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Optimizing transportation between ports and the hinterland for decreasing impact to the environment

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Abstract

Today different transport modes use to deliver cargo between regions, from ports to final destination location or visa-versa. It is quite common to use road transport, which can deliver cargo "from door to door" but road transport causes big environmental impact. Considering alternative possibilities (road, railway and/or inland waterway transport) to decrease environmental impact from transport, it is very important. Based on theoretical and experimental tests, were find optimal solutions, which transport mode make minimum environmental impact and could be the most technically and economically effective solution. Traffic congestion on the roads, in some cases very high railway traffic in some regions, generates requirements by many stakeholders on ways to decrease the environmental impact from transport modes, which studded in Article to find and identify optimal transportation solutions with minimum environmental impact. A theoretical method evaluation conducted on the optimal transportation possibility that minimizes environmental impact. A transport modes environmental comparative index (ECI) is developed and used for evaluations. This paper presents possible alternative transportation conditions based on multi-criteria evaluation system, proposes theoretical basis for the optimal solutions from environmental and economic point of view, and provides for experimental testing during the specific case study, and finally provides recommendations and conclusions.

Keywords: transport modes; environmental impact; emissions; environmental comparative analysis; environmental comparative index

1. Introduction

A lot of the cargo in the World are transporting between regions, ports and industrial or other regions. At the same time, industrial areas (hinterland) are often located on long distances from the ports, e.g., the "Ruhr" area in Germany, which is the largest industrial area is located up to 250 – 400 km from the main West European ports, such as Antwerp, Rotterdam, Hamburg, etc. Similar situation regarding long distances between industrial areas and port are observed in many other European and World regions.

Optimizing transport processes and reducing environmental impact to be one of the key challenges for research and application, which is the main aim of this paper.

Road transport is used very intensively, because of the flexibility to deliver cargo by system "from door to door", as well from port to cargo destination place or transport cargo from shipper to ports and visa-versa. At the same time, road transport mode has its limitations: limit units capacity, relatively high engine power used as result of which high fuel combustion and emission generated in most times is not optimal compared to other alternatives, especially from environmental impact point of view [1, 2].

Railway transport often links many ports and cargo consignees' locations and is often using to transport cargo from port to its destination places or from shippers' location to the ports. Railway transport has sufficient capacity and less environmental impact in comparison with road transport for the same quantities of cargo transportation, but at the same time, in most cases cannot be using as the "door to door" transportation system [3 – 5].

In some Countries, inland waterway transport connects seaports with industrial and population concentration regions and using for cargo delivery from port to its destination areas and from shippers' areas to the ports. Inland waterway transport (barges and inland waterways cargo ships) in many cases uses less fuel for the transportation of the same cargo volumes [6, 7] and generate less emissions in comparison with other transport modes but at the same time, in most cases cannot be using as the "door to door" transportation system, same as railway transport [3 – 5].

Today, there are many methods for assessing optimal transport modes between consignors and consignees [8, 9], but at the same time, many of them do not allow for a complex assessment of optimal transport with minimum environmental impact and application impacts in difficult transport conditions, especially when changing transport mode needed in logistics chains [10].

The paper aims to develop scientifically based assessment methods for minimize environmental impact evaluation during cargo transportation between ports and cargo destination places or transport cargo from shipper to ports and visa-versa.

Optimization transport chains between ports and consignees/shippers, taking in account minimum environmental impact, as a key market driver is considered is important by evaluating different transport modes. The main trends and consequence that influence transport systems environmental impact presented on table 1.

Table 1. Key markets drive influence on optimization transport systems from environmental impact point of view

Trends	Consequence
Increasing competition between transport modes	More efficient systems from environmental impact and economics
Globalization	More investments in modern transport systems, decreasing environmental impact
More effective transport systems	Faster logistics, less emissions
Increasing energy costs	Energy savings, new energy types with less generating emissions
Increasing environmental demands	New fuels, removable energy, automation

In this paper the technical and environmental factors influence on selection transport chains are analyzed in detail. It aims to develop a method allowing an assessment of the possible optimization of the transport modes in transportation chain, considering environmental aspects technical possibilities, cargo delivery time and costs. The research questions were formulating as follows: how much influence does competition exists between transport modes that include environmental demands on selection optimal transport chains; what the advantages in are improving transportation processes during cargo deliver with minimum environmental impact.

It is assuming there will be differences in the cargo delivery time, costs as well volume of emissions created by transport modes when selecting different transport chains between ports and consignees/shippers. The proposed method presented in this paper based on empirical data analysis and indicates the best way to analyze the data using dispersion method. The aim is to identify possibilities that optimize transportation processes between port and consignees/shippers, with the potential to reduce environmental impact in transportation processes. The case study presented in this paper based on data from Lithuania in which an analysis performed to verify the method. Real data of transportation cargo between port and consignees/shippers are considered. Identified differences in transportation processes parameters allow an estimation and environmental impact and other transportation parameters.,

Section 2 of this paper presents the analysis of possible cargo transportation systems between seaports and final cargo destination areas supported with a literature analysis. Section 3 describes the methodology used to conduct the research. The results of case study analysis presented in Section 4. Discussions, conclusions, and directions of future research, which presented in Sections 5 and 6, summarize the paper.

The scientific contribution of this paper is on the development of a methodology for calculating a means of comparison of the transport modes, using the calculations of environmental results of different vehicles in real conditions.

The paper analyses the current situation of cargo transportation from ports to consignees and back, includes transportation evaluation methods, develops a comparative transportation evaluation methodology, including environmental impact aspects, economic, technological, performs a case study, presents the practical and theoretical significance of the research results and conclusions. The conducted analysis of available literature revealed that there are many studies that seek to optimize environmental sustainability in shore and waterborne transport [11, 12, 13]. The reviewed studies often analyze the technical and technological aspects of sustainable transportation, which identifies organizational challenges and possible economic effects, assess the volume of pollution, and propose ways to decrease it [2, 5, 6, 8, 9, 14].

Optimization of transport modes for cargo transportation from seaports to the final destination is very important from economic, environmental and reducing of roads traffic points of view [15]. Optimization of transport modes could be useful for the transport companies, cargo consignees as well as society, especially, in people living areas, because it could reduce road congestion, especially in cities [16 - 19].

This paper proposes improvement of cargo transportation systems between seaports and final cargo destination areas by conducting an analysis of relevant literature sources. A theoretical basis generated for improving the cargo transportation modes and its combinations, while considering means to reduce emissions. A case study conducted to evaluate the different transport modes and environmental impact, discussions and conclusions.

2. Analysis of possible cargo transportation systems between seaports and final cargo destination areas, environmental impact and relevant literature sources.

Today a lot of cargo is transported between seaports and final cargo destination areas caring by road transport, which impacts very busy roads and causes traffic jams, dramatically increases negative environmental impact (especially, during traffic jams) and, finally, demands additional resources [20, 21]. In most cases, cargo needs to be transported using road transport (at least on short distances), but at the same time a major part of cargo volumes could be delivered using much more environmentally friendly transport modes [22 - 26].

For example, transportation of cargo from main European ports like Rotterdam, Antwerp, Le Havre and other ports to Benelux, North France, West Germany, and other industrial regions is organized mainly by using road transport (about 55 % of cargo inside European union is transporting by road transport [27, 28]). However, it is worth noting that there exist many alternative transportation possibilities, such as using railways and inland waterways which last decade increase very much (up to 32 % by railway and up to 25 % by inland waterway transport [27, 28]).

Distance between main West European ports, like Rotterdam, Antwerp, Hamburg, and others, using road and railway transport is similar, using inland waterway transport - distance increase about 10 – 20 %. Due to big traffic on roads and limitation in railway transport, transportation time, on average distances about 300 km, takes between 8 and 12 hours. In same time, inland waterway transport takes about 20 – 28 hours. It is wort noting that on average that one freight train or relatively small barge can replace about 50 trucks. The “Last mile” destination must organize between railway station or inland waterway transport loading/reloading places and destination point.

Similar situation can be ascertained between Szczecin Seaport and Berlin region because Szczecin Seaport is closest port to the Berlin region (Figure 1). Consequently, for transportation needs between Szczecin Seaport and Berlin region the road, railway and inland waterway transport could be used [29].

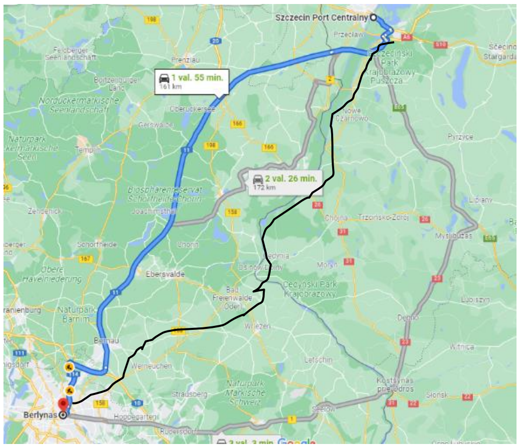

Figure 1. Road, railway and inland waterway between Szczecin port and Berlin area [6].

The route covers the Oder River area from Szczecin to the Hohensaaten lock, the Oder–Havel Canal and the Havel River, which connects to the inland waterway system of Western Europe [6].

Generally, inland water transport plays a significant role in caring bulk, general, and liquid cargo, including intermodal transport units, such as containers or vehicles. Inland water transport takes more and more attention as a sustainable alternative for road and railway transport since focus for CO_2 emission reduction is growing in the past years [30]. As an example, fuel consumption and CO_2 generated emissions (on average) look as follows: road transport generates about 180 – 200 g/t km; railway transport generates about 100 – 120 g/t km; inland waterway transport generates about 20 – 30 g/t km; sea transport generates about 7 – 10 g/t km [8 - 14].

In order to develop an inland transport, it is necessary to induce and ensure flexibility for logistic chains so that advantages could gain from environmental and economic point of view. However, trains and trucks do not have a real operating electric alternative at this time, but electric boats, barges and tug projects already exist in the world [31]. There exist many research studies that were conducted on various hybrid propulsion configurations for inland water transport, especially for tugs, i.e., as (LNG)-Diesel, LNG-Diesel-Electric, LNG-Diesel-Battery-Electric. The results from research studies suggest a potential to reduce energy consumption by approximately 13% in comparison to conventional systems that run on a diesel engine, and reduction of CO_2 emissions by approximately 29% compared to conventional diesel engines [32, 33]. Inland waterways transport is also an option to reduce traffic problems, which obviously related with scheduling and CO_2 emission. A country, which has natural rivers and channels, should take more attention to invest and benefit from advantages provided by inland waterways [34].

The infrastructure network of inland shipping systems consists of two components. The first is a global one and includes shipping lines where cargo comes to seaport hubs where it is sorted and prepared for distribution by inland water transport deeper into continent to final inland cargo port from where cargo are delivered to other destination by road or rail transport (Figure 2). Cargoes can transport on a variety of routes that connect seaports with inland waterway ports. The second one is local when inland waterways are used to transport cargo inside the continent or country and cargo is not exported from or imported into the [34, 35]. It is quite common to use inland water transport to delivery mining production until manufacturing, decrease CO_2 and other emissions.

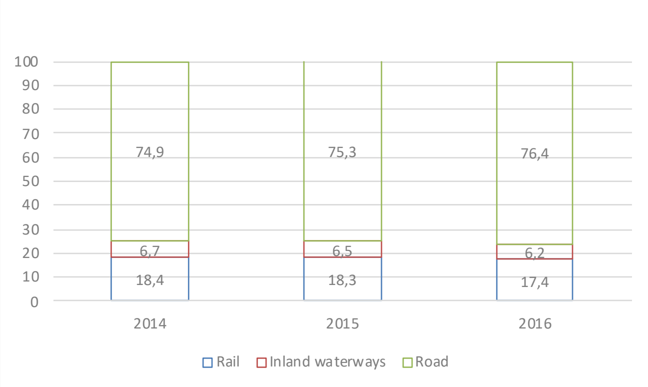

Figure 2. Freight transport in the EU-28 modal split of inland transport modes (% of total ton-kilometers), (Eurostat, 2017) [36].

In many European regions as well as in other places of the world, it is possible to use a various transport modes for the cargo transportation between cargo shippers and consignees and it is very important to find sustainable transportation systems oriented to optimizing the transportation costs and at same time to minimize the environmental impact. Research in this area can assist in locating optimal solutions and reducing the need for energy resources, decrease environmental impact and optimize cargo transportation and storage costs [37 – 40].

A number of methods are presented in which they seek to reduced environmental impact which are located in literature, such as morphological analysis [8], transportation network improvement and tolling strategies method [9], graph theory methods [41], which partly are adopted for the transportation and environmental impact assessment. Methods for the time and/or costs evaluation in road transportation evaluation of performance measures for two-lane intercity presented by Penmetsa et al (2015) [22], assessing road network accessibility comparative analysis by Belen et al [2], which is based on separate factors.

Methods for costs and time transportation calculations by railway, for example employ mixed integer linear programming method, which is presented by Zhou et at (2020) [5] and railway transportation problems and solutions, presented by Saakian, Savchuk (2013) [3], can be used for the same factors calculations, but it is very complicated to calculate all the main factors.

A number of methods for the different factors calculations in waterborne transport [6, 7, 34], port and logistics [20, 24, 26] mainly analyzed typical situations but in same time it is very important complex evaluation and comparison, including environmental impact assessment.

Environmental impact assessment from transport modes, especially generated CO2 emissions are analyzed by road transport in research papers [1, 11, 19], by railway transport in research papers [3, 19], by waterborne transport in research papers [12, 13, 15-17, 21, 33], by transport and logistics processes in research papers [24, 26, 37] and others, but mainly based on the typical transportation conditions.

For the research and practical tasks, it is very important to develop methodic, which can cover all main factors, including environmental impact, transportation costs and time, which can show comparative transport processes in different transport roads or corridors?

3. Theoretical basis for the cargo transportation modes and its combinations, emissions evaluation methods.

3.1. Research methodology

To develop the research methodology, an initial study was performed in analysing available literature that then allowed conducting a review on "the state of the art" in cargo transportation. Transportation between port and consignees/shippers, transport corridors selection, including environmental impact, transportation costs, time and other factors by transport means, existing models used for the selection optimal transport corridors etc. Data was collected based on literature sources and observations of cargo transportation between ports and consignees/shippers movement in transport corridors and experimental data received from ports, consignees/shippers, forwarding and transport companies (Figure 4).

The methodology was stated in this research that it should consider possible transport corridors, transport means, environmental impact as well transportation time and costs factors. Main cargo transportation parameters were considered: transportation distances between main transportation points, "last mile" distances, fuel consumption and generated emissions, transportation costs, on different transportation sections, cargo loading equipment, transport means capacity, fuel consumption by transport modes and cargo handling equipment, transportation and reloading time, transport modes and cargo handling equipment power and time using coefficients etc. (Figure 3).

Literature analysis and possible data collection

Identification of transport corridors, possible transport modes, as well as other necessary data

Analysis of the transport and environmental elements

Mathematical model development

Case study analysis under the set conditions and mathematical models evaluation and correction

Elaboration of discussions and recommendations for the environmental impact minimization and optimal transport corridors and conditions

Figure 3. The algorithm of the research methodology

Hydro-meteorological and hydrological conditions for the inland waterway ships (barges) were considered in the proposed method, e.g., wind velocity, wind course angle (the angle to a waterway access), current velocity, current course angle barge etc.

Moreover, additional data, such as navigation channels (waterways) width, channels bandings, etc. necessary for conducting research taken in account collected and analyzed. Furthermore, the relevant weight coefficients, received by theoretical and experimental investigations considered.

A mathematical model developed to calculate fuel consumption and fuel quality, generated emissions, transportation time and costs, as well as hydro meteorological conditions on inland waterways, roads, railways and cargo loading points. This model takes into consideration implementation of following steps:

- collection and analysis of data mentioned above,
- planning possible distances between port and main reloading points (intermodal terminals),
- calculation of the cargo reloading time and environmental impact in cargo reloading points, based on collected needed data,
- calculation of particular transportation parameters, such as time and fuel consumption,
- calculation and analysis of total generated emissions during cargo transportation and reloading,
- calculations of environmental comparative index for the transport corridors, drawing the conclusions and recommendations for the specific conditions.
-

Boundary conditions of the methodology and mathematical model mainly link with infrastructure parameters (inland waterway transport), optimal superstructure (inland waterway and railway transport), and transportation distances (road transport).

The proposed methodology verified based on case study analysis. The containers transportation between Klaipeda port and Kaunas region was analyzed in detail and calculations based on real data carried out. Based on the archived results recommendations for the selected optimal transport corridors were proposed. In same time, proposed methodology could be adopted in any other similar places and conditions.

3.2. Mathematical model

The main conditions for the development of the route network are to estimate possible alternative routes between seaports and consignee locations lower environmental impact and to create preconditions for optimal route selection, assessing, the worst technical possibilities, and acceptable environmental and economic conditions.

Methodology for the cargo transportation optimization between ports and consignee locations developed on basis of graph theory and multi-criteria analysis [41 – 45]. Main tasks of the developed methodology are based on the research of theoretical models, which can assist in finding optimal transportation modes, minimization of environmental impact and practically useful applications.

In individual cases, the total cost, including environmental payments may be included in the common price and reported on a "lump sum" basis.

Considering at least one transport mode capacity (the number of containers transporting by train); it is possible to make analysis and find optimal solutions [46, 47]. Optimal solutions could include environmental impact assessment by different transport modes, time and costs of transportation [48].

The main types of emissions from fossil fuel of the vehicles could be named as follows: carbon dioxide (CO_2); carbon monoxide (CO); sulphur oxides (SO_x); nitrogen oxides (NO_x) and particulate matter (PM). The amount of carbon dioxide and sulphur oxides generated depends on the quantity of the fuel burned, and the amount of carbon monoxide, nitrogen oxide and particulate matter generated depends on the actual engine power and operating time used by the engine [48 - 52].

Because transport modes engines are powerful enough, consume a lot of fuel. Ships, for example, use a lot of fuel while sailing and use a little less when are at the ports or anchorages, i.e., waiting for the loading and unloading. The amount of fuel consumed by a transport mode could be calculated during the round trip or during another period. In general, the transport mode fuel consumption during concrete period (voyage) (q_F) can be calculate as follows [17, 33]:

$$q_F = \int_0^t q_F^{'} \cdot N \cdot dt \ , \qquad (1)$$

Where: $q_F^{'}$ - the relative fuel consumption of the transport mode (kg/kWh). For the many type of transport modes the relative fuel consumption is from 0.13 to 0.25 kg/kWh (data that are more precise can be find in the specifications of the engines of a particular transport mode); N - power of engines during analysed period; t - the transport mode working time in hours, for example, during round trip, in a separate voyage and so on.

Emissions are calculated using formulas consisting of the amount of fuel consumed, the actual engine power used and the relative magnitude of the specific emissions. In this way, the carbon dioxide content is calculated using the following formula [13, 17, 24, 26]:

$$CO_2 = \Delta CO_2 \cdot \int_0^t q_F^{'} \cdot N \cdot dt \ , \qquad (2)$$

Where: ΔCO_2 - a carbon dioxide factor of 3.0 to 3.5 for petroleum products (diesel, heavy fuel oil) and 2.5 to 2.9 for LNG.

The sulphur oxides (SO_x) content is calculate using the following formula [21, 50]:

$$SO_X = \Delta SO_X \cdot \int_0^t q_F^{'} \cdot N \cdot dt \ , \qquad (3)$$

Here: ΔSO_x - sulphur oxide factor, which depends on the type of fuel: for petroleum products it is about 0.001, for LNG it is about 0.

The carbon monoxide content can be calculated using the following formula [11, 12, 50]:

$$CO = \int_0^t \Delta CO \cdot N \cdot dt \ , \qquad (4)$$

Here: ΔCO - carbon monoxide factor depending on engine type.

The amount of nitrogen oxides generated can be calculated using the formula [17, 48, 50]:

$$NO_X = \int_0^t \Delta NO_X \cdot N \cdot dt \ , \qquad (5)$$

Here: ΔNO_x - nitrogen oxides factor depending on engine type.

The amount of particulate matter generated can be calculated using the formula [17, 49, 50, 51, 52]:

$$PM = \int_0^t \Delta PM \cdot N \cdot dt \ , \qquad (6)$$

Here: ΔPM - Particulate matter factor, depending on engine type and fuel type, can be up to 10 g/kWh for petroleum products and close to zero for LNG.

Sustainable transport systems that connect ports with delivery points are crucial in analysing the various options for delivering cargoes to ports and vice versa. In many cases, it is necessary to solve the "last mile" problem, which can be done by using graph theory [41 - 45]. It is essential for the optimal development of the transport system that it is sustainable in terms of environmental impact, time, and transportation cost.

The application of graph theory method is used, where the model is built in such a way so that incorporates a set of vertices, which are representing possible transport roads or corridors, and a set of edges, which represents the distances, fuel consumption and so on between main connecting points like terminals, railway stations (intermodal terminals) and final destination points. This could be modelled as a graph and expressed as follows [41 - 45]:

$$G = (V, E) \ , \qquad (7)$$

Where: V - the set of vertices; E - the set of edges. Such graph model can be expressed, as shown on figure 4.

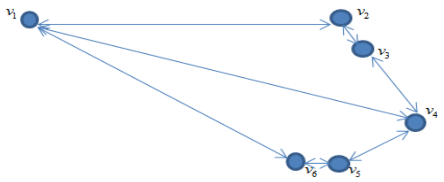

Figure 4. The graph tree for transport modes possible ways: v_1 – departure point; $v_{2,}, v_3, v_5, v_6$ – waypoints; v_4 – destination point.

Departure point could be Seaport (v_1) and destination point could be as cargo consignee (v_4). Depending on the transport mode, it could be a direct delivery by road transport mode (from door to door), that means from (v_1) to (v_4), a railway mode could be used between points and, from point to point, and from point-to-point road transport could be used as "last mile destination”. Similarly, inland water way transport mode could be used from seaport point up to inland waterway ships loading place and road transport could be used from inland waterway transport loading place to final destination as “last mile destination “.

For the graph tree, presented at figure 6, the sets of vertices and the set of edges can be expressed as follows [41 - 45]:

$$V = \{v_1, v_2, v_3, v_4, v_5 \dots\} \tag{8}$$

$$E = \{(v_1, v_2)(v_2, v_3)(v_1, v_3)(v_1, v_4)(v_4, v_3)\dots\} \tag{9}$$

The incident matrix of all vertices, consisting of connecting direct graph connections provided by the graph tree G, can be presented as follows [41 - 45]:

$$A = a_{ij} \,, \tag{10}$$

Where
$$a_{ij} = \begin{cases} 1 \text{ if } \mathrm{v}_i \text{ is the initial vertex of } \mathrm{e}_j \\ \text{-1 if } \mathrm{v}_i \text{ is the terminal vertex of } \mathrm{e}_j \\ 0 \text{ otherwise.} \end{cases}$$

In this case study (figure 5) for possible transport corridors network adjacency matrix can be explained as follows [41]:

$$A = \left\{ \begin{matrix} v_1, v_2, v_3, v_4, \dots \\ v_2 \\ v_3 \\ v_4 \\ \dots \end{matrix} \right\} \tag{11}$$

For the graph tree covering transport corridors network, which is explained at Figure 5, mentioned matrix in formula (9) can be calculated as follows:

$$A = \begin{bmatrix} 0111\dots \\ 1010 \\ 1101 \\ 1010 \\ \dots \end{bmatrix} \tag{12}$$

Matrix (12) could be used for the calculation of environmental impact, time, and transportation costs. Finally, the optimum distances, optimal price, or minimum environmental impact in transport routes at the network could be calculated using the following optimization formula [41 - 45]:

$$f : E \Rightarrow R^+ \,, \tag{13}$$

It is also necessary to find a graph tree $T = (VE^{'})$ for minimum environmental impact *F(T);* price and optimal distance:

$$F(T) = \sum_{xy \in E^{'}} f(xy) \,, \tag{14}$$

Where: $f(xy)$ - minimum environmental impact, transportation price, optimal distance, or other factors.

Here the edges $e = xy \in E$ as minimum environmental impact, price, optimal distance, or other minimum factors could be calculated as follows [41]:

$$f(e) = \min_{xy \in E} f(xy) \,, \tag{15}$$

Based on the proposed graph theory it is possible to design optimal transport corridors based on minimum environmental impact transportation time, cost, or other factors [53, 54].

To find optimal solutions, evaluation methods with weight coefficients could be used. In case different transport modes are used, evaluation for the selected transport routes could be made using environmental comparative index (ECI), which can be calculated using the following equation:

$$ECI_i = \eta_k (k_{CO_2} \frac{CO_{2(i)}}{CO_{2(0)}} + k_{SO_X} \frac{SO_{X(i)}}{SO_{X(0)}} + k_{CO} \frac{CO_{(i)}}{CO_{(0)}} + k_{NO_X} \frac{NO_{X(i)}}{NO_{(X(0)}} + k_{PM} \frac{PM_{(i)}}{PM_{(0)}}) \,, \tag{16}$$

Here: η_k - correlation coefficient. In case of 5 factors it could be taken as 0,95 – 0,97, using more factors could improve in identifying correlation coefficients by using a matrix systems [44]; $CO_{2(i)}, SO_{X(i)}, CO_{(i)}, NO_{X(i)}, PM_{(i)}$ - carbon dioxide, sulphur oxides, carbon monoxide, nitrogen oxides, particulate matter analyse transport road (corridor) generate emissions; $CO_{2(0)}, SO_{X(0)}, CO_{(0)}, NO_{X(0)}, PM_{(0)}$ - carbon dioxide, sulphur oxides, carbon monoxide, nitrogen oxides, particulate matter etalon road (corridor) generate emissions; k_{CO_2} - CO_2 emissions weight coefficient.

Depending on the type of fuel, it could be taken between 0,25 – 0,35; k_{SO_X} - SO_X emissions weight coefficient. Depending on the type of fuel, it could be taken between 0,10 – 0,15; k_{CO} - CO emissions weight coefficient. Depending on the type of fuel, it could be taken between 0,10 – 0,15; k_{NO_X} - NO_X emissions weight coefficient. Depending on the type of fuel, it could be taken between 0,20 – 0,30; k_{PM} - PM emissions weight coefficient. Depending on the type of fuel, it could be taken between 0,10 – 0,15. In all cases sum of the weight coefficients must be equal to 1.

Developed equation (16) is based on multi-criteria methods and can be used for many tasks, for example for passenger and cargo transportation optimization including environmental impact evaluation in case if few of transport corridors could be used, as well for the logistics chains evaluations. Using mentioned equation is necessary to pay attention on weight coefficients, which can be calculated by matrix in case of existing wide data base or could be used expert methods in case of limited real data.

For the analysis and evaluation of the experimental data distribution, it is proposed to use dispersion (σ) [20, 53, 54] method to find possible factors range (band).

$$\sigma^2 = \frac{1}{n-1}\sum_{1}^{n-1}(x_i - x_m)^2 , \qquad (17)$$

Here: n - measured quantity (statistics data); x_i measures results; x_m - mathematics' factor, which can be calculated as follows:

$$x_m = \frac{1}{n}\sum_{1}^{n} x_i , \qquad (18)$$

Then the relative environmental comparative index (ECI), transport modes comparative index band (ΔECI) can be calculated using the following formula:

$$\Delta ECI = \pm\sqrt{\sigma^2} , \qquad (19)$$

The main scientific contribution of the developed methodology is on based on using graph theory, multi-criteria, and comparative methods. Received tool is more accurate in comparison with existing methods for evaluation on finding optimal transportation possibilities including environmental impact between ports and consignee locations, for the evaluation.

4. Case study on the different transport modes and environmental impact: Lithuania case

Analysis of cargo transportation and using of methodology, presented in section 3, were performed practical tasks – minimum environmental impact during cargo transportation between port and consignee location. For this case study transportation of containers from (to) Klaipeda port to (from) Kaunas area is taken. It is possible use three transport modes between transportation points: road, railway, and waterway transport. In case of railway and inland waterway transports, it is necessary use "last mile" solutions (figures 5 – 7) [29].

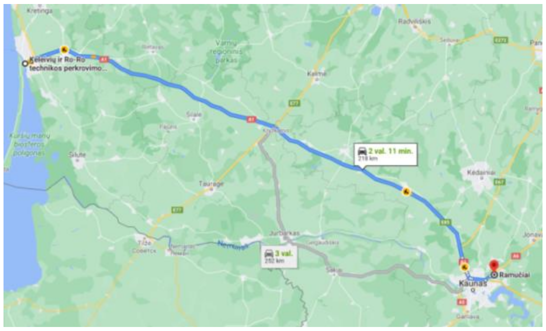

Figure 5. Road transport system between Klaipeda port and Kaunas free economic zone.

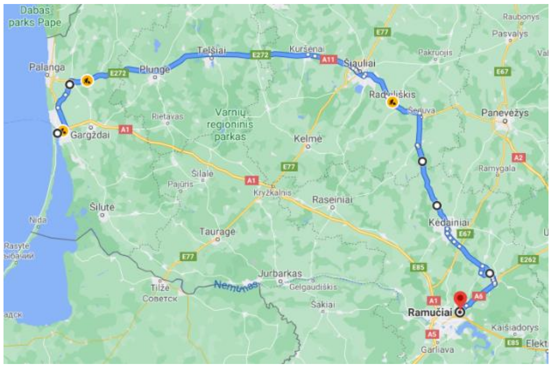

Figure 6. Railway transport system between Klaipeda port and Kaunas free economic zone.

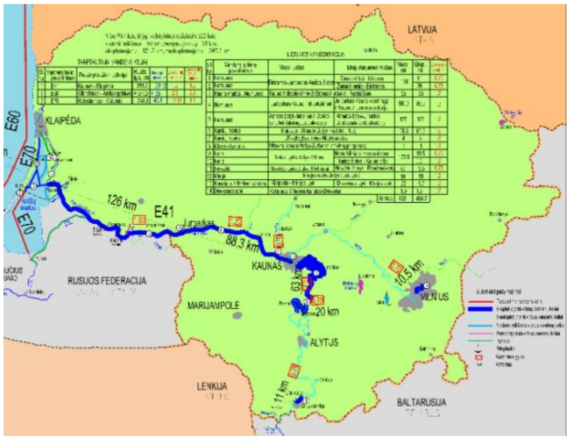

Figure 7. Inland waterway system between Klaipeda port and Kaunas free economic zone.

Graph model for the selected transport systems in general between Klaipeda port and Kaunas free economic zone customers transportation situation can be explained as follows (figure 8) [41]:

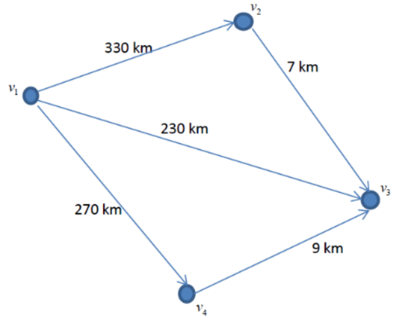

Figure 8. Case study graph: V_1 - Klaipeda container terminal; V_2 - Kaunas intermodal terminal; V_3 - Kaunas free economic zone; V_4 - inland waterway loading place.

In Figure 8, the distances are as follows: 330 km by railway from Klaipeda container terminal to Kaunas intermodal terminal, 7 km by road transport from Kaunas intermodal terminal to Kaunas industrial area, 230 km by road transport from Klaipeda container terminal to Kaunas industrial area, 270 km by inland waterway from Klaipeda container terminal to inland waterways unloading place in Kaunas area and 9 km by road transport from inland waterway barges loading place in Kaunas area to Kaunas industrial area.

As a typical transportation case a train and inland waterway barge, which can transport about 80 TEU (figure 10), have been taken. For some 20' (TEU – Twenty Foot Equivalent Unit) and 40' foot or 2 TEU containers it will be necessary to have approximately 50 road transport trucks. Propelled barge or tug-pusher engine power is about 400 kW (figure 9), and the average speed is about 15 km/h. The engine power of train locomotive, which can transport 80 TEU, is about 4000 kW and the average speed is about 35 km/h. The engine power of one road truck is about 300 kW and average speed is about 60 km/h. Above mentioned transport modes parameters should be taken as a basis for the calculation fuel consumption and generated emissions (environmental impact) using the methodology described at section 3 of this paper. It is also necessary to take distribution procedures at intermodal terminal into account in case railway transport and road transport on "last mile" is to be use. The latter shall also apply in case waterway transport and road transport on "last mile" is used.

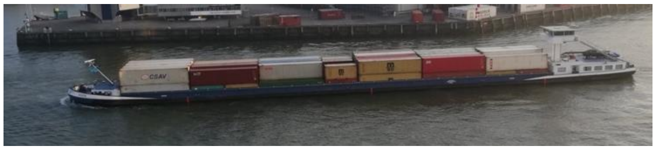

Figure 9. About 80 TEU can be transported by inland waterway transport mode (barge).

Inland waterway barges carry a lot of cargo with relatively low power engine and may keep constant speed in case of absence of any locks or other obstacles on the waterway (Lithuania case). At the same time due to required transhipment between inland waterways (railways) transport mode and road transport the following items need to be considered - „last mile "distance, additional time, costs and environmental impact [53, 54].

Transhipment at the intermodal terminal or at the inland waterway barges loading and storage site by a mobile crane with 15 movements per hour and average engine power of about 500 kW should be considered when calculating the environmental impact.

Adjacency matrix of the graph at figure 8 for the transportation time in hours in case of transportation of 80 TEU (on average, delivery of 50 boxes using one train or one barge, or 50 road trucks), for the emissions calculating taken in account conditions mentioned above, could be made as follows:

$$A_T = \begin{bmatrix} 0 & 9 & 12 & 37 & 0 & 0 \\ 9 & 0 & 3 & 28 & 0 & 0 \\ 12 & 3 & 0 & 25 & 0 & 0 \\ 150 & 28 & 25 & 0 & 25 & 28 \\ 21 & 0 & 0 & 25 & 0 & 3 \\ 18 & 0 & 0 & 28 & 3 & 0 \end{bmatrix}$$

Experiments on the real transportation time have shown that differences in the road transport reach up to 7 – 8 %, mainly due to traffic conditions in cities areas, differences in railway transport - up to 5 – 7 % in case of good planning and differences in inland waterway transport find up to 10 %, mainly due to departure issues from the port area.

Adjacency matrix of the graph at figure 8 for the total engines power in kW (on average, delivery of 50 boxes using one train or one barge, or 50 road trucks), could be made as follows:

$$A_N = \begin{bmatrix} 0 & 2500 & 250 & 200 & 0 & 0 \\ 2500 & 0 & 250 & 200 & 0 & 0 \\ 2750 & 250 & 0 & 200 & 0 & 0 \\ 200 & 350 & 200 & 0 & 200 & 450 \\ 600 & 0 & 0 & 200 & 0 & 250 \\ 400 & 0 & 0 & 450 & 250 & 0 \end{bmatrix}$$

Adjacency matrix of the graph at figure 8 for the fuel consumption in kg (on average, delivery of 50 boxes using one train or one barge, or 50 road trucks) for transportation of 80 TEU could be made as follows:

$$A_K = \begin{bmatrix} 0 & 3600 & 3720 & 4320 & 0 & 0 \\ 3600 & 0 & 120 & 720 & 0 & 0 \\ 3720 & 120 & 0 & 600 & 0 & 0 \\ 4800 & 720 & 600 & 0 & 600 & 720 \\ 1200 & 0 & 0 & 600 & 0 & 120 \\ 1080 & 0 & 0 & 720 & 120 & 0 \end{bmatrix}$$

Experiments on the real fuel consumption in analysed transport corridors have shown that differences in the road transport reach up to 5 – 12 %, mainly due to traffic conditions, differences in railway transport reach up to 6 – 11 % in case of good planning and differences in inland waterway transport find up to 10 %, mainly due to manoeuvring of the ship.

Adjacency matrix of the graph at figure 8 for the emission generation, for example, NOx, for transportation of 80 TEU in kg could be made as follows:

$$A_{NO_x} = \begin{bmatrix} 0 & 78 & 80.1 & 106.1 & 0 & 0 \\ 78 & 0 & 2.1 & 28.1 & 0 & 0 \\ 80.1 & 2.1 & 0 & 26 & 0 & 0 \\ 109 & 28.1 & 26 & 0 & 26 & 28.1 \\ 25.9 & 0 & 0 & 26 & 0 & 2.1 \\ 25.1 & 0 & 0 & 28.1 & 2.1 & 0 \end{bmatrix}$$

CO_2, SO_x, NO_x, CO and PM emissions are created by different transport modes during transportation of 80 TEU between Klaipeda port container terminal and Kaunas industrial area (on average, 50 containers (boxes)) using one train or one barge, or 50 road trucks between port container terminals and industrial area or 50 road trucks (voyage) on "last mile "destination between intermodal terminal or inland waterway cargo loading place and free economic zone. This means that road transport can deliver cargo by mode "door-to-door".

Rail transport can deliver cargo from the port to Kaunas intermodal terminal. After that, cargo from the intermodal terminal to Kaunas industrial area can be transported by road as "last mile" transportation.

Inland waterway transport can be used for the caring containers from the port of Klaipeda to the place of unloading of inland waterway cargo (Kaunas). After that (cargo loading place in inland waterways), the cargo is transported by road from the place of unloading to the Kaunas industrial area by road transport as "last mile".

Transport modes today mainly using diesel fuel. In same time some transport modes start use LNG fuel, which is more environmentally friendly. Transportation options and calculation results, using methodology presented in section 3, are described at figures 10 -14 below.

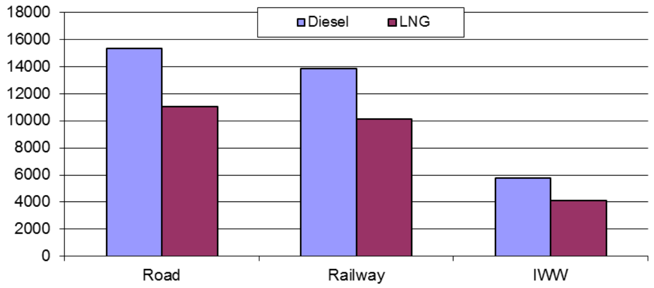

Figure 10. Generated CO_2 emission in kilograms for the transportation of 80 TEU using diesel and LNG fuel by different transport roads.

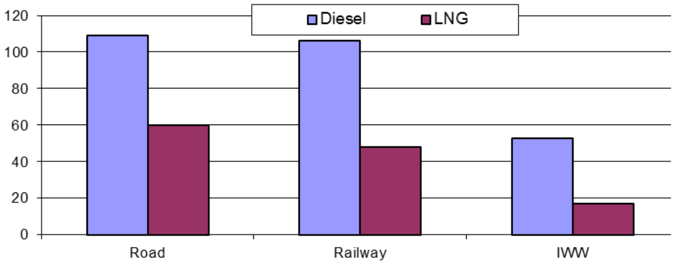

Figure 11. Generated NO_x emission in kilograms for the transportation of 80 TEU using diesel and LNG fuel by different transport roads.

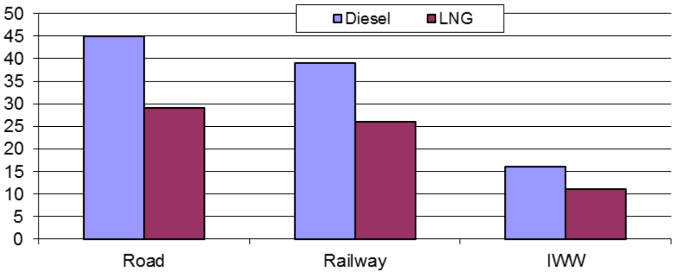

Figure 12. Generated CO emission in kilograms for the transportation of 80 TEU using diesel and LNG fuel by different transport roads.

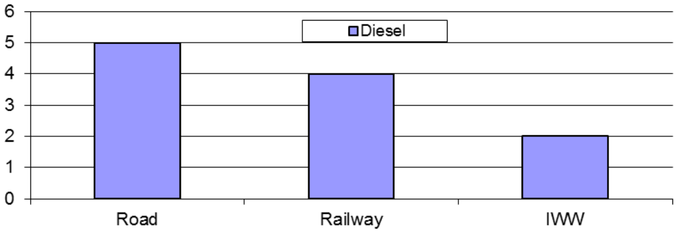

Figure 13. Generated SO_2 emission in kilograms for the transportation of 80 TEU using diesel fuel (using LNG fuel SO_x emission close to 0) by different transport roads.

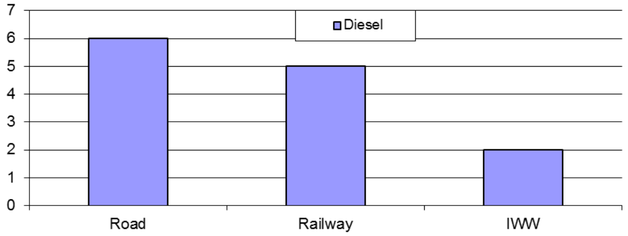

Figure 14. Generated *PM* Emission in kilograms for the transportation of 80 TEU using diesel fuel (using LNG fuel *PM* emission close to 0) by different transport roads.

The analysis of environmental comparative index (ECI) by using equation (16), based on theoretical and experimental research results, presented in this paper, of the transportation between Klaipeda container terminal and Kaunas industrial area for the different transport modes and using methodology presented in section 3. In calculations correlation coefficient is taken 0,97; CO_2 emissions weight coefficient taken 0,30; SO_X emissions weight coefficient taken 0,10; CO emissions weight coefficient taken 0,20; NO_X emissions weight coefficient taken 0,25; PM emissions weight coefficient taken between 0,15 is presented in figure 15.

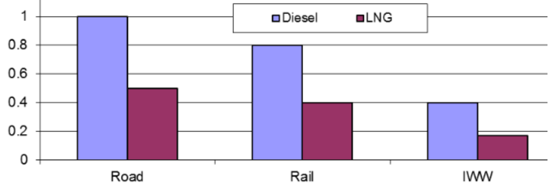

Figure 15. Environmental comparative index (ECI) for the transportation of 80 TEU between Klaipeda container terminal and Kaunas industrial area by different transport corridors using diesel and LNG fuels.

Received environmental comparative index (ECI) for the different transport corridors and modes shows that containers transportation between selected container terminal and destination in industrial area from environmental impact point of view is more useful by railway or inland waterway transport including "last mile" destination.

Environmental comparative index (ECI) and relative environmental comparative index (ΔECI) is assessed for the selected case study by assessing environmental impact, using the real parameters presented in the table 2.

Table 2. Environmental comparative index (ECI) and relative environmental comparative index (ΔECI) for the selected case study based on collected real data

Transport mode	Number of real data (cases)	ECI	Dispersion	ΔECI , %
Road	53	1,0	0,038	19
Railway	22	0,8	0,025	16
Inland waterway	7	0,4	0,016	12

The obtained results indicate that container transportation between Klaipeda port container terminal and Kaunas industrial area is most acceptable using water or railway transport (difference in ECI relative is up to 35 – 45 %).

At the same time, it is necessary to take in account that in case if containers must be delivered in shortest time road transport for the direct transportation between port terminal and cargo recipients/shippers could be used as well.

5. Discussions

Green transportation solutions very important because terminals and industry regions are located close to living areas and it is necessary reduce the environmental impact from transport and increase life standards there.

Developing a theoretical methodology and application for the decreasing environmental impact between port and cargo receiver/sender oriented on practical matters often requires a quantitative technological approach, economic and environmental impact. Therefore, we try to relate productivity benchmarks based on environmental comparative index for the transportation using different transport modes management's risks and environmental impact analysis approach.

Carrying out real transportation experiments on the routes indicated in the paper, as well as theoretical calculations using the methodology developed in this paper, showed practical importance for optimization of transportation processes, as there are no big differences between the results (experimental and theoretical calculations results differences mainly were up to 10 – 12 %). Specified methodology for optimization of transportation processes, with the introduction of CO2 taxation, integrated assessments using the approach set out in the paper have attracted a great deal of interest from logistics and transport companies.

During the experiments, the transport companies, as well as the authors of the paper, identified some additional sources of uncertainty that could be useful for future research. This is mainly due to additional disruptions on individual routes, such as traffic congestion on roads, environmental cataclysms, especially during the winter. Weighting factors for the comparative method, adapted to the specific routes and conditions, are very important for future research.

Studies have shown that the approach to reducing environmental impact presented in the paper can be adapted to other regions where similar conditions exist.

In this study, we have found that several parameters are needed that can be quantified and that are consistent with the management of transport corridors and transport modes by optimizing transport processes and environmental impact. The environmental comparative index (ECI) used in this paper includes environmental impact factors. This allows the impact category to be assessed in the selected transport corridor. The few main factors can then be used as the basis for stakeholders to plan or improve the organization of the transportation process. Based on the results of the study, it has been found that, at least for the time being, the price factor in study case, is the most important and has the greatest influence on the choice of transport corridor and vehicles.

6. Conclusions

Combination of different transport modes can optimize transport links, decrease environmental impact, and minimize transportation time and costs.

Possible transport alternative routes between ports and consignors/consignees using different modes of transport have been explored, which is very important in the light of the demanding environmental requirements and economic situation.

The use of graph theory method for the optimization of shipments between ports and consignors/consignees using different modes of transport are important from a theoretical and practical point of view and have aroused great interest among transport researchers and transport and logistics companies.

The developed ECI evaluation model presented in the paper allows determining the optimal transportation options, considering environmental impact factors.

The analysis of the case using the developed methodology and real experimental factors of environmental impact confirmed the theoretical expediency and practical applicability of the developed methodology.

The results of the case study have shown that the developed methodology can be successfully applied in many parts of the world.

Proposed calculation of environmental comparative index can assist the transport and industry companies as well Administrations to identify the most optimal solutions in transport infrastructure development and choosing optimal transport corridors and transport modes.

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