Journal of Machine Construction and Maintenance
PROBLEMY EKSPLOATACJI
QUARTERLY
ISSN 1232-9312 2/2017 (105)
p. 123–129

Izabela KOTOWSKA
Maritime University of Szczecin, Faculty of Economics and Transport Engineering
i.kotowska@am.szczecin.pl

EXTERNAL COSTS IN FEEDER SHIPPING AS AN ELEMENT OF A SOCIO-ECONOMIC ANALYSIS

Key words: external costs, sustainable transport, container vessel, feeder shipping.

Abstract: A socio-economic analysis is part of each EU funded investment project. One of the major problems is the assessment of social benefits resulting from such investment. In the case of investing in feeder container terminals, external benefits are estimated in terms of the modal shift from road to maritime transport. There are many tools that enable such assessment at different levels of detail. In each case, assessment methodologies are based on computed freight movement expressed in tonne-kilometres. Due to the specific nature of the feeder transport, this approach is incomplete. This is mostly because of the fact that ships call at many ports in a loop, where additional external costs are generated. This article proposes a methodology of evaluating external costs generated in feeder ship service and estimates external costs for three sample routes and three ship sizes.

Koszty zewnętrzne w żegludze feederowej jako element analizy społeczno-ekonomicznej

Słowa kluczowe: koszty zewnętrzne, żegluga morska bliskiego zasięgu, transport zrównoważony, żegluga feederowa.

Streszczenie: Analiza społeczno-ekonomiczna jest elementem każdego projektu inwestycyjnego dofinansowanego z funduszu europejskiego. Jednym z większych problemów jest ocena korzyści społecznych wynikających z takiej inwestycji. W przypadku inwestycji w terminale kontenerowe o charakterze dowozowo-odwozowym szacowane są korzyści zewnętrzne wynikające z przeniesienia modalnego z transportu drogowego na morski. Istnieje wiele narzędzi o różnym stopniu uszczegółowienia pozwalających dokonać takiej oceny. We wszystkich metodyka oceny oparta jest na wykonanej pracy przewozowej wyrażonej w tonokilometrach. Ze względu na specyfikę przewozów feederowych, które zawijają do wielu portów w podróży okrężnej takie podejście jest niekompletne. Statki feederowe zawijają do wielu portów w podróży okrężnej, gdzie generowane są dodatkowe koszty zewnętrzne. W artykule zaproponowano metodykę określania kosztów zewnętrznych generowanych w żegludze feederowej oraz oszacowano koszty zewnętrzne dla trzech przykładowych tras i trzech wielkości statków.

Introduction

The main goal of the EU transport policy is increasing the European transport system efficiency while reducing its negative environmental impacts. The basic task aimed at achieving this goal is shifting cargo from road transport to other modes that are characterised by smaller negative environmental impacts, such as feeder shipping.

The commonly applied measure to assess any benefits resulting from shifting cargo from road transport to maritime transport is a comparative analysis of fuel consumption, CO_2 emissions, or external costs in relation to the freight movement, most often expressed in tonne-kilometres. This approach is a far-reaching simplification that may lead to erroneous results, particularly when it is applied to feeder shipping. In the case of feeder shipping aimed at distributing containers from/to container hubs to/from feeder ports, the way the ship transport is organised has a significant impact on external costs amounts. In feeder shipping, a ship calls at several feeder ports and one or two hub ports. Consequently, in order to correctly assess the social impacts of the maritime link of a transport chain, it is necessary to account for the roundabout route (loop), which results in longer transport distances, a greater number of calls at ports, and limited transport capacity of the vessel.

1. Literature overview

External costs of transport – understood as costs that are not covered by transport users, such as costs of air pollution, greenhouse gases emissions, accidents and congestion [26] – are mainly related to threats posed to the natural environment as well as to human health and life. The emissions are caused mainly by fossil fuel combustion by vehicles. Road transport is considered to be the most energy-consuming transport mode. According to various research studies, to carry the same amount of cargo, road transport uses up even ten times more fuel than inland shipping and four times more than railway transport [21, 24]. One of the methods to reduce external costs of transport is the modal shift from road transport to more environmentally friendly forms of transport: railway, inland waterway, and maritime transport [4, 13, 21].

Within maritime transport, short sea shipping is the most promoted form [5]. The advantages of short sea shipping include the following: reduced congestion, a lower number of accidents, and lower emissions [14, 16, 18]. The lower social harmfulness of maritime transport is mainly due to a much larger capacity of ships compared to other means of transport [19]. On the other hand, maritime transport is a heavy contributor to SOx and NOx emissions due to the nature of fuel used by ship engines [6, 7, 8]. In order to find out whether feeder shipping contributes to sustainable development of transport (and if so, to what extent), it is necessary to estimate external costs generated by ships.

Since the onset of the 21st century, many programmes have been implemented in order to estimate external costs of transport. These include the following: IMPACT [15], INFRAS/IWW [11], RECORDIT [20], UNITE [17], and Marco Polo II [3]. The latest published appraisal of transport external costs is RICARDO [25]. Although the report was the first to differentiate external costs of maritime transport depending on the place of origin (Baltic Sea, North Sea, Mediterranean Sea, Black Sea, and other regions), far-reaching simplifications were made with regard to the kind of vessel. The report estimated external costs onlyfor four types of ships: crude oil tanker, product tanker, general cargo and bulk carrier, each in two or three size categories.

The presented Programmes involve methods based on estimating the freight movement (tonne-kilometres) and take into account the direct distance between the container hub port and the feeder port. In the case of feeder shipping, this approach is erroneous, as the costs should be estimated for the whole loop trip. Moreover, the Programmes do not present any costs connected with nodes. It is known that each transport node not only has an adverse effect on transport time and operating costs, but also generates considerable external costs. The goal of this article is to present a method of estimation of external costs generated in feeder shipping, while accounting for the roundabout route and the nodal points. As opposed to the commonly applied methods, this method is based on the ship's cargo capacity (TEU) rather than on its deadweight. This article also estimates external costs for three sample loops and three size categories of vessels used in feeder shipping.

2. Methodology

In feeder shipping, costs are incurred differently than in the case of e.g.Ro-Ro and ferry shipping. The main difference consists in the fact that feeder ships travel along the loops, calling at even several ports. A complete turnover of containers takes place in the container hub, whereas in the feeder ports - only some of them are loaded/unloaded. As a result, while covering the loop route, the feeder ship may transport twice as many containers than its nominal capacity (2 · Q), regardless of the number of ports called on the loop route (Fig. 1).

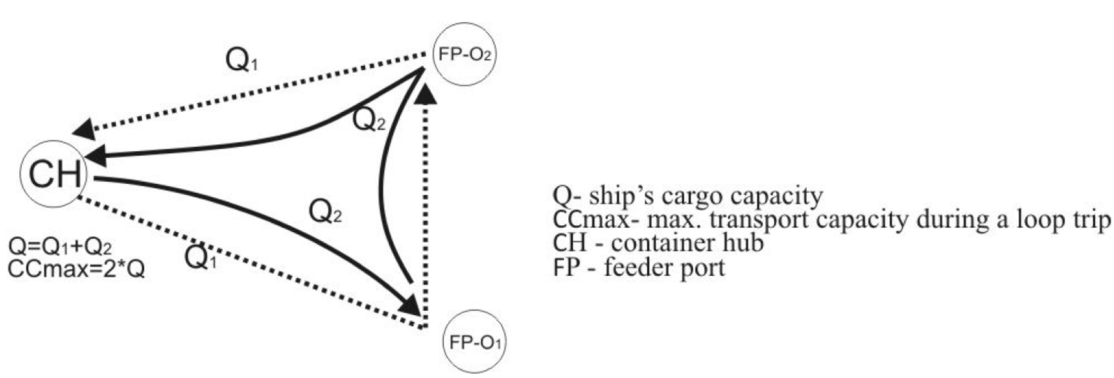

Fig. 1. Transport capacity of a feeder ship

Source: Author.

In maritime transport, external costs resulting from congestion and accidents are negligible and thus ignored in a socio-economic analysis. Therefore, the proposed method accounts for external costs generated as a result of emissions of harmful pollutants (sulphur oxides, nitrogen oxides, solid particles, non-methane volatile organic compounds (NMVOCs) and greenhouse gases (carbon dioxide) emissions.

External costs of transport generated by a feeder ship per freight unit (EC_f) are a sum of costs generated by the feeder ship during sea journeys (EC_{MT}) and costs generated in ports (EC_p) .

$$EC_f = EC_{MT} + EC_p \quad (1)$$

External cost incurred at sea per freight unit (EC_{MT}) is directly proportional tototal time spent by the ship at sea during a loop trip (T_{RT}) (and inversely proportional to the ship's cargo capacity (CC_{TEU}).

$$EC_{MT} = \frac{TEC \cdot T_{RT}}{2 \cdot CC_{TEU} \cdot \lambda} \quad (2)$$

where

TEC – total external cost generated by the feeder vessel [EUR/day],

T_{RT} – total time the ship spent at sea during the loop trip [in days],

CC_{TEU} – cargo capacity of the container vessel [TEU],

λ – the ship's cargo-capacity ratio [%].

Total external cost generated by the feeder vessel is a sum of external cost of emissions of a specific pollutant:

$$TEC = \sum_{i-1}^{n} C_{pi} = \sum_{i-1}^{n} (E_{pi} \cdot UC_{pi}) = = \sum_{i-1}^{n} (E_{UPi} \cdot F_{AVE} \cdot UC_{pi}) \quad (3)$$

where

C_{pi} – external cost of emissions of pollutant i by the feeder vessel (EUR/day),

E_{pi} – emissions of pollutant i (tonnes of pollutant/day),

UC_{pi} – unit cost of pollutant i (EUR/tonne of pollutant) at sea,

n – number of pollutants, $n=5$ (CO2, SOx, NOx, nmVOC, PM),

F_{AVE} – average fuel consumption at sea (tonnes of fuel/day),

E_{Upi} – unit emission of pollutant i (tonnes of pollutant/tonne of fuel).

The total time the ship spends at sea during a loop trip is directly proportional to the total distance (TD_{RT}) (NM) and inversely proportional to the vessel's average speed (V_{AVE}) (kn).

$$T_{RT} = \frac{TD_{RT}}{V_{AVE} \cdot 24} \quad (4)$$

The cost of pollution generated at seaports (EC_p) results from external costs generated by the ship in port (EC_{sp}) and costs generated by cargo handling facilities (EC_{cr}) per freight unit.

$$EC_p = EC_{sp} + EC_{cr} \quad (5)$$

External costs generated by the ship in port (EC_{sp}) are directly proportional to total time in ports (TT_p) (day) and costs of daily emissions (TEC_{sp})

$$\mathrm{EC_{sp}} = TT_p \cdot TEC_{sp} = TT_p \cdot \sum_{i-1}^{n} CP_{pi} = = TT_p \cdot \sum_{i-1}^{n} (EP_{pi} \cdot UCP_{pi}) \quad (6)$$

where

CP_{pi} – external cost of emissions of pollutant i by the feeder vessel (EUR/day) in port,

EP_{pi} – emissions of pollutant i in port [tonnes of pollutant/day],

UCP_{pi} – unit cost of pollutant i in port [EUR/tonne of pollutant],

n – number of pollutants, $n=5$ (CO2, SOx, NOx, nmVOC, PM).

Emissions of pollutant i in port depends directly on fuel consumption in port (FP_{AVE}) [tonnes of fuel/day] and the contents of the pollutant in fuel (EP_{Upi}) (tonnes of pollutant/tonne of fuel).

$$EP_{pi} = EP_{UPi} \cdot FP_{AVE} \quad (7)$$

The total time the ship spends in ports (TT_p) can be calculated as follows:

$$TT_p = \frac{\sum_{j-1}^{m} T_{pj}}{24} = \frac{\sum_{j=1}^{m} \left(\frac{TEU_{INOUT\,j}}{CRANE_j \cdot CAP_{AVE\,j}} + T_{INOUT\,j}\right)}{24} \quad (8)$$

where

$TEU_{INOUT\,j}$ – number of TEU loaded and unloaded in port j,

$CRANE_j$ – number of cranes loading/unloading the vessel in port j,

$CAP_{AVE\,j}$ – average crane capacity in port j [TEU/h],

m – number of ports in the loop trip,

$T_{ONOUT\,j}$ – time of entering and leaving port j by the ship [h].

Assuming that in all the ports the ship is served by the same number of cranes with similar capacities, equation (8) takes the following form:

$$TT_p = 1/24 \cdot \left(\frac{4 \cdot CC_{TEU} \cdot \lambda}{CRANE_i \cdot CAP_{AVE\,i}} + m \cdot T_{INOUT\,j}\right) \quad (9)$$

Costs generated by cargo handling facilities (EC_{cr}) per freight unit constitute the sum of costs related to individual pollutants i (CP_{pi}):

$$EC_{cr} = \sum_{i=1}^{n} CP_{pi} = EN_{CON} \cdot \sum_{i=1}^{n} (E_{EN\,i} \cdot UCP_{pi}) \quad (10)$$

where

EN_{CON} – energy consumption in the container terminal [GJ/TEU],

$E_{EN\,i}$ – unit emission of pollutant i in connection with the electric power used [tonnes of pollutant/GJ],

UCP_{pi} – as above.

3. External costs model application

In order to correctly estimate external costs in feeder shipping, the HEATCO Programme [2] was used, which – as opposed to other programmes – presents original costs related to the weight of emitted pollution. Then, the air pollutant emission inventory guidebook EMEP/EEA 2007 [9] was applied to specify pollution generated from 1 tonne of fuel (0,1% sulphur content), whereas emissions resulting from using electric power were estimated on the basis of EMEP/EEA 2016 [10]. To specify the amount of energy used by cargo handling facilities, the results of research done by G. Wilmsmeier [27] were used, which show the total energy consumption by a container terminal per TEU. The following value was assumed: EN_{CON} = 0.2 GJ/TEU.

The model application was prepared for three sample loop trips in the Baltic Sea area with one container hub port in Hamburg [22]:

– Route I: Hamburg – Riga – Hamburg – total distance of the loop trip TD_{RT} = 1280 *NM*;
– Route II: Hamburg – Gdynia – Tallinn – Stockholm – Hamburg — total distance of the loop trip TD_{RT} = 1636 *NM*;
– Route III: Hamburg – Gdynia – Kaliningrad – Klaipeda – Riga –Tallinn – Kotka-Stockholm – Hamburg — total distance of the loop trip TD_{RT} = 2113 *NM*,
– based on the model vessels presented in Table 2.

The presented model vessels included in the calculationreflect the sizes of feeder ships operating on the Baltic Sea, and those most often found have the capacity of 1,500 TEU.

Partial results and assumptions are presented in Table 3.

Table 1. External costs and emissions indicators

factor	E_{Upi}	UC_{pi}	EP_{Upi}	$E_{EN\,i}$	UCP_{pi}
unit	tonne of pollutant/ tonne of fuel	EUR/tonne of pollutant	(tonne of pollutant/ tonne of fuel)	tonne of pollutant/ GJ	EUR/tonne of pollutant
	sea		port		
CO2	3.1700	29	3.1700	0.1200000	29
NOx	0.0870	3,053	0.0870	0.0002090	5,166
SOx	0.0020	4,344	0.0020	0.0008200	6,575
NMVOC	0.0024	587	0.0024	0.0000010	1,174
PM	0.0067	1,409	0.0011	0.0000034	30,527

Source: [2 (updated by GDP to 2014), 9, 10].

Table 2. Parameters of container vessels

Container vessel	Symbol	500 TEU	1500 TEU	3500 TEU
Gross tonnage	GT	3,999	16,705	35,491
Cargo capacity (TEU)	CC_{TEU}	508	1,560	3,364
Average vessel speed (kn)	V_{AVE}	18	18	18
Average fuel consumption at sea (tonnes of fuel/day)	F_{AVE}	14	38	73
Average fuel consumption in port (tonnes of fuel/day)	FP_{AVE}	2	5	9
Cargo-capacity ratio (%)	Λ	90%	90%	90%

Source: Author's study based on [23].

Table 3. Assumptions to the model and partial results

Parameter	Symbol	Route 1.	Route 2.	Route 3.
Total time at sea (days)	T_{RT}	3.0	3.8	4.9
Number of ports	*m*	2	4	8
Number of cranes per ship	$CRANE_j$	1	2	4
Crane capacity	CAP_{AVEj}	50	50	50
Time of port entering and leaving	T_{INOUTj}	4	4	4
Total time in ports (days)	TT_p	1.9	3.0	3.9

Source: Author.

Figure 2 shows external costs generated in feeder shipping. Depending on the variant, the cost ranges from 21 to 31 EUR/TEU. Assuming that all the ships follow the same route (the analysis assumed the most often used Route 2, calling at 3 feeder ports), the bigger the ship, the lower the external cost per unit (Fig. 2 a). However, the decrease is not significant. When the ship's cargo capacity increases sevenfold from 500 to 3,500 TEU, the external costs decrease by ca. 20%.

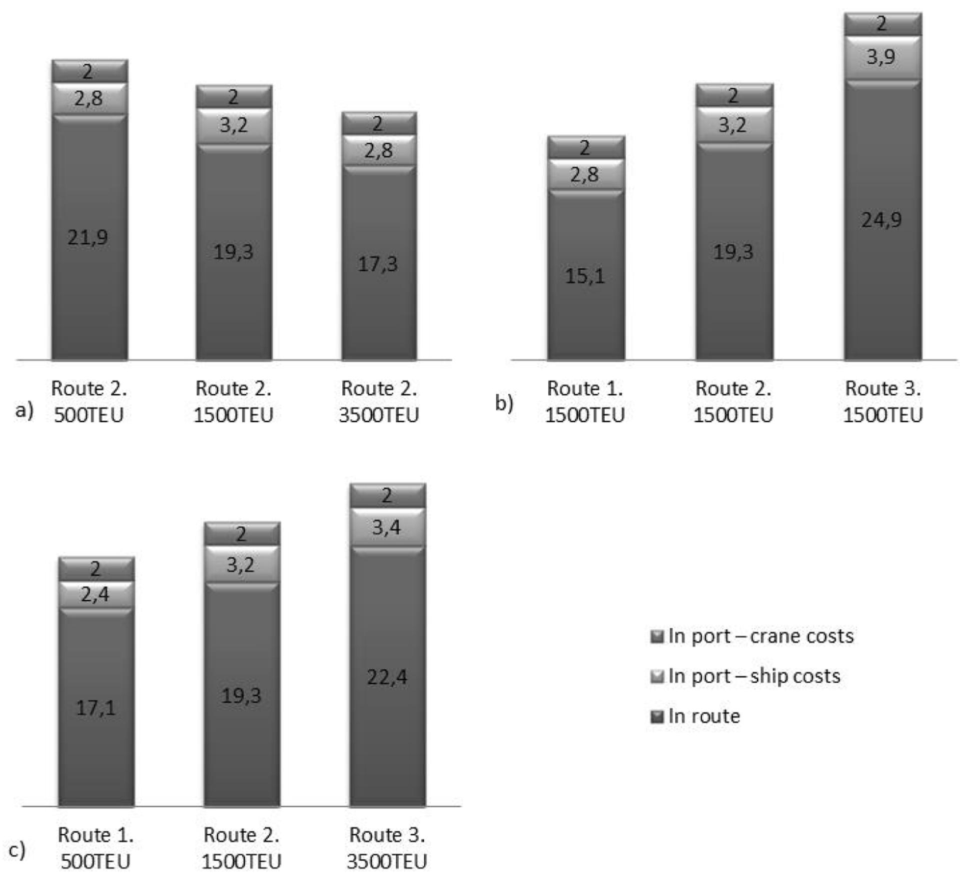

Fig. 2. External costs generated in feeder shipping for different routes and different container vessels (EUR/TEU)

Source: Author.

It is interesting to note that, for the same ship (the analysis involved a 1500 TEU container ship), the longer the loop trip distance and the bigger the number of ports of call (Fig. 2b), the more significant is the increase in external costs. In the analysed example, the increase exceeded 50%. It is important to the extent that all of the Programmes aimed at the estimation of transport external costs take into account only the direct distance between ports rather than length of the whole loop. For example, according to the RICARDO programme recommended by the EU for 5–10 k DWT general cargo vessels (the programme does not detail typical container ships), the external cost for the analysed route is as follows: from Gdynia – 32 EUR/TEU, from Tallinn – 52EUR/TEU, and from Stockholm – 44 EUR/TEU.

As bigger and bigger vessels are used in deep sea shipping, the smaller onesthat were previously engaged in the ocean services are moved to feeder service. To ensure the ship's cargo capacity is optimally used, operators increase the number of ports in a loop trip. This is reflected in external costs. The increase in external unit costs as a result of extending the roundabout trip length may not be compensated by an increase in the vessel's capacity (Fig. 2c).

Conclusions

Feeder shipping is an important element of the European transport system. In the light of the EU policy, sea shipping constitutes a major factor contributing to sustainable development of transport. In many programmes regarding transport external costs, maritime transport is ignored or underestimated, or the Programmes do not account for many variables that are decisive in the computation of actual costs. One of those variables is the cost incurred in seaports, resulting from the costs generated both by the berthing ship and the cargo handling facilities, as well as the way shipping is organised. The presented studies have shown that the factors may reach up to 25% of total external costs and they should not be ignored in computations. These factors contribute significantly to competitiveness of a land-sea transport chain. Due to them, in some cases, the land-sea transport chain may generate higher social costs than an alternative road route.

Summing up, it is difficult to unambiguously specify external costs generated in feeder shipping. This is because total social costs depend on, *inter alia*, fuel consumption, which in turn depends on the transport capacity of a given ship, its age, velocity, journey duration, and the number of ports of call in a loop trip. Therefore, any analyses of external costs should account for all constituents of costs, including those generated in transport nodes.

Acknowledgements

Research outcomes obtained as a result of a research study entitled "Sustainable development of land-sea transport chains no. 8/S/IZT/17" financed with a subsidy from the Ministry of Science and Higher Education for financing statutory activity.

References

1. A Vision for the 21st Century. The Maritime Administration and the US Marine Transportation System, US DOT/MARAD 2007.
2. Bickel P. et al.: Developing Harmonised European Approaches for Transport Costing and Project Assessment. HEATCO. Proposal for Harmonised Guidelines, IER, 2007.
3. Brons M., Christidis P.: External cost calculator for Marco Polo freight transport project proposals. Call 2012 version, JRC Scientific and Policy Reports, European Comission, Brussels 2012.
4. Chen K., Yang Z., Notteboom T.: The design of coastal shipping services subject to carbon emission reduction targets and state subsidy levels. Transportation Research Part E: Logistics and Transportation Review, 2014, 61, 192–211.
5. Communication from the Commission to the European Parliament, the Council the Economic and Social Committee and the Committee of the Regions (1999). The Development of Short Sea Shipping in Europe: A Dynamic Alternative in a Sustainable Transport Chain. Second Two-yearly Progress Report, Brussels, COM(99)317 final.
6. De Meyer P., Maes, F., Volckaert, A.: Emissions from international shipping in the Belgian part of the North Sea and the Belgian seaports. Atmospheric Environment, 2008, 42, 1, 196–206.
7. Dore A.J., Vieno M., Tang Y.S., Dragosits U., Dosio A., Weston K.J., Sutton, M.A.: Modelling the atmospheric transport and deposition of sulphur and nitrogen over the United Kingdom and assessment of the influence of SO2 emissions from international shipping. Atmospheric Environment, 2007, 41, 11, 2355–2367.
8. Doudnikoff M., Lacoste R.: Effect of a speed reduction of containerships in response to higher energy costs in Sulphur Emission Control Areas. Transportation Research Part D: Transport and Environment, 2014, 27, 19–29.
9. EMEP/EEA 2007: Other mobile sources and machinery, Shipping activities. Emission Inventory Guidebook, European Environmental Agency 2006.
10. EMEP/EEA 2016: Energy Industries. Combustion energy and Transformation Industries. Emission Inventory Guidebook, European Environmental Agency, 2016.
11. External costs of transport. INFRAS/IWW, Update Study, Zurich/Karlruhe, 2004.
12. Holland M. et al.: Damages per tonne of PM2.5, NH3, SO2, NOx, and VOC's of EU25 Member State (excluding Cyprus) and surrounding seas. Service Contract for carrying out cost-benefit analysis of air quality related issues, in particular in the Clean Air For Europe. CAFÉ, Didcot, AEA Technology Environment, 2005.

13. Janic M.: Modelling the full costs of an intermodal and road freight transport network, Transportation Research Part D: Transport and Environment, 2007, 12, 1, 33–44.
14. Kotowska I.: Method of Assessing the Impact of Polish Container Terminals in Reducing the External Costs of Transport. PROMET-Traffic & Transportation, 2013, 25, 1, 73–80.
15. Maibach M. et al.: Handbook on estimation of external costs in the transport sector Produced within the study Internalisation Measures and Policies for All external Cost of Transport. IMPACT, Deft, 2007.
16. Medda F., Lourdes T.: Short-sea shipping: an analysis of its determinants. Maritime Policy & Management, 2010, 37, 3, 285–303.
17. Nash C.: UNIfication of accounts and marginal costs for Transport Efficiency. UNITE, EU project, final report, Leeds, 2003.
18. Ng A., Yu K.: Competitiveness of short sea shipping and the role of port: the case of North Europe. Maritime Policy & Management, 2009, 36, 4, 337–352.
19. Paixão Casaca A.C, Marlow P.B.: Strengths and weaknesses of short sea shipping. Marine Policy, 2002, 26, 3, 167–178.
20. Real Cost Reduction of Door-to-door Inter-modal Transport. RECORDIT. EU project, final report, 2003.
21. Reis V.: Analysis of mode choice variables in short-distance intermodal freight transport using an agent-based model. Transportation Research Part A: Policy and Practice, 2014, 61, 100–120.
22. Sea Distances. [online] http://sea-distances.com/ (Accessed 04.05.2016).
23. Ships Register, [online] http://www.ships-register.com/ (Accessed 12.05.2016).
24. The Development of Short Sea Shipping in Europe: A Dynamic Alternative in a Sustainable Transport chain – Second Two-yearly Progress Report, European Commission, COM (99) 317 final, Brussels.
25. Umweltschonend mobil, Bahn, Auto, Lkw, Flugzeug und Schiff im Umweltvergleich. Datenbank Umwelt & Verkehr. Alianz pro scheine. [online] http://www.allianz-pro-schiene.de/publikationen/umweltschonend-mobil/umweltschonend-mobil-2012.pdf]).
26. Update of the Handbook on External Costs of Transport. RICARDO, Final Report, Report for the European Commission, DG MOVE, 1, 2014.
27. Verhoef E.: External effects and social costs of road transport. *Transportation Research Part A: Policy and Practice*, 1994, 28, 4, 273–287.
28. Wilmsmeier G.: Environmental challenges. Energy consumption and efficiency in ports and termianls. Seminario Transporte Aereo, 2015.