Maritime Transport Research 3 (2022) 100070

Contents lists available at ScienceDirect

Maritime Transport Research

journal homepage: www.sciencedirect.com/journal/maritime-transport-research

Economic and environmental competitiveness of container shipping on alternative maritime routes in the Asia-Europe trade flow

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ARTICLE INFO

Keywords:
Container transport
Asia-Europe, Alternative routes
Competitiveness
Mathematic modeling

ABSTRACT

Most share of the Asia-Europe containerized traffic passes through the Suez Canal. The changing fundamental market forces and the influence of climate change initiated the necessity to analyze the alternative passages' commercial viability. Technical specifics of routes contribute to the overall attractiveness and cost competitiveness. This paper verifies the economic and environmental feasibility of a container loop Vladivostok-Bremerhaven along three shipping routes, including the traditional Suez Canal transit and the alternative voyages via the Northern Sea Route and Cape of Good Hope. By applying mathematic modeling, the shipping and external cost components were quantified based on the most reliable data sources and ship operational data to determine the profitability of a singular container route. Despite having high potential, especially in the shorter route length context, the Northern Sea Route was less competitive than the conventional Suez transit. The results show higher profitability for the voyage through the Suez Canal concerning alternative shipping routes besides the lower fuel price case when the Cape of Good Hope route becomes viable. In addition, the research findings highlight the impact of sustainability with external costs involved in cost calculation and the importance of implementing mechanisms to reduce environmental damage in shipping.

1. Introduction

The powerful globalization of commercial business, increased demand for various manufactured products and commodities (i.e., development of the world economy), and attractive transportation costs of shipping have contributed to intensifying the traffic on main maritime shipping routes. The consequences of higher density of shipping routes have also initiated the discussion on the alternative transport passages use. The reasons primarily can be found in the high-utilized capacities of existing commercial networks, market imbalances, rising congestion, and a further optimizing tendency of the transportation costs by exploiting the competitive advantages of the individual route, depending on the geographical network distribution and finally, climate change. Mentioned implications can be found, e.g., in the emerging market in the Arctic due to the influence of global warming. There is also companies' strategic solution to organize the voyage along the longer route to avoid expensive transit tolls or congestion in the case of low price of fuel oil. These fundamentals of the economic geography concept (Verny and Griegentin, 2009) and the cyclical behavior of the

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https://doi.org/10.1016/j.martra.2022.100070
Received 5 May 2022; Received in revised form 20 July 2022; Accepted 8 August 2022
Available online 18 August 2022

shipping market generally result in high fluctuations in the freight rates levels and overall shipping costs leading to increased dialogues, deeper analysis of the cost competitiveness and feasibility of specific maritime routes in both academic community and the whole industry. One of the most famous shipping routes, suitable for modeling the cost competitiveness analysis and studied extensively in the recent period, is the Asia-Europe containerized trade route. Generally, it is a consequence of the commercial importance of world trade, spatial distribution, and comprehensive geographical network. Asia-Europe containerized trade is a part of the mainline East-West shipping route contributing to more than 23 million twenty-foot equivalent units (TEU) handled in 2020 (UNCTAD, 2020). The most predominant commercial maritime directions along the Asia-Europe traffic flow are via the Suez Canal (SC) and the service around Africa. Today, the trade between Asia and Europe is mainly dependent on the Suez Canal route (SCR), and the current most utilized alternative is via the Cape of Good Hope (CR), having longer distances (Schøyen and Bråthen, 2011). However, the Northern Sea Route (NSR), which runs along the coast of Siberia, has been imposed as a second alternative mainly due to the shorter navigational distance, which is associated with operational energy efficiency. This shipping route has primarily become viable under climate change influence, reflected in the continuous retreat of Arctic sea ice (Zhang et al., 2016).

The focal point of shipping industry policy in the last decade, besides the basic pretension of cost optimization and profit generation, specifically comprises the business philosophy of providing the utmost respect to the preservation of the environment. Considering the long distances and high energy consumption, the current trends in technical, technological, operational, and other shipping aspects intend rising awareness for implementing the measures towards reaching sustainable development goals. According to the International Maritime Organization (IMO), shipping is responsible for 2.5% of global greenhouse gas (GHG) emissions. This value is more significant when considering its contribution to the realized volumes of world trade and global economic growth and prosperity. Therefore, it is hardly surprising that the new IMO incentives are intended to tackle emissions from ships. The threshold was set to a 50% reduction of annual GHG emissions by 2050 compared to levels from 2008. Aiming to limit and reduce the expanding environmental damage from transport emissions, the European Commission introduced the polluter pays principle as a market-based mechanism (EC, 2011). The negative impact on the environment implies external cost calculation and internalization. It is a process of monetary valuation and effectuation of the polluter pays principle. Thereby, these trends indicate that the role of the external costs has expanded beyond the general damage payment and has developed into an integral component of the decision-making process and traffic planning. External costs are side effects of transport, which impose costs on society, and can be categorized into three main structural elements: environmental costs, traffic congestion, and accidents (Korzhenevych et al., 2014). The literature analysis, which considers the monetary valuation of these costs, points to environment costs as a predominant component of external costs in the shipping industry. It is an implication in the absence of the congestion and accident costs, which jointly contribute to about 60% to 70% of overall external costs (Korzhenevych et al., 2014). These conclusions imply that ship emissions are the principal determiner of negative externalities.

This paper focuses on the integral economic and environmental competitiveness along the present shipping routes on the Asia-Europe container traffic flow including the cost competitiveness of alternative shipping routes around the Cape and across the arctic corridor, with the predominately utilized direction operating through Suez Canal. They were primarily selected according to their specific environmental importance in the world economy, geographical distribution of shipping routes, high freight volumes, and vulnerability to high fluctuations in freight rate levels and fuel oil prices. There is a strong need to develop a model based on industrial data to determine the commercial viability of container shipping. The profit estimation was calculated considering the model settings and hypothetical voyage of a containership on the route from Vladivostok to Bremerhaven. Modeling the economic viability of three selected shipping routes was performed by calculating the costs of the vessel's single transit to determine the efficiency of alternative shipping routes between selected destinations. The authors follow the premise from a commercial standpoint that the decision-making key variable on a new shipping route is economic viability (Wan et al., 2021). With the current environmental incentives in shipping, it is necessary to examine the overall profitability by integrating the external costs into profit estimation as a validation parameter of the environment damage. The results of this research should indicate the competitiveness analysis examining the formal presumptions that the reduction of distance can convert savings in time and costs (Zhang et al., 2016) and that air emissions from ships correlate to travel distances (Schøyen and Bråthen, 2011). The focus is on transferring the weight factor to the costs risen as an implication of environmental degradation.

2. Literature review

The impact of external factors in shipping has always provided severe side effects and implications in the decision-making concept of container companies. Their strategic goal to achieve cost optimization and profit generation has resulted in the need to examine those structural elements, which could broaden the comparative company advantage in the long run. As container carriers tend to reduce distance on a specific route, the ability to exploit the benefits of the alternative passages and determine the conditions of their cost-effectiveness represents a viable possibility to increase efficiency, productivity, competitiveness, and overall market share. The savings in distances are proportional to time reduction and total voyage costs, mainly in the fuel oil costs of container vessels, which are the single most significant item in voyage costs of running ships (Stopford, 2009). Further, these consequences create spillover to the financial growth of their business activity and reduce costs.

The Suez Canal passage is a principal shipping route for Asia-Europe container flow and provides the shortest distance between Asia and Europe. It has an important historical, geopolitical, and economic significance for global trade by a share of approximately 12% and by 30% of overall container traffic (MFAT, 2021). The carriers are obligated to compensate for the transiting across the Suez Canal in transit fee form regulated by the Suez Canal Authority to cover the waterway maintaining costs based on the net tonnage. Concerning cost-effectiveness, these incremental costs are fundamental in voyage planning and calculation. Depending on the market conditions, they can become a deficiency in the decision-making of route selection. The SC transit toll is one of the reasons that the route around the Cape of Good Hope has developed as the main competitor of the Suez Canal passage and is mainly competitive during the petroleum market recession, which lowers bunker prices. The bunker price is a single principal indicator of the utilization of the SR in containerships traffic. Moreover, due to the SC restrictions on the maximum size of the vessel allowed to perform the transit, mostly large tankers, and bulk carriers are utilizing the round Africa route.

The main reasons for the rerouting to the CR have been mentioned already as low bunker prices, costs of appointing security guards for the voyage along the route of Bab-el-Mandeb, high SC fees, and volatile freight rates (Essallamy et al., 2020). The Suez Canal authority implemented a rebate system, which could reduce the nominal toll on a specific voyage and attract more ships to use the SC route in that mode. The ship's deviation on the route around the Cape increases the distance by 4000 to 6000 miles from China to Europe and the Mediterranean line (Gao and Lu, 2019). Notteboom (2012) indicated remoteness and limited cargo potential of southern African ports as the main constraining elements compared to traditional centers along the east-west and north-south trade crossroads.

Also, Gao and Lu (2019) argued that the blockage of the SC route due to natural disasters, piracy, and war could lead to increased utilization of NSR. However, due to the rising global temperature and reduction of the Arctic sea ice, the NSR stretching along the northern coast of Russia has become mostly ice-free and analogously suitable for navigating during the warm season (Koyama et al., 2021). In 2021, the Russian government announced the possibility of the NSR year-round navigation in 2022 or by 2023 at the latest (Splash, 2021). With the continuous Arctic sea ice melting, shipping transportation activities, offshore energy, and service activities to these industries are developing (Nguyen et al., 2021). As a result of global warming, this area has become attractive to utilize Arctic shipping lanes for intercontinental transport. The Northern Sea Route navigable passage on the northern coast of the Russian Arctic from Novaya Zemlya in the west to Bering Strait in the east has a total distance of 5600 km.

The huge advantage of the NSR is reflected in shorter distances, which contributed to high interest in its potential exploitation (Xu et al., 2011). Wan et al. 2018 state that by rerouting to the NSR on the Asia-Europe traffic flow, the carriers can realize significant energy savings and reduce pollution compared to conventional southern routes. However, the NSR competitiveness as a container-shipping alternative on Europe-Asia traffic flow is limited so far due to numerous constraining points such as: the absence of transshipment points and transit ports, shallow segments of the route for large container carriers, extreme climatic conditions, and especially environmental issues (Makarova et al., 2021).

There was only one commercial voyage of containership along the NSR in 2018 when the ice-class ship "Venta Mærsk" completed the route in 37 days on a trial passage from Vladivostok to Bremerhaven (Humpert, 2019) and realized savings of 10 days compared to traditional Suez route (Makarova et al., 2021). All ships transiting the way should be escorted by nuclear icebreakers, the most significant factor which determines the economic aspect of NSR (Xu and Yin, 2021). The icebreaking assistance fee depends on the following parameters: ships' gross tonnage, ice class, navigation period, and the quantity of utilized NSR zones of a maximum of seven in the area (NSRA, 2021). The Suez Canal toll is referred to as a reference for the NSR icebreaking assistance fee, considering the requirements to compensate for the transit costs of the individual passages. The complexity and comprehensiveness of examined container shipping routes consequently to their natural, operational, legal, economic, but especially concerning their environmental impacts, has been an indication for developing a competitiveness model and cost analyses to provide tangible profit estimation for container shipping.

Numerous authors examined the competitiveness of the Asia-Europe shipping route considering the comparative analysis of container shipping via the Suez Canal, Cape of Good Hope, and Northern Sea Route, mainly individually from the economic viability perspective. In addition, there were many studies on diverse topics under the cost competitiveness of the selected traffic flow, with a large diversity of approaches and methods. The authors expressed their interest in research problems, especially with shipping economics and NSR profitability calculation compared to the conventional voyage through Suez Canal for container shipping (Verny and Grigentin, 2009; Xu et al., 2011; Furuichi and Otsuka, 2015; Lasserre, 2014; Zhang et al. 2016; Wan et al., 2018; Sibul and Jin, 2021). The lesser interest was found for topics that dealt with the competitiveness of routes around Africa (Notteboom, 2012; Shibasaki et al., 2016; Essallamy et al., 2020).

More on route choice competitiveness between NSR and CR can be found in Theocharis et al. (2018) , which performed a systematic review of comparative studies between the Arctic and traditional routes. The authors conclude that majority of 24 articles published since 2011 dealt with the large spectrum of liner shipping topics and included the comparison of the NSR and Suez Canal route. Also, Meng et al. (2017) published research that focused on the overview of trans-arctic shipping route viability from navigational and commercial perspectives, while Lasserre (2014) provided the literature overview on Arctic shipping from the profitability standpoint of the container sector. Sibul and Jin (2021) updated the mentioned literature overview focusing on the NSR, while Nguyen et al. (2021) applied social network analysis to determine the trends in the research on the NSR. Generally, reviewing the extensive literature on the research topic and shipping routes, the absence of cost analysis considering all three selected shipping routes is visible.

Relevant literature on the environmental and economic viability of the shipping routes is scarce. Instead of an environment costs comparison of the two or more shipping routes, a calculation of externalities of the individual one is presented. The most related study concerning this paper's objective is by Zhu et al. (2018), which evaluated the economic benefits of NSR compared with the traditional route via the SC with accompanied environmental costs. The authors analyzed air emissions as an indicator of environment costs adapted from Korzhenevych et al. (2014). The damage costs along the NSR tend to be higher than the SC route in the present constellations, primarily concerning smaller ship size and low load factor if environmental outcomes per TEU ratio are considered. However, lower environment costs and increased competitiveness can be realized using higher loads and larger ships along the NSR.

Zhao and Hu (2016) calculated transport costs and emissions assessment for liner shipping on NSR and Suez Canal routes. The authors conclude that the carbon dioxide emissions decrease proportionally with the decline in fuel consumption. The results showed the reduced environmental footprint related to carbon emission and total costs using the NSR compared with the SC route. Moreover, these findings reveal that NSR, besides the limitations in the relativity of individual parameters, can be considered an alternative route, saving navigable time and costs. Contrary, Chou et al. (2017) analyzed navigation efficiency based on the fuel consumption ratio for transiting the ports on Asia-Europe traffic flow via NSR. The authors calculated the efficiency of a route via NSR with the additional calculation of carbon dioxide emissions per TEU as an environmental indicator concluding that based on the research results, there is a high competitiveness potential of the latter related to the Suez route in the cost comparison.

Also, Chou et al. (2020) calculated navigation efficiency considering transport costs and carbon emissions by comparing the ship voyage through the Suez Canal and Cape of Good Hope. They concluded that the lower navigation efficiency of a ship traveling through Suez strongly correlated with the higher ratio of fuel consumption, which increases the overall transport costs. Skarbø et al. (2015) used the simulation modeling of the NSR with the applied emission control area (ECA) standard having the decision of its use as a primary objective compared to the SC route between Europe and Asia. The authors calculated the voyage and capital costs, along with fuel consumption and emissions of both directions, combining four different scenarios, and concluded that with the implementation of emission reduction technology, the NSR provides savings in fuel consumption and especially total emissions related to the SC route. Contrary, neither simulation showed the cost competitiveness of the NSR labeled with Arctic ECA, as for the high investment costs of the technology for tackling the harmful emissions.

The approach of Ding et al. (2020) comprised the comparison of the NSR and SC route by applying the carbon tax as a market-based measure and analyzing the effects on the economic viability of NSR for container shipping. The authors created a model scheme based on a numerical analysis of total shipping cost. The research results show the higher economic viability of NSR when the carbon tax is applied or excluded for both routes and when only NSR is burdened with a carbon tax.

Makarova et al. (2021) provided an overview of economic and environmental aspects determined as critical elements in the NSR development, an alternative shipping route from Europe to Asia. The authors indicate several prerequisites for NSR to become an alternative to traditional lines from Europe to Asia. Investments in infrastructure, which would enable all-year navigation, creation of Arctic support zones, modernization of nuclear iceberg fleet, and similar are necessary to project comes truth. Joseph et al. (2021) examined the commercial viability of Arctic shipping by developing a model architecture to explore financial and damage costs, opportunities, and environmental risks by integrating the parameters of policy, alternative fuels, emissions, and microeconomics and their interactions. The settings of the techno-economic environmental model enabled the feasibility analysis of Arctic shipping on a selected sample. The results indicated the need to integrate a strict environmental policy if the net societal losses from emissions are concerned. Also, these research implications contribute to the promotion of Suez transit as the most profitable in the projection of future trends.

Lindstad et al. (2016) focused the research on costs, emissions, and climate change damages of NSR trade concerning traditional ones by mathematic modeling the research settings of input parameters related to shipping, route, charges, and environmental footprint. The authors emphasize realized cost savings per ton of freight transported when using NSR compared to traditional shipping routes. However, the main conclusions indicate the absence of climate benefits for the voyage along NSR even when utilizing cleaner fuels, as for the additional effects of ship emissions in the Arctic environment. Contrary, Schröder et al. (2017) discussed the impact of emissions on Arctic shipping by applying simulation programs to define the route viability compared to Suez. They determined a great advantage of NSR concerning the Suez route. The authors state the savings in time and fuel as decisive parameters accompanied by lower consumption and exhaust gas emissions. El-Taybany et al. (2019) calculated exhaust emissions to determine the impact of shipping considering the air pollution in the Suez Canal waterway combining EPA and ENTEC methodology. The research results indicate that the largest share of total annual emissions in the Suez Canal waterway is accompanied by containerships (48–59%).

The above-mentioned reveals the importance and attractiveness of the subject among the research and industrial community.

This paper aims to develop a real-life container shipping model based on the cost estimation, considering the research sample of three alternative shipping routes on the traffic flow between Vladivostok and Bremerhaven. The significance of the selected origin and destination (OD) pairs lies in their presence in the Asia-Europe containerized trade, which is a part of the mainline East-West shipping route. As the previous research was mainly based on the economic and commercial competitiveness of the maximum two alternatives (SCR vs. NSR, SCR vs. CR), the authors created a model considering the shipping efficiency of the conventional transit through the Suez Canal and two alternative passages along the arctic corridor and around Africa. The economic viability calculation of each alternative on the selected OD pair is similar to the model developed by Zhang et al. (2016), with significant upgrades and up-to-date data. In this research, unlike those considering two alternative routes three alternatives are considered on Asia-Europe traffic flow. Besides, the added value of this research is the integration of economic viability with the environmental damage costs generated by ships on the individual route. Emission external costs were taken as a basis for the ecological transport damage calculation. The model contributes to the comprehensive and broader view of the total generated costs and more tangible profit estimation.

The paper provides a cost competitiveness model between three alternative shipping routes by combined calculation of the economic and environmental implications of the voyage on the selected traffic flow. Only a few previous studies integrated the ecological component in determining the shipping efficiency by building the profit estimation model and decision-making process. As mentioned above, different authors interpret the ecologic footprint of the NSR route differently. Also, none of the existing research performed simultaneous comparisons of all the alternatives and accompanied cost components of a ship in the voyage. The most relevant and reliable data from various sources were applied to the model to provide valid presumptions on the model parameters.

3. Material and methods

Based on van Essen et al. (2019) data, the authors calculated the main ship and port emission categories (CO_2, NO_X, SO_2, PM_{10},

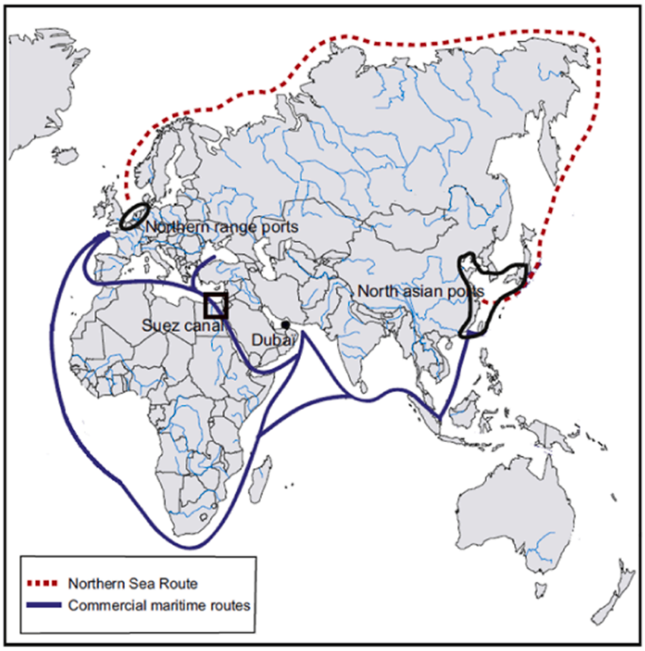

Fig. 1. Shipping routes on the Asia – Europe container flow.
Source: modified from Verny and Grigentin (2009)

Table 1
Ship specifications used in the model.

Category	Arc4 ice-class 1A container feeder vessel
Capacity	3,596 TEU (600 reefer plugs)
LOA	200
Draft	10.5 m
Beam	36
Total deadweight (tdw)	42,000
GT	34,882
NRT	16,947 (used for Suez transit)
Engine	MAN B&W 6 cylinder 6G60ME-C9 MAN
Power	16,080 kW

Source: compilation of various sources

$PM_{2.5}$). Following the EU environmental policy guidelines, complete internalization of externalities was presumed. The mathematical formulation was retrieved from Vukić et al. (2021).

The authors calculate the costs of running containership and generated emissions and compare ship efficiency in a single voyage activity among trans-arctic, around Africa, and conventional transit via Suez. The running ship's costs are based on Stopford (2009). As a referent type of vessel used in this research, an Arc4 ice-class 1A container feeder vessel is selected. The origin-destination points between Vladivostok (Russia) and Bremerhaven (Germany) are taken as a research sample on analyzed container flow. Fig. 1 shows the shipping routes taken into model calculation.

The authors consider the performance characteristics of a single realized commercial voyage of a containership Venta Maersk along the NSR and the related ship specifications as reference points in determining the input data. Regardless of the common utilization of larger container vessels on the Suez route to exploit economies of scale, the aim was to perform the analysis based on the same conditions, so the larger vessels were excluded from the research. Additionally, the authors use actual ship specifications for input model creation. The specifications of a modeled ship are listed in Table 1.

The flowchart of the present research is demonstrated in Fig. 2. The central point of this research is the determination of the competitiveness model based on the profit estimation of economic and environmental indicators, considering the alternative shipping routes as a research subject. It consists of three phases aimed at the same objective and can be divided as follows:

1 These container routes are shaped using the input data of specific voyages, where voyage distance, speed, and time are marked as fundamental parameters and jointly represent the second phase of the research. Shipping time details on the container loop via alternatives are based on actual, regular container loops and modified in some parts to be comparable.

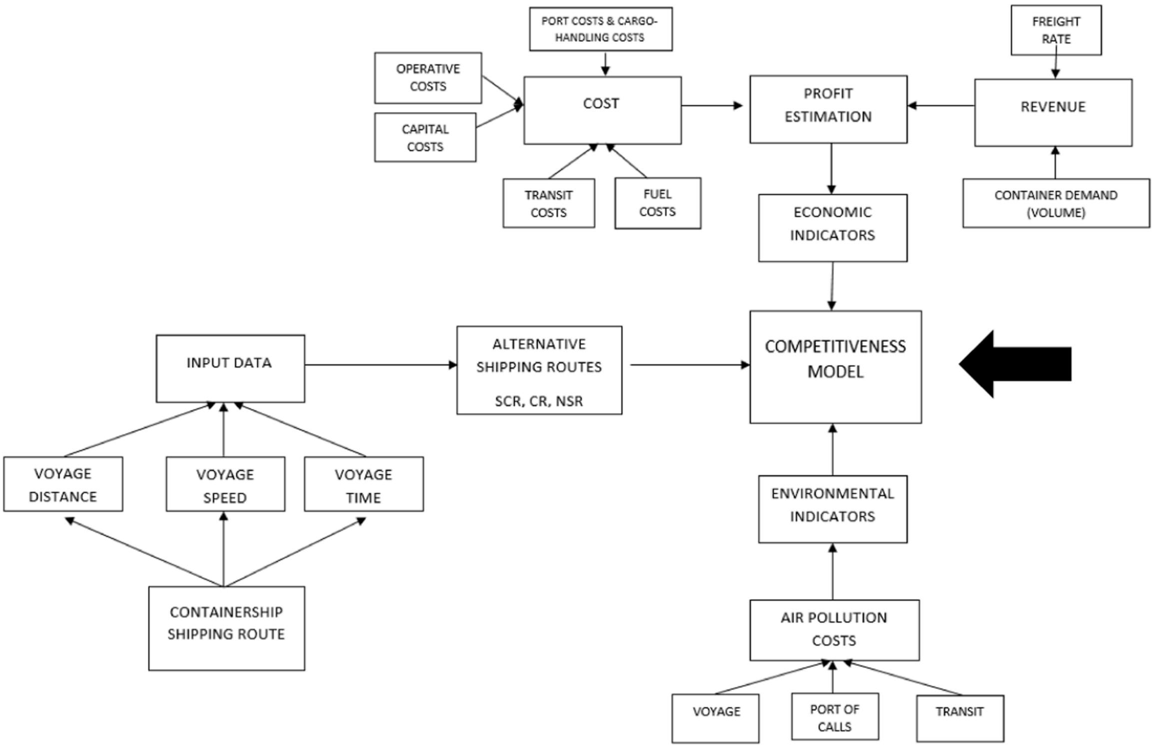

Fig. 2. Flowchart calculation.

2 The second structural element is a profit estimation phase based on economic indicators. The authors considered the cost of running ships and revenue generated on the individual voyage as weight variables of the economic viability.
- Running costs were based on Stopford (2009) and consisted of operative costs, capital costs, port and cargo-handling costs, transit costs, and fuel costs. Daily operative and capital costs are determined due to the shipping time, speed, and distance of individual voyage and are considered for the entire journey. Port costs and cargo-handling costs are calculated at a flat rate and assumed for all transportation routes. Transit costs are determined as a Suez Canal toll and Northern Sea route charge, while the latter represent ice pilot and icebreaking fee. Fuel oil costs, the most significant category of overall daily running costs, are calculated based on the created model and consider specific fuel oil consumption (SFOC), engine power, and voyage time. Fuel costs are categorized as consumption on the voyage and in port.
- The revenue of a specific shipping route includes the freight rate level that differs, interconnected with the voyage plan and shipping demand, a parameter assumed as a constant value between two ports.

3 The ultimate phase consists of environmental damage costs calculation in the form of ship-generated air emissions along the voyage stage, emissions generated while calling the individual port on the container loop, and air pollution while transiting the Suez and NSR. All of these costs are determined according to the established model. The overall externalities include the multiplication of total emitted pollutant amount (CO_2, NO_X, SO_2, PM_{10}, and $PM_{2.5}$) and air pollution costs. Fuel oil consumption and emission factor of individual pollutants are indicators of generated pollutants in tons.

Therefore, the competitiveness model for container shipping can be mathematically formulated as the difference between profit estimation of economic implications for individual shipping routes and generated external costs of air emissions Eq. (1). It is defined as follows:

$$OC_{sr} = PE_{eco} - EC_{env} \tag{1}$$

where OC_{sr} is the overall competitiveness of a single route, PE_{eco} refers to the profit estimation of economic indicators, and EC_{env} overall external costs as an environmental indicator. Furthermore, as already stated, the profit estimation model is based on the modified methodology of Zhang et al. (2016) and can be further shown as Eq. (2):

$$PE_{eco} = R - TC = \sum_{o=1}^{n-1} \sum_{d=o+1}^{n} FR_{od} * Q_{od} - \left[(CaC_l + OpC_l) * T_l + FuC_{sea} * T_{sea} + FuC_{port} * T_{port} + \sum_{o=1}^{n} (PC_o + ChlC_o) + TC \right] \tag{2}$$

where profit estimation of economic indicators can be defined as the difference between revenue (R) and total costs (TC). Revenue of specific shipping routes is the sum of freight rates of the origin and destination points along the container loop (FR_{od}), multiplied by the

Table 2
Voyage distance on the container loop between Vladivostok and Bremerhaven.

via		SUEZ	NSR	CAPE
DISTANCE (nm)	No ice	11,564	5,070	14,776
	Ice water	/	2,200	/

Source: Classic SeaRoutes (2021); (Zhang et al., 2016)

Table 3
Average voyage speed on the selected container loop.

		SUEZ	NSR	CAPE
Average speed (kn)	No ice	17,5	17,5	18,0
	Ice water	/	11	/

Source: Marine Traffic, 2021; speed recorded on the trial voyage of the vessel; average speed 18,6 kn (July 13th 2021)

number of shipped containers on the shipping route and OD pair (Q_{od}). CaC_l is an average daily capital cost, and OpC_l is a daily average operative cost, which is multiplied by the total days on the container loop T_l. FuC_{sea} is a daily fuel cost at sea, multiplied by T_{sea}, representing the overall days at sea. Furthermore, FuC_{port} is a daily fuel cost at the port, respectively; T_{port} is the total days in port. Lastly, PC_o is port cost, $ChlC_o$ is cargo-handling costs in port, n is the number of port calls, and TC is the transit costs of specific container shipping alternatives. The second part of the equation relates to the calculation of external costs. The authors refer to Vukić et al. (2021) for a detailed breakdown of air pollution damage generated along the specific voyage, and can be defined as follows Eq. (3):

$$EC_{env} = \sum_{n=1}^{n} EPA_l * APC_l = \sum_{n=1}^{n} (FUC_l * EF_x) * APC_l = \sum_{n=1}^{n} \{[(EP_l * t_l) * SFOC_e] * EF_X\} * APC_l \quad (3)$$

where EPA_l represents a content of emission pollutants along the container loop and APC_l is air pollution costs generated on the voyage. The EPA_l variable can be further fragmented as the fuel oil consumption of the vessel (FUC_l) multiplied by the emission factor of the individual pollutant considered (EF_x). Ultimately, fuel oil consumption can be expressed as the relation between EP_l, representing a ship's engine power (dependent on the engine load factor), t_l voyage time on the selected shipping route, and $SFOC_e$, the engine-specific fuel oil consumption.

This research uses actual values to define the most accurate estimation of total costs incurred on the individual alternative routes to determine the competitiveness of a containership on a container-shipping line Vladivostok-Bremerhaven. Each model parameter is individually defined, considering the specifics of the voyage, comparing three shipping alternatives, via the Suez Canal, around Cape of Good Hope, and along the Northern Sea Route.

4. Data curation and model building

The variables of the selected model settings are defined, considering the conducted research model, specifications of the ship, and shipping routes using the latest data. Firstly, the variables related to input data are assigned, thus the general characteristics of the transport directions according to the pre-defined flowchart. The data settings follow determined variables on the economic and environmental aspects of the individual shipping routes. These model settings are used to determine and compare the overall competitiveness of container vessel transit along three selected shipping routes.

4.1. Input data

The input data of specific transit on the voyage from Vladivostok to Bremerhaven consist of three parameters: distance, speed, and time. The estimation of the voyage distance is calculated using the Classic SeaRoutes (2021) online calculator. As the route via the arctic corridor also contains ice water, the entire length of the container loop is divided into two legs. The data on ice water is set to 2, 200 nautical miles and is partly covered with ice (Zhang et al., 2016). The voyage distances are indicated in Table 2. The authors excluded the port-to-port route distances as negligible compared to the overall length of the route.

The ship's average speed estimation along the individual route is taken over from the actual recordings of the trial containership voyage via NSR, and the average speed is retrieved from AIS data (Table 3). Regarding the existence of ice along the NSR, lower velocities are recorded consequently to nuclear icebreaker escort. According to the voyage logs, the speed recorded along the ice-covered area was between 8 and 11 knots. The authors applied a vessel velocity of 11 knots in an ice-covered area. Due to the slow-steaming strategy of container shipping companies in the pre-COVID-19 period, the lower levels of vessel design speed of 22 knots along the remaining shipping routes is adopted.

The remaining parameter of shipping time particulars and transshipment activities are based on actual, regular Maersk (for Suez) and CMA-CGM (Cape route) container loops, which are modified in some parts to be comparable. As indicated in Table 4, only three transshipment ports were considered along with the selected loops enabling the close comparison of results generated. The analysis of the container transport along the alternatives comprises the complete loop from origin to destination (without considering back

Table 4
Shipping time details on the container loop via alternatives.

SCR		NSR		CR	
Vladivostok	0	Vladivostok	0	Vladivostok	0
Shanghai	6	Vostochny port	1	Shanghai	6
Tanjung Pelepas	17	Busan	3	Port Kelang	17
Rotterdam	38	Kirkenes	21	Rotterdam	51
Bremerhaven	41	Bremerhaven	32	Bremerhaven	54
Days at sea	27,2	**Days at sea**	23,2	**Days at sea**	35,1
Days in port	13,8	**Days in port**	8,8	**Days in port**	18,9

Based on: modified from SeaRoutes, 2021; Maersk, 2021 (SCR – the shortest route on the schedule, includes stopovers and change of terminals, truck transport); Marine Traffic, 2021 (NSR – based on Venta Maersk voyage); CMA CGM, 2020 (CR – base on round the Africa CMA-CMG service)

Table 5
Freight rate and container demand on alternative shipping routes.

SCR	Vladivostok	Shanghai	Tanjung Pelepas	Rotterdam	Bremerhaven
Shipping demand (TEU)	800	1,000	600	600	/
Freight rate ($)	850	850	6,373	650	
NSR	Vladivostok	Vostochny port	Busan	Kirkenes	Bremerhaven
Shipping demand (TEU)	800	1,000	600	600	/
Freight rate ($)	300	300	7,500	450	
CR	Vladivostok	Shanghai	Port Klang	Rotterdam	Bremerhaven
Shipping demand (TEU)	800	1,000	600	600	/
Freight rate ($)	850	850	6,418	650	

Source: Freightos, 2021 (state July 2021); expert feedback

voyage). According to the realized journey via NSR, the port and shipping time are retrieved and utilized in the model. The authors used the Classic SeaRoutes (2021) software as a supporting tool for data review and confirmation.

4.2. Shipping route economic estimation settings

According to the mathematically formulated profit estimation economic model, all the revenue and cost parameters are determined and quantified.

4.2.1. Revenue generated on individual routes

Generally, the revenue estimation on the selected OD pairs in shipping is marked with high uncertainty. The shipping companies rarely declare this set of data. It implicates a questionable quantity of TEUs handled, thus shipping demand in transshipment ports. For that reason, the authors based the container demand on the feedback of experts involved in commercial shipping activities taking it as a constant for all the shipping routes examined. The authors declare the lower level of container activity applied in the model (Table 5). Revenue generated on the specific OD pair is calculated considering the following formula Eq. (4):

$$Revenue\ (R_{od}) = Freight\ rate\ (FR_{od}) * TEU\ quantity_{od} \tag{4}$$

In addition, the freight rates on each segment of the container shipping route are determined according to the Freightos (2021) online software.

4.2.2. The costs of capital

The structure of the total costs of the examined shipping routes consists of diverse cost parameters intended to determine the profit estimation model. The total costs of a referent ship are fragmented as capital costs, operating costs, fuel costs, port costs, cargo-handling costs, and transit costs. The capital cost of an Arc4 ice-class 1A container feeder vessel is expressed through daily depreciation costs (DDC). For DDC, the annual depreciation (ADC) is calculated as Eq. (5):

$$Annual\ depreciation\ cost\ (ADC) = \frac{cost\ of\ ship - salvable\ value}{useful\ life\ of\ ship\ (years)} \tag{5}$$

Furthermore, the salvable value of the ship is determined as Eq. (6):

$$salvable\ value = LWT * price\ of\ scrap\ metal \tag{6}$$

Table 6
Operating costs components of an ice-classed ship.

COST COMPONENTS	Daily costs as in 2010 ($ per day)	Premium for ice-class vessel (%)	Drewry operating cost index 2010 -2020 increase	
			NSR	SCR/CR
Manning	3,640	10	+7.5% plus premium	+7.5%
Hull and Machinery insurance	1,200	50		
Protecting and Indemnity insurance	630	25		
Repairs & Maintenance	725	20		
Others	1,250	/		

Source: Drewry, 2007, Lasserre, 2014, Sarrabezoles et al., 2014; Drewry 2020

Table 7
Fuel costs for selected shipping routes and accompanied consumption items.

NSR			KW (80% / 50%)	SFOC	t	MT	VLSFO*
On voyage	No ice		12,864	163.5	289.7 h	609.3	485
	Ice water		8,040	165.5	200 h	266.1	485
In port			12.9 mt/day		8.8 days	113.52	485
SCR			**KW (80% / 40%)**	**SFOC**	**t**	**MT**	**VLSFO***
On voyage		Voyage	12,864	163.5	638.8 h	1343.6	485
		Transit SC	6,432	166	14 h (speed 8,6 kn)	14.9	485
In port			12.9 mt/day		13.8 days	178.0	485
CR			**KW (85%)**	**SFOC**	**t**	**MT**	**VLSFO***
On voyage			13,660	164	842.4 h	1888.3	485
In port			12.9 mt/day		18.9 days	243.8	485

Source: Ship & Bunker, 2021
* average price January – July 2021

The referent ship's lightweight tonnage value is determined by suggestion of industry experts. Currently, the scrap prices are in the range of 400 $ - 550 $ per ton. The authors utilize the price of 450 $ in the model. The DDC is determined as follows Eq. (7):

$$Dailiy\ depretiation\ cost\ (DDC) = \frac{ADC}{350} \tag{7}$$

Based on Georgiev and Garbatov (2021), the authors consider that the ship is 350 days per year in service, and the useful life of 25 years. In this study, the authors assume the loan payment as a method of ship financing. The actual new building price of a vessel used in the model is 39 million $. As the final price of purchasing cost of a ship is increased by interest rate, the following financial terms are determined:

- Newbuilding price is taken as the cash price of a ship
- Down payment: 30% of the overall new building price
- Interest rate: 5%
- Installment: paid yearly, over ten years

It should also be indicated that the capital recovery factor (CRF) is calculated from the following relation Eq. (8):

$$CRF = \frac{r*(1+r)^n}{(1+r)^n - 1} \tag{8}$$

where r is the interest rate which depends on the agreed period, and n is the number of installments. The capital costs calculation terminates with the multiplication of total days generated on the container loop and DDE.

4.2.3. Daily operating costs

The following cost category relates to the daily containership operating costs, where the data on cost structure are retrieved from Drewry (2020). As the values of individual operating cost components are from 2007, the authors increased the overall costs by 7.5% based on the total increase from 2010 to 2020 (Drewry, 2020). As for the NSR, the authors added the premiums according to Lasserre (2014) for manning and Repairs and Maintenance costs for ice-classed vessels, while the premium shares for P&I insurance and H&M insurance are based on Sarrabezoles et al. (2014). These cost categories are indicated in Table 6.

4.2.4. Voyage and port costs of fuel

The fuel cost is a single cost element, which highly influences the overall profitability of the conducted sailing due to its large share in the total voyage costs. For the calculation of the total fuel consumption of a ship on a single shipping route, the following formula is

Fig. 3. Seven zones along the NSR as a subject to an icebreaking fee.
Source: Cariou et al., 2021

used Eq. (9):

$$fuel\ consumption = specific\ fuel\ oil\ consumption\ (SFOC) * engine\ power * sailing\ hours \tag{9}$$

The SFOC of an ice-class container ship corresponds to the engine load factor and route characteristics. The values are higher in the transit voyage phase via SCR and NSR. According to the engine type considered, these data are retrieved from the manufacturer's official data having the nominal SFOC of 167 g/kWh. The load factors are also determined for the voyage and transit segment following the operating speed realized. The consumption level of 12.9 mt/day is assigned as a constant for all shipping routes examined (Zhang et al., 2016) due to the fuel consumption generated during the cruising, maneuvering, and hotelling modes. As the ice-classed vessel taken into account for the present research was purpose-built to run low sulfur fuel aiming to compile with Emission Control Area (ECA) in Baltic and Northern Sea region, the authors assume the utilization of VLSFO with the price of 485 $. The price level of VLSFO is the average fuel price from January to July 2021 (Ship and Bunker, 2021). Table 7 shows the data on fuel costs and remaining consumption parameters.

4.2.5. Port and cargo-handling costs

Port costs consist of several elements which reflect the price of services realized in ships' port of call. These costs are nominated as port tariffs and divided into dues and charges. They reflect the costs of using port facilities and remaining services provided by service providers: port concessionaires, pilotage, tug service, line handling, cargo handling, and others. Because these costs vary between ports, the authors applied the lump sum value based on the realized algorithm. In this study, port dues are assumed to be 0.428 (USD/GT/call) in total for each port entry, including port due, berthing due, and line-handling charge (Furuichi and Otsuka, 2018; Zhu et al., 2018). The calculation of port dues is as follows Eq. (10):

$$Port\ dues = 0.428 * GT * number\ of\ calls \tag{10}$$

Loading and unloading costs of containers are retrieved from Hackett (2009). It follows the formula Eq. (11):

$$L\&U\ costs = 2 * 100\$ * (loading\ capacity * utilization\ rate) \tag{11}$$

A container handling charge of 100 USD/TEU is assumed for loading and unloading, respectively (JICA 2013). The utilization rate of loading capacity is set at 70%, based on the expert suggestion.

4.2.6. The costs of transit

Transit costs are applied for Suez and Northern routes. Xu and Yin (2021) indicate the critical influence of the icebreaking tariff along the NSR when comparing these costs with the SCR transit toll. The calculation of the transit cost along the two routes differs according to the vessel specifications. As for the Suez Canal toll, several data are taken into account suchlike, ship type, direction, ship status, Suez Canal Net Tonnage (SCNT), Suez Canal Gross Tonnage (SCGT), draft, beam, and others. Lasserre (2014) indicated the toll of 240,000 $/transit for a 4,500 TEU containership. For this research Suez Canal toll online calculator is used, determining the average value of 205,000 $ for a laden containership directing northbound. The transit costs along the NSR also comprise various services, among which the icebreaker support and ice pilots are the most influential to the final price. The icebreaker support applies to seven (7) NSR zones and is subject to the icebreaking fee defined by the Northern Sea Route Administration (Fig. 3). As the vessel considered in this research refers to the Arc4 ice-class and technical specifications, four NSR zones are taken into calculation. For efficient transit of the NSR, a minimum of two icebreaker escorts are necessary. The icebreaking assistance fee also depends on the navigation period (summer/autumn and winter/spring). The authors calculated the arithmetic value of transit between periods using the official NSR

Table 8
Pollutant emission factors of examined fuel type.

Fuel (EF in g/kg)	$PM_{10}/PM_{2.5}$	NO_x	SO_2	CO_2
MDO (0.1% S)	1.6/1.5	46.58	1.158	3,170

Source: Statistics Norway, 2017

Table 9
Air pollution costs of main pollutants in maritime traffic (€/t).

	CO_2	SO_2	NO_x	$PM_{2.5}$	PM_{10}
Atlantic	100	3,500	3,800	7,200	4,100
Mediterranean	100	9,200	3,000	24,600	14,000
North Sea	100	10,500	10,700	34,400	19,700

Source: van Essen et al., 2019

calculator. The value of the fee obtained was at the level of 351,413 $. The ice pilot fee is taken from Furuichi and Otsuka (2015), which determined the price of 673 $/day between Cape Dezhnev and Cape Zhelaniya.

4.3. Shipping route environmental estimation settings

The external costs estimation, keeping in focus the air pollution as the principal damage factor in shipping, is divided into the voyage phases and external costs generated in ports. The emissions factors are integrated into the model settings to determine the total generated external costs on the individual container route (Table 8). The data on emission factors of a single examined pollutant is considered for marine diesel oil (MDO) instead of VLSFO primarily as for the lack of relevant data. MDO reflects the fuel type with 0.1% sulfur content and is compliant with ECA, so the results represent the lower level of total emissions generated. It contributes to the general premise in research settings that air pollution damage has a lower value degree.

When the air pollution unit values of individual pollutant categories have not been available for the entire targeted container loop navigable areas, the authors applied the available data according to van Essen et al. (2019). The authors emphasize the utilization of the lower values according to the specific sailing area, except for the ice-infected navigation stage, where the highest ones are applied due to the sensitivity of the influenced environment by shipping activity. Table 9 represents the air pollution costs of selected pollutant categories and navigable areas, adjusted to the route specifications.

The external damage costs in ports are assessed based on the power ratio of auxiliary-main engine relations, as indicated in Merk (2014). Table 10 provides these values.

As the data on the total deadweight tonnage of the vessel is a known variable, the load factor for auxiliary engines in maneuvering and hotelling modes is considered at 18% for containerships (Starcrest, 2011). The emission factors of auxiliary engines are presented to determine the level of external cost damage in ports (Table 11). Marine distillate having 0.1% sulfur content is considered, with an assumed SFOC of 200 g/kWh.

5. Results

The economic implications of container shipping utilizing different routes are shown in Table 12 and Table 13. Table 12 presents the total costs according to the quantified components for shipping routes considered. The results show the high competitiveness of

Table 10
Auxiliary (AE) to main engine (ME) power ratio.

VESSEL TYPE	AE TO ME POWER RATIO
Container	0.220
Tanker	0.211
Bulk carrier	0.222
RO/RO ship	0.191

Source: Merk, 2014

Table 11
Auxiliary Engine Emission Factors (g/kWh).

Fuel	CH_4	CO	CO_2	NO_x	PM_{10}	$PM_{2.5}$	SO_x
Marine Distillate (0,1% S)	0.09	1.10	690	13.9	0.25	0.35	0.40
Marine Distillate (0,5% S)	0.09	1.10	690	13.9	0.38	0.35	2.10
Heavy Fuel Oil	0.09	1.10	722	14.7	1.50	1.46	11.10

Source: CARB, 2008

Table 12
Cost results of alternative container routes between Vladivostok and Bremerhaven.

(in $)	SCR	NSR	CR
Capital costs	188,857	147,400	248,738
Operating costs	328,246	299,784	432,324
Fuel costs	752,250	479,660	1,034,065
Transit fees	205,000	357,021	/
Port costs	74,647	74,647	74,647
Loading & unloading costs	504,000	504,000	504,000
Total costs per container loop	**2,045,969**	**1,862,512**	**2,293,775**

Table 13
Results of economic profit estimation for individual container routes.

(in $)	SCR	NSR	CR
Revenue*	5,743,800	5,310,000	5,770,800
Costs	2,045,969	1,862,512	2,293,775
Profit	**3,697,831**	**3,447,488**	**3,477,025**

* Freightos, 2021

NSR compared to alternative shipping routes when all cost components are considered. Despite the high transit costs, strong efficiency is capitalized on this route. The comparative advantages were also shorter distance and voyage time. Concerning the items above, the highest expenses were generated utilizing the route around the Cape of Good Hope.

However, when the estimated revenue is integrated into the economic model of profit estimation, the competitive advantage of both NSR and especially CR weakens, and the Suez Canal route produces high profitability for the carriers (Table 13). These results correlate with highly developed markets and regions along the SCR, opposed to the limited commercial activity via alternatives. It is important to note that the revenue was estimated, and thus it wasn't based on real-time data due to the constrained transparency of carriers and restricted data.

According to the created algorithm, the valorization of the environmental footprint on the selected OD pair was applied to individual shipping routes. The results of the external costs generated as air emissions are presented in Table 14, Table 15, and Table 16. All values shown in the tables were rounded on the whole number, but during the calculation process, decimal numbers were considered. As mentioned above, the data on air pollution costs of available navigable areas were retrieved from relevant literature and applied in the model exclusively for the lack of relevant data on exact route specifics. The pollutant unit costs along the container loop were processed according to the specific criteria, where the length of single navigable areas presented a share of the overall voyage. These relations enabled the calculation of the air pollution costs for each share of the voyage plan.

Table 14
Total external costs generated along the Cape route.

	NORTH SEA	ATLANTIC	MEDITERANEAN
EC VOYAGE	6%	63%	31%
CO_2	33,255	376,887	188,444
SO_2	1,276	4,819	6,333
NO_X	52,285	210,443	83,070
$PM_{2.5}$	5,413	12,840	21,936
PM_{10}	3,307	7,799	13,316
Total EC on voyage	95,535	612,789	313,098
Total EC in ports	4,140	23,067	11,326
Overall (voyage + port)	**1,059,955 €**		

Table 15
Total external costs generated along the Suez Canal route.

	NORTH SEA	ATLANTIC	MEDITERANEAN	SC TRANSIT (MEDITERRANEAN)
EC VOYAGE	7%	51%	41%	100%
CO_2	31,164	218,149	176,597	4,739
SO_2	1,195	2,789	5,935	159
NO_X	48,998	121,808	77,847	2,089
$PM_{2.5}$	5,073	7,432	20,557	552
PM_{10}	3,099	4,514	12,479	335
Total EC on voyage	89,529 €	354,693 €	293,415 €	7,873 €
Total EC in ports	3,550 €	15,485 €	11,055 €	
Overall (voyage + port + transit)	**775,600 €**			

Table 16
Total external costs generated along the Northern Sea route.

	ATLANTIC	MEDITERANEAN	NSR TRANSIT(NORTH SEA)
EC VOYAGE	50%	50%	100%
CO_2	96,577	96,577	84,361
SO_2	1,235	3,246	3,236
NO_X	53,926	42,573	132,638
$PM_{2.5}$	3,290	11,242	13,732
PM_{10}	1,999	6,824	8,388
Total EC on voyage	157,026 €	160,461 €	242,355 €
Total EC in ports	8,790 €	8,632 €	
Overall (voyage + port)	**577, 264 €**		

Table 17
Recapitulation of the results on route profitability.

	SCR	NSR	CR
Revenue	5,743,800	5,310,000	5,770,800
Costs	2,045,969	1,862,512	2,293,775
Profit ($)	3,697,831	3,447,488	3,477,025
External costs (€)*	775,600	577,264	1,059,955
External costs ($)	913,261	679,723	1,248,086
TOTAL ($)	**2,784,570**	**2,767,765**	**2,228,939**

* converted according to the exchange rate 1 € = 1.17749 $ (August 2021)

The total external costs in this research are the highest via the Cape route, primarily as for the correlation between route length and external costs, which is highest in maritime transport. The lowest external cost values were found for NSR, but there is a lack of specific navigable area data.

As the focal point of the research is to determine the competitiveness between selected shipping routes on the OD pair Vladivostok-Bremerhaven, considering economic and environmental efficiency, the final recapitulation of the results generated are calculated and shown in Table 17.

The final results show the highest profitability by sailing through Suez Canal on freight flow between Vladivostok and Bremerhaven compared to alternative ones. This shipping route generates around 2,8 million USD of profit when all cost components and environmental damage are considered, and is marked as optimal for the present research. Despite having a lower share of voyage costs and shorter distances, the NSR provides lower revenue reflecting the 17,000 USD lower total profit than SCR. These values are negligible for the overall results but significant if several round voyages a year are realized. Finally, the Cape route generates 2,2 million USD considering the model settings.

6. Discussion and conclusions

Based on the research results, the container route via Suez Canal was optimal, following the Northern Sea Route, which generated negligible lower profitability. The Arc4 ice-classed vessel was integrated as a referent vessel in the model, even though the typical containership on this container loop has significantly larger capacities. The selection of the ship with lower overall capacity and specifications makes results more authentic. Large container vessels (10,000+ TEU) are still not operating on the northern routes for the climate conditions and ice-infected areas. The obtained economic efficiency values support the dominant status of the SCR, where the voyage does not get the highest revenue nor the highest transportation costs. However, the highest incomes are realized by sailing in the CR direction, exclusively due to the absence of transit fees. These relations reveal the importance of the transit component in the total cost structure. Some economic cost components were estimated, influencing the results, e.g., the revenue of individual shipping routes, which was adjusted to make it comparable with other samples. In addition, several cost categories were over-simplified and calculated as a lump sum as a port and cargo-handling costs, primarily for the restricted data from carriers. Generally, the demand for services and market activity along the SCR is more intense than the Cape route, which runs along the West African coast and ports with lower commercial activity. The Northern Sea route is also characterized by the deficiency of intermediate markets in the Arctic area, despite the economic viability, which was implied in several studies. The future development of this route will be closely related to navigation and ice conditions in the long term. As already indicated, the Cape of Good Hope route becomes viable in case of a lower freight rate and fuel price. Considering the model settings and selected container loops, the bunker price of 70 $/MT of VLSFO makes the Cape route a viable and cost-effective solution if all other components remain stable, constant, and unchanged. It confirms that primarily premise, that the fuel price determines the competitiveness of the round Africa route. Besides the traditional cost-effectiveness analysis, this research integrates the environmental damage costs in the final profit estimation. The complete internalization of external costs was assumed in the model. By including environmental expenses generated along the specific loop, the close correlation between these incremental costs and route distances is visible. This function is a characteristic of maritime transport, and the research results confirm these relations. According to the achieved values of environmental parameters, the lower amount of total

Table 18
Costs per TEU of a ship sailing along the selected alternative routes.

Unit costs	SCR	NSR	CR
$/TEU without EC	569	518	638
$/TEU with EC	823	707	985

emitted pollutants is found by navigating in the direction of NSR due to the use of MDO fuel with low sulfur concentration and lower load factor of the propulsion engine. The amount of pollutants emitted in navigation does not exceed 2,000 tons, and is reduced by almost 1,100 tons or 44% at a lower speed in transit. The average amount of emitted pollutants is generated by sailing along the SCR and is very high in the CR direction, due to the high fuel consumption. As stated by Zhu et al. (2018), air pollution correlates with the economic development of the coastal area. Depending on the traffic routes, the total costs of air pollution with an obvious advantage on the alternative route NSR were calculated. With external costs calculation, the final profits of container shipping companies on the SCR and NSR routes are found almost identical, and differ almost by $ 17,000. The lowest profit level is realized by sailing in the direction of CR. The dominant influence of CO_2 in the structure of air pollution costs reveals the necessity to increase energy efficiency, but more important the utilization of alternative fuels to reduce carbon footprint.

Providing a novel dimension to the effects generated on the selected shipping routes, they are interpreted from the other perspective by calculating the price of a single container or TEU unit for the modeled ship (a total of 3,596 TEU). Costs per TEU unit with external costs included are shown in Table 18.

Results from Table 18 reveal a strong influence of the external costs on the overall price per TEU, where the value increases by 36% to 54% when external costs are considered. These results confirm the significant influence of environmental components on the cost structure. If the cost per TEU as the competitive criteria is analyzed, the Northern Sea route predominates, exceeding the overall efficiency over SCR and CR. When comparing the results generated with other relevant studies, the differentiation of data is found as the consequence of different model settings. Considering the results of Zhu et al. (2018) on NCR, the total costs per TEU are similar, 560.23 $/TEU compared to 518 $/TEU, a value determined following the applied model in the present research. Other data, especially those related to SCR, is not applicable, while the mentioned authors also neglected the route around Africa in their research.The costs of the remaining pollutants (as NMVOC, N_2O, BC, and others) and global warming were not comparable. When these pollutant categories are excluded from the research settings, a close correlation between study results occurs.

Other studies considered economic viability only. Research performed by Lasserre (2014) differs in the higher ship capacity of 23, 850 TEU and 15,930 TEU integrated into the model, implicating higher costs generated from 941 $/TEU on SCR and 762 $/TEU on NSR. Zhang et al. (2016) indicated the unit profit of sailing via NSR (1124.27 $/TEU) as less efficient than voyage along with the traditional SCR (1150.70). This research also considered higher capacity vessels in the model. Verny and Grigentin's (2009) results show the total costs per TEU along the NSR of 925 $ and 1,400-1,800 $/TEU when SCR is considered. The analysis of the results of the individual studies revealed high differences in conclusions but especially for the different model settings. As the current research provides a novel standpoint and research settings, comprising all three shipping alternatives on the Asia to North Europe container loop, the significance of external costs internalization is emphasized. These results indicate a consequence of the integral calculation of transport and external costs. The Suez Canal Route is still optimal despite introducing external costs as a compettitive variable. But, by including external costs in the calculation, the profitability of this optimal route decreases compared to alternative ones. This indicates the ascertainment, that with the growth of external transport costs due to the growth of unit costs of pollutants and changes in policy and legislation and IMO regulations towards sustainable development, alternative paths could become optimal in the future. This knowledge can serve as a guideline for the future sustainable development policy in maritime transport. The prescribed sustainability goals by relevant policymakers require the environmental damage cost attached to the overall expense and profitability calculation of the transport route. This research underlines the sustainable development paradigm as the fundamental emerging initiative in shipping. Internalization of external costs is the foremost tool to reach that goal. Empirical research results can be helpful to all stakeholders providing transport services in decision-making procedures on the mode of transport and the choice of the transport route, following the environmental protection policy in maritime transport.

Despite providing several significant facts, this study faced certain limitations. This research relies on several estimated parameters and assumptions integrated into the model. Furthermore, some of the retrieved data and values, such as fuel prices, emission standards, and navigation rules, are subject to constant changes within the maritime industry. Due to the predefined model settings, the obtained results apply exclusively to container ships of polar class with a capacity of 3,000 TEU up to 5,000 TEU maximally. Thus, the utilized indicators do not examine the effects of economies of scale. The recommendations for future studies are directed to the integration of real-time data in the input data phase, directly provided by the carriers. Also, a larger sample would be more appropriate for the importance of the topic examined.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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