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EFFICIENCY ASSESSMENT OF SOME DANUBE PORTS BY USING DEA WINDOW ANALYSIS

Summary. The aim of this paper is to empirically assess the efficiency / inefficiency of five Danube ports in five neighbouring countries and to observe how it evolves over an eight-year period ranging from 2014 to 2021. The five ports are located on the lower course of the Danube River and are the most important in their states: Smederevo (Serbia), Ruse (Bulgaria), Galați (Romania), Giurgiulești (Moldova), and Izmail (Ukraine). The study uses a mixed-method, namely the Data Envelopment Analysis (DEA) window analysis method and Andersen and Petersen's super-efficiency model to evaluate the efficiency of these ports over time. Port efficiency analysis is based on a single output, i.e. the cargo throughput, and four inputs: the total port area, the total area of warehouses, the quay length, and the number of cranes. It was determined that none of the five ports analysed reaches the maximum efficiency of 1.000, their average efficiency being quite low, only 0.631. The highest average efficiency is recorded by the Serbian port of Smederevo, with 0.768, this port being found to make good use of its resources for production. On the other extreme, the Bulgarian port of Ruse was found to be the least efficient port, obtaining the lowest average efficiency over an eight-year period, with only 0.360. The study tries to capture the causes of the inefficiency of selected ports and propose some measures to improve their efficiency.

Keywords: DEA window analysis, Andersen and Petersen's super-efficiency model, Danube River ports, port efficiency

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1. INTRODUCTION

It is well known today that any human activity, any type of organization (enterprises, banks, schools, hospitals, ports, etc.) in which people are involved is subject to the evaluation process to establish any sources of inefficiencies. Evaluation requires a systematic determination of the value of any activity or organization and measuring it based on clear criteria. One of these criteria is efficiency. From this perspective, evaluation is a first step in adopting those measures that can improve efficiency. That is why benchmarking similar organizations is very important and necessary.

River transport is currently experiencing an increasing development worldwide due to the multiple advantages it has over the other communication routes. Among these advantages, it can be mentioned the following ones: the least expensive transportation modes, transportation of a large quantity of goods, a good solution for all kinds of goods (especially bulk cargo), safety in transporting even dangerous goods, minor damage in case of very rare accidents, lower environmental impact, etc. Fluvial ports, serving as the interface between maritime and inland transportation, play a significant role in the economic development of a region. Ports are the engines of growth in their host cities and regions, being multimodal hubs with varying levels of intermodal facilities. One of the most significant characteristics of Danube ports is that they are located on the Trans-European Transport Network (TEN-T) (central network TEN-T Rhine-Danube/Alps) transited by several important transport corridors. Some of them can strengthen their role as regional distribution centres. Therefore, the competition between ports is more intense nowadays than it used to be.

The Danube River is a very important transport corridor – Pan-European corridor VII (the only inner channel between Pan-European corridors X). The corridor VII links 10 European countries which have exits to the navigable parts of the river Danube. As corridor VII, the Danube River is a significant line of communication, especially after the opening of the Rhine-Main-Danube canal (1992). The Danube links the Black Sea with the West European industrial centres and the port of Rotterdam [42].

The objective of the study is to evaluate the efficiencies of ports to identify the sources of inefficiencies and propose some measures to improve port activity.

To the author's knowledge, no empirical study has been undertaken to determine the relative efficiency of the most important five ports in five neighbouring countries on the lower course of the Danube River.

The present study is further organised as follows: section 2 presents the literature survey, section 3 the materials and methods, the results and discussions are provided in section 4, and finally, the conclusions are presented in section 5.

2. PORT EFFICIENCY: LITERATURE SURVEY

Data Envelopment Analysis (DEA) is a non-parametric method that measures the relative efficiency of decision-making units (DMUs) based on multiple inputs and outputs. The method was developed and launched by Charnes, Cooper and Rhodes in 1978 [8], the CCR (or CRS – constant return to scale) model and by Banker, Charnes and Cooper in 1984 [6], the BCC (or VRS – variable return to scale) model. In 1982, Charnes, Cooper, Divine, Klopp and Stutz [9] first used DEA window analysis to determine the efficiency of district army recruitment offices [10], a non-parametric panel method for dynamically evaluating decision-making units over several years.

Since then, thousands of scientific articles have appeared using the two methods to evaluate decision-making units in different fields of activity, including the port industry, most of them using the cross-sectional data model.

In the 1990s only a few studies applied the DEA method, while during and after the 2000s, the DEA technique was gradually expanded to compare ports from all over the world. The first attempt to assess port performance dates back to 1993 and belongs to Roll and Hayuth [43], information found in the work done by [12]. Based on hypothetical data and using the DEA-CCR model, the two authors measure the efficiency of 20 ports using four inputs (the number of employees, annual investment per port, the uniformity of facilities, and cargo traffic) and four outputs (the number of containers, the level of service, customer satisfaction, and the number of ship stop-over). In contrast, Martínez-Budría et al. [30] use three inputs (labour expenditures, depreciation charges, and ”other expenditures”) and two outputs (total cargo, measured in tonnes, and the revenue obtained from the rent of port facilities) and classify 26 Spanish ports into three groups: ”high complexity ports”, nine ports with relative efficiency 0.887 (of which Algeciras, Barcelona, and Tenerife have 1.000 efficiency in each year of the period 1993-1997), ”medium complexity ports”, 11 ports with 0.801, and ”low complexity ports”, six ports with 0.857. The average efficiency of the three port groups is 0.848. Tongzon, cited in reference [46], diversifies inputs to estimate the efficiency of four Australian ports and 12 international container ports for 1996. It uses the DEA-CCR model and DEA-Additive model, with six inputs: the number of berths, cranes and tugs, the number of port authority employees, the terminal area of the ports, amount of delay time, and two outputs: cargo throughput (in TEUs – Twenty-foot Equivalent Units – a container of 20 feet long) and ship working rate. The analysis found that Melbourne, Rotterdam, Yokohama, and Osaka are found to be the most inefficient ports in both models, while the other ports are efficient in one model and inefficient in another. As for Valentine and Gray [48], they used the DEA method to examine 31 container ports out of the world's top 100 container ports for 1998. The ports of Hong Kong, Singapore, and Santos have 1.000 efficiency resulting from the use of two inputs (total length of berth and container berth length) and two outputs (total throughput in TEUs and the number of containers). Concerning Ito [26], he applies DEA window analysis to measure the operational efficiency of eight Japanese container ports for the period between 1990 and 1999, Tokyo having the highest efficiency score. Barros and Athanassiou [7] calculate the efficiency of ports in two European countries, Greece and Portugal, over the period of 1998-2000, using DEA-CCR and DEA-BCC models.

Cullinane et al. [13] consider five inputs to find out the relative efficiency of 25 international container ports by applying DEA window analysis during the time period 1992-1999. The inputs used were as follows: the quay length, the terminal area, the number of quay gantry cranes, the number of yard gantry cranes, and the number of straddle carriers. The study authors used only one output: the container throughput (in TEUs). The highest efficiency was achieved by Los Angeles (0.980).

Over the past two decades, most studies that have applied DEA window analysis to measure port efficiency around the world have applied almost the same inputs used by Cullinane in his study. However, other inputs were also used, namely: the number of berth (and quays), the number of docks, the number of terminals, the area of warehouses, the number of employees, the number of reach stackers, the number of tractors, the number of forklifts, the number of transshipment destinations, the number of straddle carrier, the number of tugs, the depth alongside, etc. In contrast, almost all studies used a single output: the container throughput (in TEUs), and very rarely, a second output: the number of ship calls. As a rule, inputs used to study port performance can be organised into three groups: the infrastructure (e.g. the terminal area and the storage area), the equipment (the number of yard handling machines and the number of cranes), and the labour (the number of employees and the number of port authority workers).

Many studies have appraised the performance of ports in Africa applying not only DEA window analysis, but especially the conjunction with other models (DEA-CCR, DEA-BCC, Stochastic Frontier Analysis, Malmquist Index, etc.). All studies mentioned below have applied DEA window analysis to evaluate port performance, except for the study conducted by Demirel et al. [20].

Al-Eraqi et al. [3] use DEA-CCR and DEA-BCC models, both cross-sectional data and window analysis (panel data) to assess efficiency of 22 ports in the Middle East and East Africa. From the year 2000 to the year 2005, the most efficient port in these two regions was Khor Fakkan Sharjah (United Arab Emirates), with a score of 0.973. Furthermore, Al-Eraqi et al. [4] use in another article DEA with window analysis model (panel data) to evaluate the efficiency of cargo seaports situated in the regions of East Africa and Middle East. This paper is the first study to use super-efficiency with window analysis to compare the efficiency estimated with the normal efficiency and with super-efficiency. Nwanosike et al. [36] find Apapa (0.841) to be the most efficient port of the six Nigerian ports analysed regarding the period 2004-2010. For the purpose of estimating the Tunisian port's performance, Zghidi, cited in reference [51], appealed to the DEA-BCC window analysis model. The average efficiency for all six ports is 0.711 covering a range of five years (2005-2010), with Gabès having the highest efficiency score (0.940). For van Dyck [49] and Acquah [2], Tema (Ghana) is the most efficient port of the six African ports measured over six/seven years (2006-2012/2006-2013), with a score of 0.910 in both works. The same score was recorded by the port of Abidjan (Ivory Coast). In van Dyck’s study, the least efficient port is Cotonou (Benin). Tema (Ghana) is also the most efficient port (0.940) of the eight East and West African ports assessed by Gamassa and Chen [24] observed during the period ranging from 2008 to 2014, and the least efficient port is Dar es Salaam (Tanzania). The results of their study confirmed that, in West Africa, the most efficient seaport is Tema in Ghana. The two authors also conclude that East African ports are more efficient than West African ports. Tema (Ghana), Lomé (Togo), and Douala (Cameroon), all with a score of 0.990, are the most efficient ports out of the seven West African ports assessed over the time starting from 2006-2013 by Miezah and Whajak [31]. Of the five African ports measured, Abdoulkarim et al. [1] find Mombasa (Kenya) with maximum efficiency (1.000) during the period 2014-2017. Dewarlo, cited in reference [22], measures the relative efficiency of four Indian Ocean Island ports between 2008 and 2011 and estimates that Louis Port (Mauritius) records the highest efficiency value, 0.940. Finally, Mwendapole et al. [33] study the efficiency of six South and East African ports covering the period of nine years (2010-2019), finding Durban (South Africa) as the port with maximum efficiency (1.000).

In Asia, the most efficient were the terminals in Busan, out of the 11 container terminals of Korean ports Busan and Kwangyang analysed in the time-lapse ranging from 1999 to 2002 [32], Johor Port (0.991), in 2000-2005, of six Malaysian container ports, plus Singapore as a reference [35], Bangkok (1.000), of four container ports in Thailand, between 2006-2013 [40], Shahid Rajaee/Bandar Abbas (0.890), from five Iranian ports, observed from 2009 to 2018 [50], Green Terminal, throughout the period 2010-2019, from 15 container terminals in the Hai Phong area in Vietnam [38]. Worth citing also is the study conducted by Den et al. [21], who applied DEA window analysis to examine the efficiency of 11 seaports in Russia (5 seaports) and South Korea (6 seaports) between 2012 and 2014. They ended up concluding that South Korean container terminals exhibited higher efficiency scores than their Russian counterparts.

Leem, cited in reference [28], analyses the relative efficiency of 10 ports in the Middle and South America from 2000 to 2005 using DEA-CCR and DEA-BCC models in both variants, with cross-sectional and panel data (window analysis). The most efficient port is Puerto Manzannillo (Panama), with an efficiency score of 0.952.

Concerning Cullinane and Wang [13], they implemented DEA panel data to investigate the efficiency scores of 25 leading container ports. With respect to Seth and Feng [45], they conclude in their study that the most efficient port out of 15 USA container ports is Los Angeles (0.980) from 2000 to 2009. The two authors used six inputs slightly different from most of the studies mentioned above for port comparison, namely: the cost of port security measures, the container facilities infrastructure cost, the dredging cost, the berth length, the number of cranes, the container terminal acreage, and two outputs: the net income and the container through put (in TEUs).

A recent study by Kammoun and Abdennadher [27] employed DEA-CCR window analysis to estimate the efficiency of 30 European container ports between 2005 and 2018. The port with the highest efficiency was identified as Felixstowe (United Kingdom), with a score of 0.944.

Demirel et al. [20] apply DEA-CCR and DEA-BCC models to evaluate the relative efficiency of 16 Mediterranean container ports for the time series 2006-2008. The study also calculates the efficiency of Constanța CSTC (Constanța South Container Terminal) located on the Black Sea coast, the results being 0.809 CCR efficiency and 0.840 BCC efficiency. Liani, cited in reference [29], uses window analysis, finding an efficiency of 0.866 for 17 Mediterranean container ports over the time period 2013-2019.

This paper comes closest to the study of Pjevčević et al. [39]. The authors adopted DEA-CCR window analysis to compare five Serbian Danube ports regarding the period 2001-2008. The port of Pančevo has the highest efficiency (0.861). Four inputs were employed, namely: the total area of warehouses, the quay length, and the number of cranes, and one output: the cargo throughput (in tonnes).

3. MATERIALS AND METHODS

3.1. Study area and ports

The Danube River (Figure 1) is the second longest in Europe after the Volga. It rises in the Black Forest mountains of Western Germany and flows for some 2,850 km to its mouth on the Black Sea. Along its course it passes through 10 countries: Germany, Austria, Slovakia, Hungary, Croatia, Serbia, Bulgaria, Romania, Moldova, and Ukraine [23]. Along its course, many river ports have been laid out in every country through which this river passes.

This study assesses the relative efficiency of five Danube River ports in five neighbouring countries. These ports are located at the end of the middle (or Pannonian) sector of the Danube (Smederevo) and in the lower (or Carpatho-Balkan) sector of the river (Ruse, Galați, Giurgiulești, and Izmail).

The port of Smederevo (Figure 2) is located on the territory of Serbia, in the centre of Smederevo, known as the iron city, with a major steel mill. It is positioned on the right bank of the river Danube, on the stretch from rkm (river kilometer) 1,116 to rkm 1,111, at a distance in a straight line of about 40 km from the border with Romania, Baziaş area, and 45 km downstream from the capital and port of Belgrade. The flow of goods is composed of iron ores and metal ores, metals and metal products, petroleum products, coal and lignite, and agricultural, forestry, fishery products and live animals [19]. Smederevo was named in a presentation of the Danube Commission in 2019 as" the fastest growing port on the Danube" [47]. In recent years, the port has benefited from massive investments from the Serbian government.

The port of Ruse is the largest river port on the Danube and the third-largest port in Bulgaria, after Burgas and Varna. It is located on the right bank of the Danube, between rkm 489 and rkm 491 (Port terminal Ruse-East) and between rkm 497 and rkm 496 (Port terminal Ruse-West).

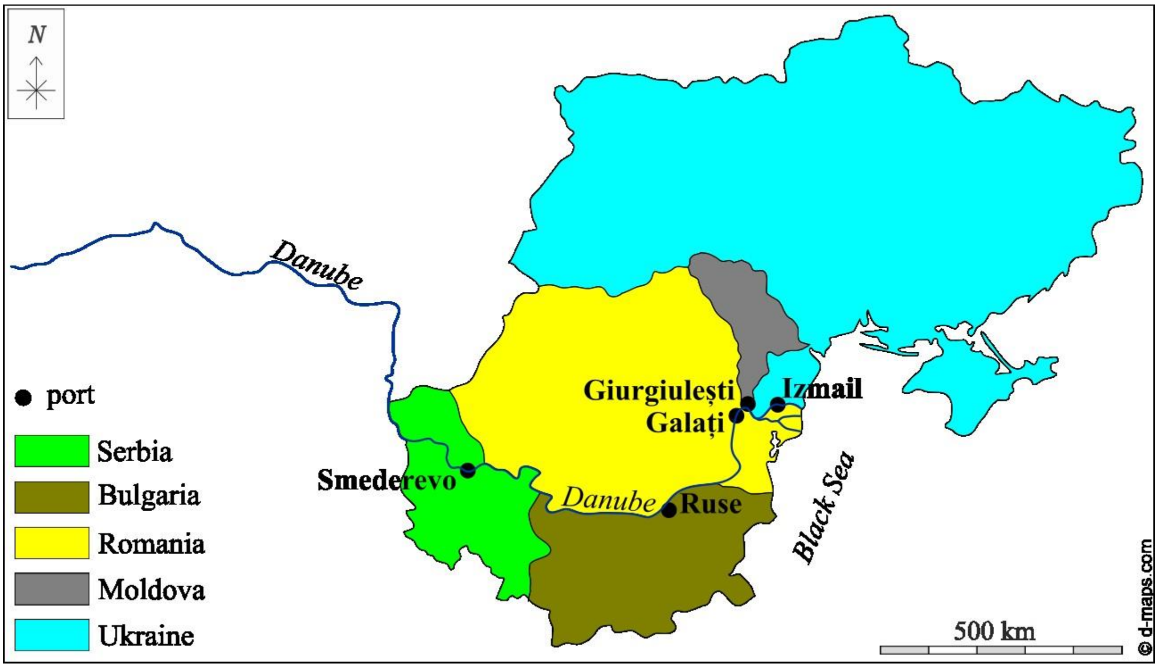

Fig. 1. Study area (Source: own elaboration)

Fig. 2. Port of Smederevo (Serbia) (Source: Israfoto)

It developed as a multimodal centre (naval, rail, and road). In the port are loaded/unloaded bulk cargo, general cargo, and any other type of cargo from and on river vessels, road, and rail transport. The port of Ruse-East also includes a container terminal and a Ro-Ro terminal [34].

The port of Galați is the largest river and seaport on the Danube and the second-largest port in Romania, after Constanța. Like the city of Smederevo, Galați is the centre of the steel industry in Romania, where there is one of the largest steel mills in the Southeastern Europe. The port is located on the left bank of the Danube at 158 rkm. It consists of two harbour basins (Docuri and Bazinul Nou) with several terminals (mineral, for the steel mill in the city, commercial, etc.). It specializes in transshipment of the following types of goods: dry bulk, break bulk, high and heavy cargo, petroleum products refined, liquid bulk, crude oil, etc. The port has facilities for the operation and storage of cereals (30,000 t capacity) [17].

The port of Giurgiulești is the only river and seaport of the Republic of Moldova positioned on the 430 m of the Danube, the one that ensures the exit of this country to the Black Sea. It is located in the southernmost point of the country, on the left bank of the Danube at 134 rkm. It has several terminals: oil terminal, for transshipment of petroleum products, vegetable oil, liquid fertilizer, general cargo terminal, for dry bulk cargo (grain and seeds, coal and petcoke, construction materials, stones, sand), break bulk cargo (big bags, equipment, machinery), container terminal. Furthermore, it also has large grain storage facilities (50,000 t capacity). The entire territory of the port has the status of a free economic zone until 2030 [16].

The port of Izmail is the largest of Ukraine's four river-sea ports located on the Danube. It is located on the left bank of the Chilia mouth between rkm 94 and rkm 85. It is one of the most modern and highly mechanized ports on the Danube. It is also a major transport hub, which has closely intertwined the operation of sea, river, rail, and road transport. The transshipped goods are as follows: metal ores, metals, and metal products, coal and lignite, sands, stones, building materials, chemicals, and petroleum products, etc. [18]. It also has a container terminal [19].

3.2. Datasets and variables

The data used in this study comes from several sources. Thus, freight traffic data for the five Danube ports for the period 2014-2021 were collected from the Danube Commission's website, namely from two sources: *Annuaire statistique de la Commission du Danube pour 2014-2021* [14] and *Observation du marché de la navigation danubienne*, results for 2019, 2020 and 2021 [15]. The other data series were extracted both from the factsheets produced by the Danube Commission for the ports of Galați, Giurgiulești, and Izmail, as well as from the websites apdmgalati.ro [41] and gifp.md. [25]. Data on the ports of Ruse and Smederevo were collected from studies by [34] and [42].

For calculating the efficiency scores of the five ports using DEA, the present study considers a single output, the cargo throughput, and four inputs: the total port area, the total area of warehouses, the quay length, and the number of cranes.

The cargo throughput represents the total amount of cargo which is loaded/unloaded by port equipment in the coastal operational area during the year in total tonnes of cargo.

The port area is a special object area which is used to represent the physical limits of all the facilities which constitute the terrestrial zone of an inland port. It can be measured in m^2 or ha.

The area of warehouses is the area inside the port area where the operations of receiving, putting away, storing, packing, and shipping goods take place. It includes both covered storages and open storages. The total area requires the quantity of cargo that could be unloaded and stored within the port area if loading does not take place directly from ship-to-ship or goods are not transferred from the port area into rail/road vehicles.

The quay length is an important input in evaluating port efficiency. In general, the length of the quay differs from port to port. River ports have smaller port areas than seaports, and the length of the quay depends on the length of ships travelling on the river.

The number of cranes influences the increase in the amount of cargo transshipped within the port. A larger number of cranes allows several ships to dock simultaneously in the berths and quays of the port for loading/unloading goods. This number includes all types of cranes used for transhipment of goods: gantry cranes, mobile cranes, floating cranes, luffing-slewing crane, and wharf cranes (transcontainer).

Table 1 presents the classification and definition of input and output variables used to perform the analysis. It is based on one output and four inputs.

Tab. 1

Descriptive form of input and output variables
(Source: own elaboration)

Classification	Variables	Definition
Input	Port area	The total area of the port in square meters (m^2)
	Area of warehouses	The total area of warehouses in square meters (m^2)
	Quay length	The total quay length in meters (m)
	Cranes	The total number of cranes
Output	Cargo throughput	Annual cargo throughput in tonnes (t)

Table 2 provides an overview of input and output variables for each of the five ports and per year of the 2014-2021 time period.

Tab. 2

Input and output variables
(Source: [14], [15], [25], [34], [41], [42])

Port	Year	Cargo throughput (t)	Total port area (m^2)	Total area of warehouses (m^2)	Quay length (m)	Number of cranes
Smederevo (Serbia)	2014	1,553,000	433,384	2,700	1,000	11
	2015	1,813,000	433,384	2,700	1,000	11
	2016	2,466,000	433,384	2,700	1,000	11
	2017	1,070,000	433,384	2,700	1,000	11
	2018	1,390,000	433,384	2,700	1,000	11
	2019	4,040,000	433,384	2,700	1,000	11
	2020	2,612,000	433,384	2,700	1,000	11
	2021	3,168,000	433,384	2,700	1,000	11
Ruse (Bulgaria)	2014	1,166,000	825,533	243,000	3,136	27
	2015	1,166,000	825,533	243,000	3,136	27
	2016	3,797,000	825,533	243,000	3,136	27
	2017	3,797,000	825,533	243,000	3,136	27
	2018	2,456,000	825,533	243,000	3,136	27
	2019	2,699,000	825,533	243,000	3,136	27

	2020	2,812,000	825,533	243,000	3,136	27
	2021	1,550,000	825,533	243,000	3,136	27
	2014	3,515,000	868,656	219,000	7,065	50
	2015	4,318,000	868,656	219,000	7,065	50
	2016	4,535,000	868,656	219,000	7,065	50
Galați	2017	4,327,000	868,656	219,000	7,065	50
(Romania)	2018	4,351,000	868,656	219,000	7,065	50
	2019	5,138,000	868,656	219,000	7,065	50
	2020	5,256,000	868,656	219,000	7,065	50
	2021	5,846,000	868,656	219,000	7,065	50
	2014	850,600	1,200,000	50,000	1,200	3
	2015	867,800	1,200,000	50,000	1,200	3
	2016	886,400	1,200,000	50,000	1,200	3
Giurgiulești	2017	1,591,000	1,200,000	50,000	1,200	3
(Moldova)	2018	1,889,000	1,200,000	50,000	1,200	3
	2019	1,299,000	1,200,000	50,000	1,200	3
	2020	1,185,000	1,200,000	50,000	1,200	3
	2021	1,819,000	1,200,000	50,000	1,200	3
	2014	3,093,000	1,074,712	221,000	3,770	48
	2015	4,825,000	1,074,712	221,000	3,770	48
	2016	5,682,000	1,074,712	221,000	3,770	48
Izmail	2017	5,097,000	1,074,712	221,000	3,770	48
(Ukraine)	2018	4,683,000	1,074,712	221,000	3,770	48
	2019	4,283,000	1,074,712	221,000	3,770	48
	2020	3,245,000	1,074,712	221,000	3,770	48
	2021	4,071,000	1,074,712	221,000	3,770	48

Table 3 illustrates descriptive statistics summarizing the characteristics of input and output variables used in this study.

Tab. 3

Descriptive statistics of variables
(Source: own elaboration)

Statistics	Variables	Cargo throughput (t)	Total port area (m^2)	Total area of warehouses (m^2)	Quay length (m)	Number of cranes
No. of observations		5	5	5	5	5
Maximum		5,846,000	1,200,000	243,000	7,065	50
Minimum		850,600	433,384	2,700	1,000	3
Range		4,995,400	766,616	240,300	6,065	47
Average		3,005,195	880,457	147,140	3,234	28
Standard deviation		1,521,858	261,867	100,107	2,196	19

Table 4 below provides an overview of the cargo throughput (in thousands of tonnes) in the five Danube ports for the period from 2014 to 2021.

Graphic representation of changes in port throughputs per years is shown in Figure 3.

Tab. 4

Cargo throughput (in thousands of tonnes) for the period from 2014 to 2021
(Source: [14], [15])

Port	2014	2015	2016	2017	2018	2019	2020	2021	Average
Smederevo	1,553	1,813	2,466	1,070	1,390	4,040	2,612	3,168	2,264.0
Ruse	1,166	1,166	3,797	3,797	2,456	2,699	2,812	1,550	2,430.4
Galați	3,515	4,318	4,535	4,327	4,351	5,138	5,256	5,846	4,660.8
Giurgiulești	850.6	867.8	886.4	1,591	1,889	1,299	1,185	1,819	1,298.5
Izmail	3,093	4,825	5,682	5,097	4,683	4,283	3,245	4,071	4,372.4

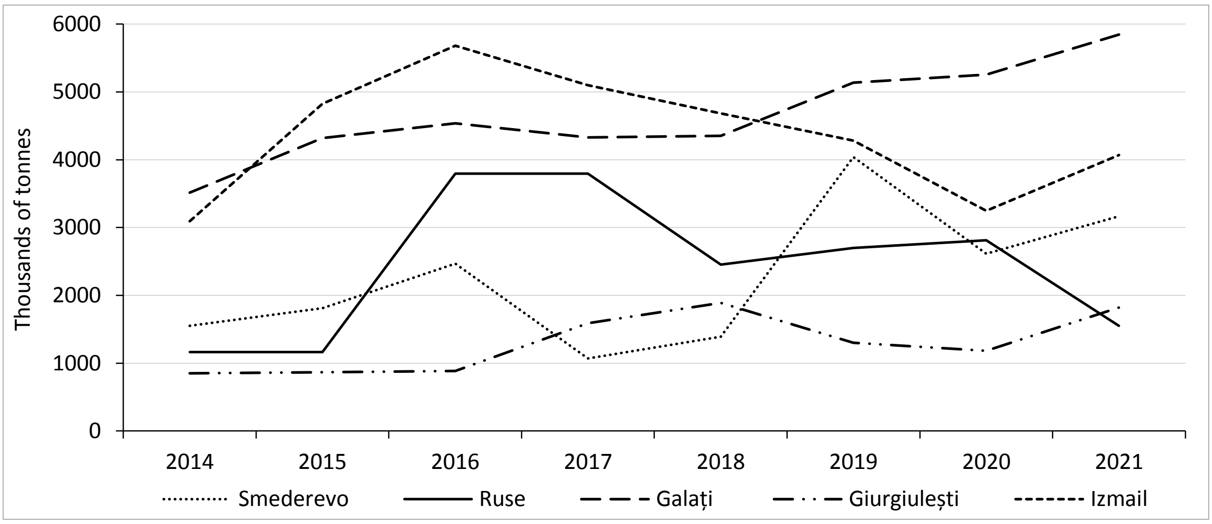

Fig. 3. Cargo throughput (in thousands of tonnes) for the period from 2014 to 2021
(Source: own elaboration)

From Table 4 and Figure 3, it can be clearly seen that all ports registered throughput oscillations. In a few cases, throughput variations are even very large from one year to another, for example, Ruse, between 2015 and 2016, Smederevo, between 2018 and 2019, and Giurgiulești, between 2016 and 2017. The only port that has an almost progressive increase in throughput is Galați. The largest cargo throughput is recorded by the ports of Izmail and Galați.

3.3. Data Envelopment Analysis (DEA)

The present study uses a descriptive-analytical method for assessing the performance of five ports located on the Danube River. It uses Data Envelopment Analysis (DEA), a non-parametric method for estimating the relative efficiency of a set of DMUs (Decision-Making Units). This method uses two sets of multiple variables called inputs and outputs, which are used to calculate an efficiency score (ratio) aligned to a number less than or equal to 1 but greater than or equal to 0. According to the DEA, the efficiency of a DMU is determined by its ability to convert inputs into desired outputs. It is a mathematical method based on linear programming (LP) for calculating border efficiency first introduced into the Operations Research (OR) literature by Charnes, Cooper and Rhodes [8], the CCR (or CRS – constant return to scale) model. The DEA-CCR model assumes constant return to scale so that a change in the input variables leads to an equiproportionate change in the output variables. The model developed by the three authors uses two variants: input-oriented and output-oriented. For this, study in particular, input-oriented productivity efficiency will be investigated.

Charnes, Cooper and Rhodes [8] propose the following model for obtaining the relative efficiency score of DMU:

$$\max h_p(u, v) = \frac{\sum_{k=1}^{s} u_k\, y_{kp}}{\sum_{j=1}^{m} v_j\, x_{jp}} \text{ for all } p = 1, 2, \ldots, n \tag{1}$$

$$\text{Subject to: } \frac{\sum_{k=1}^{s} u_k\, y_{ki}}{\sum_{j=1}^{m} v_j\, x_{ji}} \leq 1\ \forall i, \text{ and } u_k v_j \geq 0\ \forall k, j, \tag{2}$$

where:
n = the number of DMUs,
s = the number of outputs,
m = the number of inputs,
u_k = weight given to output k,
v_j = weight given to input j,
y_{ki} = amount of output k produced by DMU_i,
x_{ji} = amount of input j utilized by DMU_i.

Converting the computations above to Linear Programming (LP) form:

$$\max \sum_{k=1}^{s} u_k y_{kp} = \theta_p \tag{3}$$

$$\text{Subject to: } \sum_{j=1}^{m} v_j x_{jp} = 1 \tag{4}$$

$$\sum_{k=1}^{s} u_k y_{ki} - \sum_{j=1}^{m} v_j x_{ji} \leq 0\ \forall i,\ u_k,\ v_j \geq 0\ \forall k, j. \tag{5}$$

$$\text{CCR model: } \max \varnothing_k, \text{ Subject to: } \sum_{j=1}^{n} \lambda_j x_{ij} \leq \varnothing_r x_{ir} \quad i = 1, 2, \ldots, m; \tag{6}$$

$$\sum_{j=1}^{n} \lambda_j y_{rk} \quad r = 1, 2, \ldots, s; \quad \lambda_j \geq 0\ \forall_j, \tag{7}$$

where $\varnothing_k$ is the relative efficiency the k-th DMU.

To capture differences in port relative efficiency scores, this study uses DEA window analysis. This is a cross-sectional approach of calculating DEA through time series panel data. The window analysis is used for detecting efficiency trends over time. It is based on the principle of moving averages and it is useful to detect variations of the performance of a unit over time. Each unit in a different year is treated as if it was a" different" unit. Starting from this idea, the performance of a unit in a particular year it is not only compared to its performance in other periods but also to the performance of other units. In other words, the units of the same DMU in different years are treated as if they were independent of each other [50]. An important feature of this technique is that there are $n \times p$ units (DMUs), where n is the number of units, and p is the length of window. Before measuring the efficiency $n \times p$ relevant for each window, the length of the window p must be selected. There is no theory for the definition of window length. Actually, this choice is arbitrary. Based on three or four-year length (p), the efficiency scores obtained are convergent [10]. Cooper et al. [11] have determined the number of windows and the number of” different” units with the following formulas: $w = k - p + 1$ and $d = n \times p \times w$, where: w = number of windows, k = number of time periods, p = length of window, respectively d = number of” different” units and n = number of units.

This study also uses Andersen and Petersen’s super-efficiency model [5]. Based on efficiency scores achieved by DMUs, the DEA classifies DMUs into two groups: efficient and inefficient. Unlike the inefficient DMUs, the efficient ones cannot be ranked based on their efficiencies because of having the same efficiency score of unity (1.000). However, DMUs that achieve the maximum efficiency score can be differentiated by applying this model. In other words, super-efficiency is a ranking method to differentiate the performance of efficient DMUs.

The software Efficiency Measurement System (EMS) version 1.3 from Holger Scheel [44] was applied in this research for the computation of the efficiency score and super-efficiency of the five selected Danube ports with two models, called DEA-CCR (constant return to scale) window analysis input-oriented and Andersen and Petersen’s super-efficiency.

4. RESULTS AND DISCUSSIONS

This study assesses the performance of five river ports in five neighbouring countries along the Danube: Smederevo (Serbia), Ruse (Bulgaria), Galați (Romania), Giurgiulești (Moldova), and Izmail (Ukraine). The data include the total port area, the total area of warehouses, the quay length, the number of cranes, and the port throughput per year all collected over an eight-year period of time from 2014 to 2021 and then a four-year window is selected. To calculate port efficiency scores, DEA window analysis combined with the Andersen and Petersen’s super-efficiency model was used. In this case, based on the above formulas, the number of windows (w) = 8 – 4 + 1 = 5 and the number of” different” units = 5 × 3 × 5 = 75. If n is the number of DMUs, the analysis for each window consists of $n \times p = 5 \times 4 = 20$ observations and totally 100 observations for all the data panel.

For each port, the first set of data (W_1) includes analysis of port efficiency from the first four years (2014-2017). Analogously, the second set (W_2) includes the data from the second, third, fourth, and fifth year (2015-2018) and after three (W_3, W_4, and W_5) shifting by one year the final fifth set includes data from the last four years (2018-2021). For each window, a different set of data is made. The result of various DMUs per four-year window leads to differences in port efficiency. This approach to efficiency analysis allows comparison of port efficiency over the eight-year time period [39].

Table 5 arranges the results of the DEA window analysis. The length of the window was built for four years and for each port are represented five rows corresponding to the five windows (W_1-W_5). Each port is represented as a different DMU at each of the four successive years. At the bottom of this table is the port average. The port average has been calculated as the arithmetic mean of the data in all windows of each port from the data in Table 5. In other words, it is the arithmetic mean of the five windows (W_1-W_5).

Table 6 displays average efficiencies of ports for the years 2014-2021. The data in this table is then plotted into Figure 4.

Figure 5 shows the efficiency scores of the five selected Danube ports and their hierarchy based on the DEA window analysis scores with the Andersen and Petersen’s super-efficiency model over the 2014-2021 time period.

Tab. 5

DEA efficiencies (and super-efficiency) of ports for the years 2014-2021
(Source: own elaboration)

Port	W[1]	2014	2015	2016	2017	2018	2019	2020	2021	W av.[2]
Smederevo (Serbia)	W_1	0.630	0.735	1.360	0.434					0.790
	W_2		0.735	1.360	0.434	0.564				0.773
	W_3			0.610	0.265	0.344	1.638			0.714
	W_4				0.265	0.344	1.547	0.647		0.701
	W_5					0.344	1.275	0.647	0.784	0.763
Ruse (Bulgaria)	W_1	0.248	0.248	0.808	0.808					0.528
	W_2		0.248	0.808	0.808	0.523				0.597
	W_3			0.493	0.493	0.319	0.351			0.414
	W_4				0.493	0.319	0.351	0.106		0.317
	W_5					0.319	0.351	0.106	0.201	0.244
Galați (Romania)	W_1	0.711	0.874	0.918	0.875					0.845
	W_2		0.874	0.918	0.875	0.880				0.887
	W_3			0.560	0.534	0.537	0.635			0.567
	W_4				0.534	0.537	0.635	0.649		0.589
	W_5					0.537	0.635	0.649	0.722	0.636
Giurgiulești (Moldova)	W_1	0.535	0.545	0.557	1.795					0.858
	W_2		0.459	0.469	0.842	1.187				0.739
	W_3			0.469	0.842	1.187	0.688			0.797
	W_4				0.842	1.187	0.688	0.627		0.836
	W_5					1.039	0.688	0.627	0.963	0.829
Izmail (Ukraine)	W_1	0.506	0.789	0.929	0.834					0.765
	W_2		0.789	0.929	0.834	0.766				0.830
	W_3			0.567	0.509	0.467	0.428			0.493
	W_4				0.509	0.467	0.428	0.324		0.432
	W_5					0.467	0.428	0.324	0.406	0.406
Port average[3]	Smederevo		Ruse		Galați		Giurgiulești		Izmail	
	0.748		0.420		0.705		0.812		0.585	

W[1] – Window. W av.[2] – Window average. Port average[3] – Port average efficiency is the arithmetic mean of the data of all window (W_1-W_5) of each port.

Tab. 6

Average efficiencies (and super-efficiency) of ports for the years 2014-2021
(Source: own elaboration)

Port	2014	2015	2016	2017	2018	2019	2020	2021	Average[1]
Smederevo	0.630	0.735	1.110	0.350	0.399	1.487	0.647	0.784	0.768
Ruse	0.248	0.248	0.703	0.651	0.370	0.351	0.106	0.201	0.360
Galați	0.711	0.874	0.799	0.705	0.623	0.635	0.649	0.722	0.715
Giurgiulești	0.535	0.502	0.498	1.080	1.150	0.688	0.627	0.963	0.755
Izmail	0.506	0.789	0.808	0.672	0.542	0.428	0.324	0.406	0.559

[1] Average efficiencies of ports is the arithmetic mean of all data from each year (2014-2021).

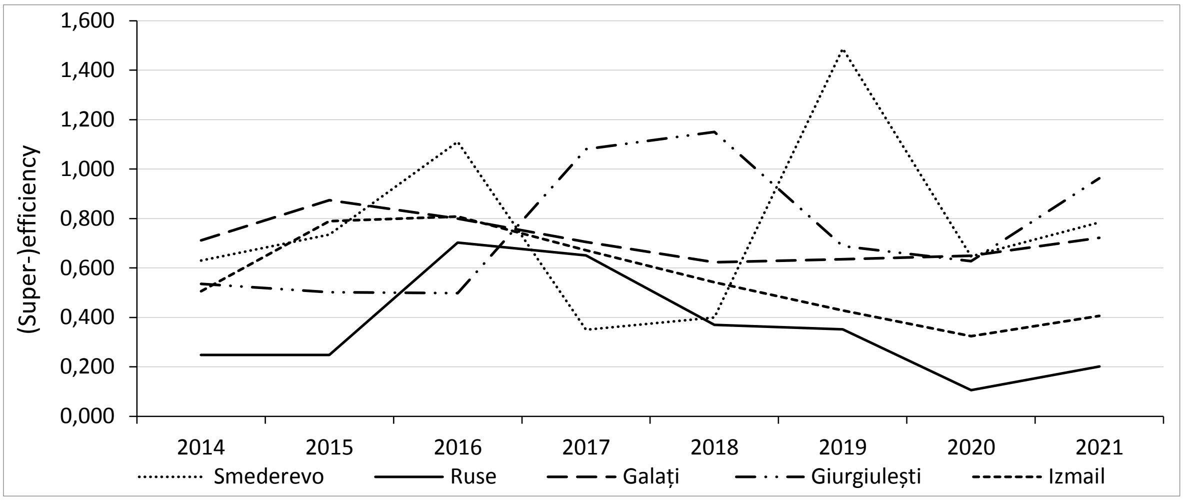

Fig. 4. Port efficiency (and super-efficiency) variation by window analysis for the years 2014-2021 (Source: own elaboration)

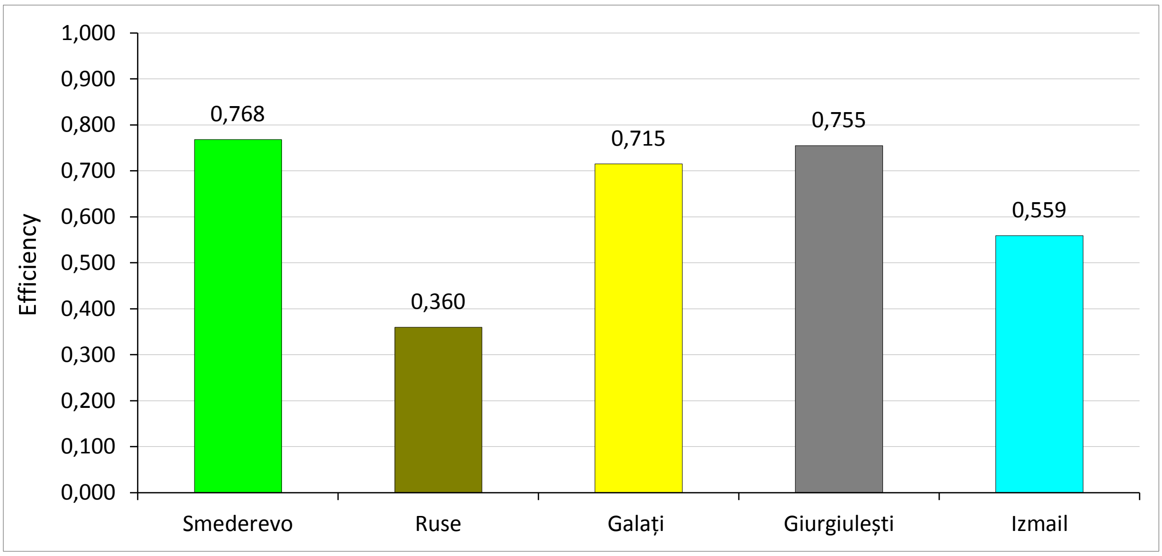

Fig. 5. Average efficiency (and super-efficiency) score of Danube ports (2014-2021) (Source: own elaboration)

Comparing the results in Table 4 and Figure 5, it can be easily seen that after the cargo throughputs, the last two positions are the" small" ports, Smederevo and Giurgiulești, which obtain the highest average efficiency scores after applying the DEA window analysis. From this, it can be concluded that the high cargo throughputs of a port do not necessarily mean that this port is more efficient.

Analyzing the data from Table 5 and Table 6, but also based on the graphical representations in Figure 4 and Figure 5, the following findings can be made:

(1) None of the ports analysed in this study reach the maximum efficiency of 1.000. In terms of average efficiency, the scores obtained by these ports are quite low. The results can be compared with those obtained by [39] in their study for estimating the efficiency of the

five Serbian ports on the Danube where Pančevo obtained the highest score (with an average efficiency of 0.861), followed by Smederevo (0.787).

(2) Only two ports (Smederevo and Giurgiulești) reached the maximum efficiency of 1.000 in the first phase of their analysis following the application of the CRS input-oriented model. The ports were efficient in 2016 and 2019 (Smederevo), respectively 2017 and 2018 (Giurgiulești) when they achived maximum efficiency (1.000). These efficiency values were subjected in the second phase to analysis with the Andersen and Petersen's super-efficiency model. These are the only ports that exceed the 0.750 mark of average efficiency.

(3) Ruse was found to be the least efficient port obtaining the lowest average efficiency over an eight-year period (0.360, or 36%), contrary to some inputs with high values compared to the other ports, namely: the largest area of warehouses, the large length of the quay, and even a large number of cranes. In order to become efficient, this port would have to reduce its inputs by 0.640 (or 64%).

(4) The ports of Galați and Izmail have low average efficiency, 0.715, respectively 0.559. The inputs used by these ports are underutilized compared to the output.

(5) Smederevo was found to be the most efficient port amongst the five Danube ports, with the highest average efficiency (0.768). Giurgiulești ranked second with an average efficiency of 0.755.

5. CONCLUSIONS

This study was conducted to compare five ports located on the Danube in five neighbouring countries and calculate their efficiency in the 2014-2021 time period. In this respect, the efficiency of Danube River ports was analysed by applying the DEA window analysis and the Andersen and Petersen's super-efficiency model. The data used in the analysis are panel data in the window analysis model.

The input data include the port area, the area of warehouses, the quay length, and the number of cranes, while the output data is represented by the port throughput per year.

The analysis results show that only two ports were efficient between 2014 and 2021 and reached 1.000 efficiency: Smederevo, in 2016 and 2019, and Giurgiulești, in 2017 and 2018. The other three ports did not reach maximum efficiency in any year of the analysed time period.

According to these results, several measures can be identified to improve port operations, those that ultimately contribute to increasing port efficiency. A first measure that can be adopted refers to increasing investments in infrastructure (quays, berths, cranes of various types, railway lines inside the port, covered and uncovered storage spaces, equipment, etc.), in modern communication technologies, and information systems. Also, in order to increase their efficiency, port authorities should turn their attention to strengthening their marketing strategies in order to attract more business, to attract more new customers, to increase the quantity of transhipped cargo. In addition, special training programs are needed for employees in these ports to improve labour productivity. Moreover, the various port equipment can be rented to other companies. Last but not least, port authorities should draw up and implement a strategic plan for the long-term development of ports, including the development of railway and road infrastructure outside ports, making faster and easier connections with them, closer connections between ports and production centres. For example, in the Development Strategy of Galați Port [37], in the investment strategy chapter from the list of infrastructure projects and measures proposed in strategic directions, the first point refers to the realization of a multimodal platform

(PMG) for removal of major blockages by modernizing the existing infrastructure and ensuring missing connections for the central network Rhine-Danube/Alps. Also, one of the general objectives of the Strategic Program of Development is to attract traffic of 10 million tons/year until 2035, by specializing in the handling of containers and bulk/general goods.

The conduct of this research has encountered several limitations. This study includes only five ports for analysis, and therefore the results do not reflect the actual position of these ports in regional transportation and economic environment. The study focused mainly on measuring the relative efficiency of these ports. Also, many other variables were not taken into consideration, such as political factors (which in the context of the war that broke out in 2022 in Ukraine influenced the activity of the three ports near the Black Sea in exporting Ukrainian grain), market characteristics, physical location (access to the railroad, highway), etc.

This research serves as a basis for more investigation among the Danube River ports. This can be done by increasing the number of ports and variables and examine how the efficiency will be affected in the context of the outbreak of the war in Ukraine.

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