive position of the SMPs and to seize emerging market niches. In the research, these relations were not distinguished, but we assumed that the total impact of the above relations is reflected in the transshipment dynamics indices that were established for important ports and then treated as a reference for producing throughput forecasts for SMPs. When forecasting transshipment for major ports, we used the historical relationship between throughputs and Polish GDP, while in the future, this relation may alter with unknown magnitude and direction.

Moreover, the Polish GDP forecast is also questionable given the current global pandemic situation caused by Covid. Furthermore, future structural social and economic changes and shocks may affect projected cargo volumes, which are unpredictable. Therefore, the question of the elaborated port demand forecast's reliability remains valid.

Further research should focus on the problems of complementarity and competition in multi-port systems. In the context of dynamics of port systems, there are issues related to the supply growth, the processes of de-concentration of port systems, the regionalization of cargo flow, and, finally, to the forms of cooperation between ports in handling the demand in major ports. It is also essential to continue research on the geographical and functional definition of relevant port systems and to identify the relationships of competition and cooperation between major ports and SMPs. Inclusion in the research the probabilistic forecasting solutions and sensitivity analysis is also encouraged.

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Notes:

[1] *Unless stated otherwise, all conversions apply to transshipments in Polish seaports excluding the port of Szczecin, transit, and ro-ro cargo.*
[2] *The forecasts did not consider the impact on the economy of the COVID 19 pandemic caused by the SARS-CoV-2 virus.*
[3] *Calculations for the entire time series in forecasting horizon are available on request.*

Appendix A*. GDP growth forecast for 2017-2043 expressed in GDP growth indicators (calculated year-on-year, previous year = 100)*

Year	Change in Polish GDP (In annual average constant prices)	Polish GDP forecast (In annual average constant prices in PLN millions)
2019	104.0	2,273,556.0
2020	103.7	2,357,677.6
2025	103.0	2,754,472.2
2030	102.7	3,165,373.7
2035	102.2	3,563,877.0
2040	102.0	3,946,388.7
2043	101.9	4,179,731.6

Source: *Polish Ministry of Development and Finance 2019.*

Appendix B*. Modes characteristics in hinterland transport from/to port of Szczecin*

Road transport	Load factor per transport mode (tonnes)
1 truck + semitrailer for 2 TEU (40' container)	18.8
dump trucks with bulk cargo	20

dump trucks with grain	18
trucks with general cargo	18
semitrailer tanker for the transport of fuels	34
semi-trailer (three-axis) for the transport of LPG	25
Rail transport	
2TEU container wagons, train sets of 30 container platforms	19.6
grain/other bulk tank wagons, train sets of 35 wagons	40
wagons for dry bulk cargo, train sets of 35 wagons	50
general cargo wagons, train sets of 35 wagons	40
Inland waterways	
barge sets consisting of a pusher tug and two pushed barges, each with a load capacity of 500 tonnes.	1000

Source: *Own study.*