A Model of Transatlantic Intermodal Freight Transportation Between the European Continent and the United States[1]

Model transatlantskog intermodalnog prijevoza tereta između Europe i Sjedinjenih Američkih Država

Alica Kalašová
Department of Road and Urban Transport
Faculty of Operation and Economics of Transport and Communications
University of Zilina, Slovakia
e-mail: alica.kalasova@fpedas.uniza.sk

Ján Kapusta
Department of Road and Urban Transport
Faculty of Operation and Economics of Transport and Communications
University of Zilina, Slovakia
e-mail: jan.kapusta@fpedas.uniza.sk

Petr Toman
University of Texas
El Paso
e-mail: petr.toman@seznam.cz

DOI 10.17818/NM/2016/1.2
UDK 656.021(4)(73)
Review / *Pregledni rad*
Paper accepted / *Rukopis primljen:* 4. 3. 2015.

Summary

This paper deals with intermodal transportation of goods from Europe to the United States. The main objective is the development of a mathematical model called Transatlantic multi-mode container routing problem. It provides a tool for network optimization in transportation science. The developed model enables users to determine the optimal collaborative routing in a network system that achieves the minimization of costs for a company that ships a single commodity from multiple origins to multiple destinations. The model consists of network of maritime shipping lines between the ports and then networks of road and railway transportation on both sides of the Atlantic Ocean. In order to develop the model it was necessary to make assumptions, define sets, parameters, decision variables, constraints and objective function. Branch and cut algorithm used by GAMS modelling software provides the solution of the model. Short analysis of trends and statistics of road and rail transportation as complements to maritime transportation on both continents is also presented.

KEY WORDS

intermodal transportation
freight transportation model
transatlantic route
model formulation
road and rail transportation analysis

Sažetak

Ovaj članak bavi se intermodalnim transportom robe iz Europe do Sjedinjenih Američkih Država. Glavni cilj je razvoj matematičkog modela koji se zove Multimodalni transatlantski problem usmjeravanja kontejnera. On osigurava alat za optimizaciju mreže u transportnoj znanosti. Razrađeni model omogućava korisnicima da odrede optimalno suradničko usmjeravanje u umreženom sustavu koji smanjuje troškove kompanije koja ukrcava pojedinu robu iz višestrukih izvora do više odredišta. Model se sastoji od mreže pomorskih brodskih linija među lukama i mreže cestovnog i željezničkog transporta na obje strane Atlanskog oceana. Da bi se razvio model, bilo je potrebno napraviti pretpostavke, definirati postavke, parametre, varijable odluka, ograničenja i funkcije ciljeva. Algoritam kojeg koristi GAMS softver daje rješenje modela. Prikazana je također i kratka analiza trendova i statistike cestovnog i željezničkog transporta, kao komplemenata pomorskog transporta na oba kontinenta.

KLJUČNE RIJEČI

intermodalni transport
model transporta tereta
transatlantska ruta
oblikovanje modela
analiza cestovnog i željezničkog transporta

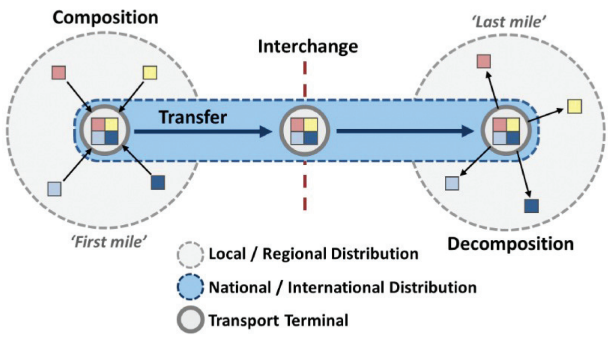
1. INTRODUCTION / *Uvod*

Transportation modes are an essential component of transportation systems since they are the means by which mobility is supported. Geographers consider a wide range of modes that may be grouped into three broad categories based on the medium they make use of: land, water and air. Each mode has its own requirements and features, and is adapted to serve the specific demands of freight and passenger traffic. This indicates apparent differences in the ways the modes are deployed and utilized in different parts of the world. Recently, there is a trend towards integrating the modes through intermodality and linking the modes even closer into the production and distribution activities. At the same time, however, passenger

[1] This paper is the result of the project implementation: Centre of excellence for systems and services of intelligent transport, ITMS 26220120028 supported by the Research & Development Operational Programme funded by the ERDF. VEGA Project no. 1/0159/13 – KALAŠOVÁ, A. and collective: Basic Research of Telematic Systems, Conditions of Their Development and Necessity of Long-term Strategy. University of Žilina, the Faculty of Operation and Economics of Transport and Communications, 2013-2015

and freight activity is becoming increasingly separated among most modes. [2]

The term intermodal transportation has been used in many applications that include passenger transportation and the containerization of freight. A more descriptive term for this process would be multimodal, because of a lack of effective and efficient connectivity for both freight and information between the various modes. Intermodal freight transportation is defined as the use of two or more modes to move a shipment from origin to destination. An intermodal movement involves the physical infrastructure, freight movement, transfer, and capabilities under a single freight bill. The recent focus has been on containerization. Figure 1 shows the principle of intermodal transportation chain. In international shipping the first mile and last mile are usually carried out by trucks or trains while the biggest part of freight transportation is usually done by maritime transportation. Intermodal transportation continues to be significant in the movement of freight over long distances. [1]



Source: [2]

Figure 1 Intermodal transportation chain
Slika 1. Intermodalni lanac transporta

Maritime transportation is essential for international trade. There is no other mode, except perhaps for air transportation, on how to transport goods between two or more countries which do not have any land connections between them. Air transportation is the fastest mode of transportation but it is indisputably much more expensive in comparison with other modes.

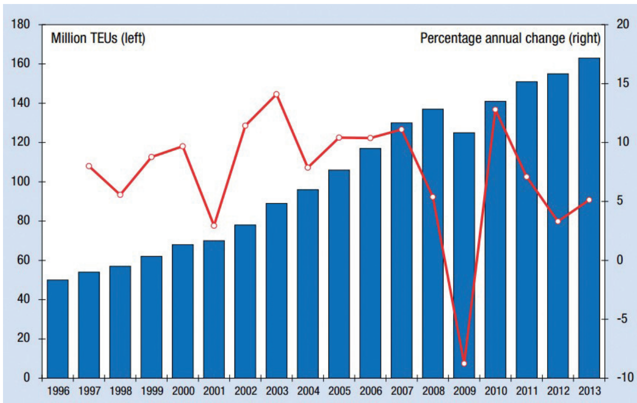
Even though maritime transportation is not the fastest mode of transportation, it is one of the cheapest options available. Thus it is crucial for world trade and its development. More than 90% of European Union´s (EU´s) external trade is transported by maritime transportation. [3] Therefore it is necessary to continuously look for better solutions and improvements of that transportation to find more economical and faster ways for the transportation of goods.

There are several ways where maritime transportation has developed in the last decades. The first one is indisputably containerization. The container was firstly used in transportation process in 1956. Since then, it has been developed into today´s different variety of containers. Container sizes were standardized so the handling and stacking of containers became much easier and faster. Considerable growth of containerization was recorded in the years 1990-2008 and during those years the containerization had the biggest impact on the world trade. It was particularly connected with the entry of China into the global economy. Another trend in maritime transportation is the development of ships. Container ships became bigger and their capacity has been increased. The largest container ships have the maximum capacity up to 18 270 Twenty-foot Equivalent Units (TEUs).

One of the most important features of the maritime transportation is its network and its connection with highway and railway systems. The maritime network has three main routes: transpacific, transatlantic and Europe-Asia.

Almost every time when the sea transportation is used in shipping goods it is necessary to connect it with one of the inland modes of transportation (truck, railway or inland waterborne). Ports play the crucial role in intermodal transportation. Therefore they have to be adequately equipped to be able to handle transshipment from ships to inland modes of transportation (truck, train, barge) and reversely. The maximum truck capacity is limited to 40 ft (to carry two TEU containers). In most countries the range of train's capacity differs from 50 to 100 TEUs. In some countries (e.g. United States) double stacking is being used and it increases the capacity of trains up to 400 TEUs. [5] The intermodal transportation segment is quite important, because it grows most rapidly compared to the other freight businesses. In years 1988 and 2008 the international combined transportation (in tons) had increased by 215% and between 2002 and 2015 it is expected to grow by 135%. [6]

The amount of world merchandise trade and international seaborne trade has been continuously increasing since 1985. [4] The only exception is in year 2009, when the international seaborne trade was influenced by the economic recession that hit the United States (U.S.) and Europe in 2008. During these years international seaborne trade decreased by 6%. Figure 2 illustrates above mentioned trend.



Source: [4]

Figure 2 Global container trade, 1999 - 2013 (millions of TEUs and percentage annual change)
Slika 2. Svjetska trgovina kontejnerima, 1999. - 2013. (milioni TEU-a i postotak godišnje izmjene)

The development of the maritime transportation and international seaborne trade are highly connected with worldwide macroeconomic conditions. World merchandise trade and world seaborne trade have been continuously shaped by the shape of the curve of world Gross Domestic Product (GDP). Moreover, global merchandise trade has been growing much faster than GDP. [4] For example, 90% of the EU´s external trade and over 40% of its internal trade is transported by sea. Europe controls 40% of world merchant fleet. Every year over 3,5 billion tons of cargo passes through the European ports. Globalization, the elimination of trade barriers, the unprecedented growth of containerization and the increase in seaborne trade level have had an impact on maritime transportation and therefore it has shaped the changes in last 20 years. [3]

2. TRANSATLANTIC ROUTE / *Transatlantska ruta*

This route connects the main ports in the east coast of North America (New York-New Jersey, Savannah, Norfolk, Charleston and Miami) with main ports of Western Europe (Rotterdam, Antwerp, Hamburg and Bremerhaven).

Since EU has proposed to the U.S. an agreement in March 2013 on a trade and investment called Transatlantic Trade and Investment Partnership (TTIP) the transatlantic route could become more important for the global trade. The total U.S. investment in the EU is three times higher than in all of Asia and EU investment in the U.S. is approximately eight times higher than the amount of EU investment in India and China together. Therefore these investments are real driver of the transatlantic trade relationship, contributing to the growth on both sides of the Atlantic. Thus the volume of transported cargo on the transatlantic route could increase. [7]

Figure 3 shows the statistics of EU-U.S. trade in the value of goods. It is obvious that EU export is higher than U.S. export. The statistic also shows the growing trend of EU-U.S. trade.

Source: [7]

Figure 3 EU - U. S. "trade in goods" statistics
Slika 3. EU – SAD statistika trgovine robom

Nowadays the route does not only connect the European ports with the ports on east coast of the U.S. but also the ports on west coast of U.S. Instead of sailing pass the shore of South America there is a possibility to sail through the Panama Canal which shortens the distance necessary to reach the ports on west coast by approximately 7 000 nautical miles (13 000 km). The time shortened by this is about 14 days compared to sailing pass South Africa. [2]

3. MODES OF TRANSPORTATION / *Načini transporta*

3.1. United States of America / *Sjedinjene Američke Države*

The first part of this section describes the most important U.S. maritime ports. The second part of the section is the description and summary of U.S. inland transportation and the connections from the most important U.S. ports to main U.S. cities. The freight inland transportation system of the U.S. consists of an extensive network of highways, railroads, waterways, pipelines and airways. Increasing number of freight vehicles, vessels, and other conveyances on both public and private infrastructure requires higher system capacity, better maintenance and threaten system performance. There are discussed two main modes of transportation: road and rail. International trade has grown considerably and the movement of these goods within the U.S. is placing pressure on the domestic transportation network and on all modes. Trucks are the most common mode used to move imports and exports between international gateways and inland locations. This trend is expected to continue with tonnage of international trade forecast to grow over the next years. [8]

3.1.1. Rail transportation / *Transport željeznicom*

The rail network for freight movement in the U.S. comprises 139 000 miles of rail lines, including nearly 96 000 miles of rail operated by the seven Class I railroads. Railroads have reduced network miles in recent decades, due to the consolidation and rationalization of rail operations, with abandonment or sale of little used lines. However, the remaining trackage is used more intensively. Most investment to maintain and upgrade the freight rail system comes from the railroads themselves. The Association of American Railroads (AAR) reports that $480 billion has been spent since 1980 on rail equipment and infrastructure. Some railroads have augmented capacity in higher density corridors by doubling, tripling, or quadrupling tracks on some stretches. In many cases, the additional tracks represented restoration of trackage that was removed decades earlier. The AAR estimates that about 65 000 miles of high-density track has the capacity to carry at least 20 million freight ton-miles per year. In 2011, railroads carried 1.7 trillion freight ton-miles. [9]

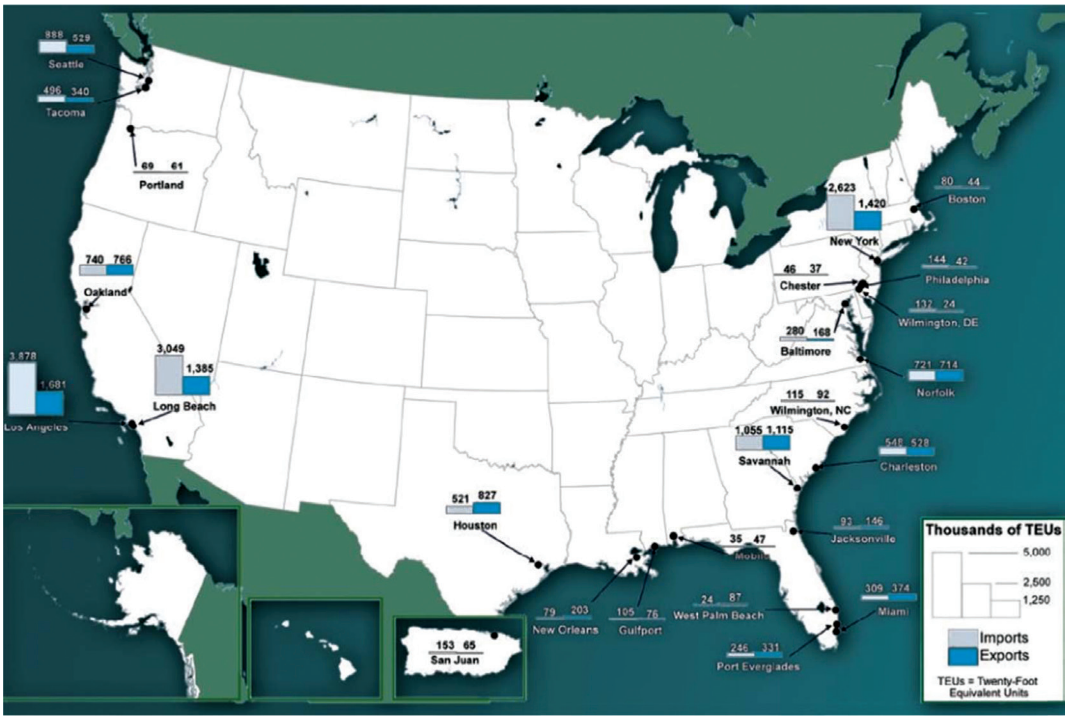
On the rails, in general bulk freight such as grain and coal ships in rail cars and consumer goods such as items that are found at a neighborhood store ship in containers or trailers called intermodal traffic. Intermodal traffic refers to the transport of goods on trains before and/or after transfers from other modes of transportation such as planes, vessels, or trucks. [10]

Almost anything can be shipped by rail. Since each person in the U.S. requires the movement of approximately 40 tons of freight every year, many of the goods people use daily are either wholly shipped or contain components shipped by rail. Of rail freight, 91% are bulk commodities, such as agriculture and energy products, automobiles and components, construction materials, chemicals, coal, equipment, food, metals, minerals, and paper. The remaining 9% is intermodal traffic which generally consists of consumer goods and other miscellaneous products. [5]

Rail is efficient at moving heavy freight over long distances, as are water and pipeline freight services. Trucks excel in providing time-sensitive delivery services for high-value goods being transported over medium and short haul distances. Raw materials and heavy freight going long distances are likely to continue their journey by rail or some combination of truck, rail, and water. With the future growth in freight, it is anticipated that freight transported by rail will continue to make investments in the capacity required to move heavy and long-distance shipments.

3.1.2. Ports / *Luke*

Maritime ports are very important in logistic chain and they play crucial role in transportation of goods to and from U.S. A maritime port has several crucial characteristics. First is the location. Second is its parameters. And finally it is the equipment of the port and its capability to handle cargo and transfer it from ship to other means of transportation for inland movement to its final destinations. Figure 4 shows 25 most important U.S. water ports in terms of export and import going through them. Their importance is crucial for international trade of the U.S.



Source: [8]

Figure 4 Top 25 water ports by containerized cargo
Slika 4. Najprometnije morske luke prema kontejneriziranome teretu

Talking about port parameters, the most important one is the maximum berth depth. It is the most important parameter for ships to enter and anchor in the ports. The deeper the ports the bigger ships they can serve. Four most important ports in the west coast Los Angeles, Long Beach, Oakland and Seattle are able to serve ships up to the capacity of 12 000 TEUs because their depth of berth is 49-60 ft. In the east coast, only ports in New York and Norfolk are able to serve such ships. Ports in Houston and Savannah are able to serve ships of size up to 5 000 TEUs because their berth depth is 39-45 ft.

3.1.3. Road transportation / *Prijevoz cestom*

Trucks carry most of the tonnage and value of freight in the U.S., but railroads carry significant volumes over long distances. It is also obvious that higher volume of freight is transported in the east coast than the west coast of U.S. A vast number of vehicles move goods over the transportation network. The trucking industry provides an essential service to the U.S. economy by transporting large quantities of raw materials, works in process and finished goods over land - typically from manufacturing plants to retail distribution centers.

Long-haul freight truck traffic in U.S. is concentrated on major routes connecting population centers, ports, border crossings, and other major hubs of activity. Except for Route 99 in California and a few toll roads and border connections, most of the routes with highest density of vehicles are on the Interstate Highway System. There is an expectation of dramatic increase of long-haul traffic on interstate highways and other important roads throughout the nation by 2040. It is estimated that truck travel may reach 662 million miles per day in this period of time. Although this is only an estimate, this number brings up many safety concerns to all the authorities. Despite doubling over the past two decades, truck traffic remains a relatively small part of highway traffic as a whole. In 2008, commercial motor vehicles accounted for about 8% of highway vehicle miles traveled. [8] Figure 5 shows that trucks carry most of the tonnage and value of freight in U.S., but railroads carry significant volumes over long distances. It is also obvious that higher volume of freight is transported in the east coast than the west coast of U.S.

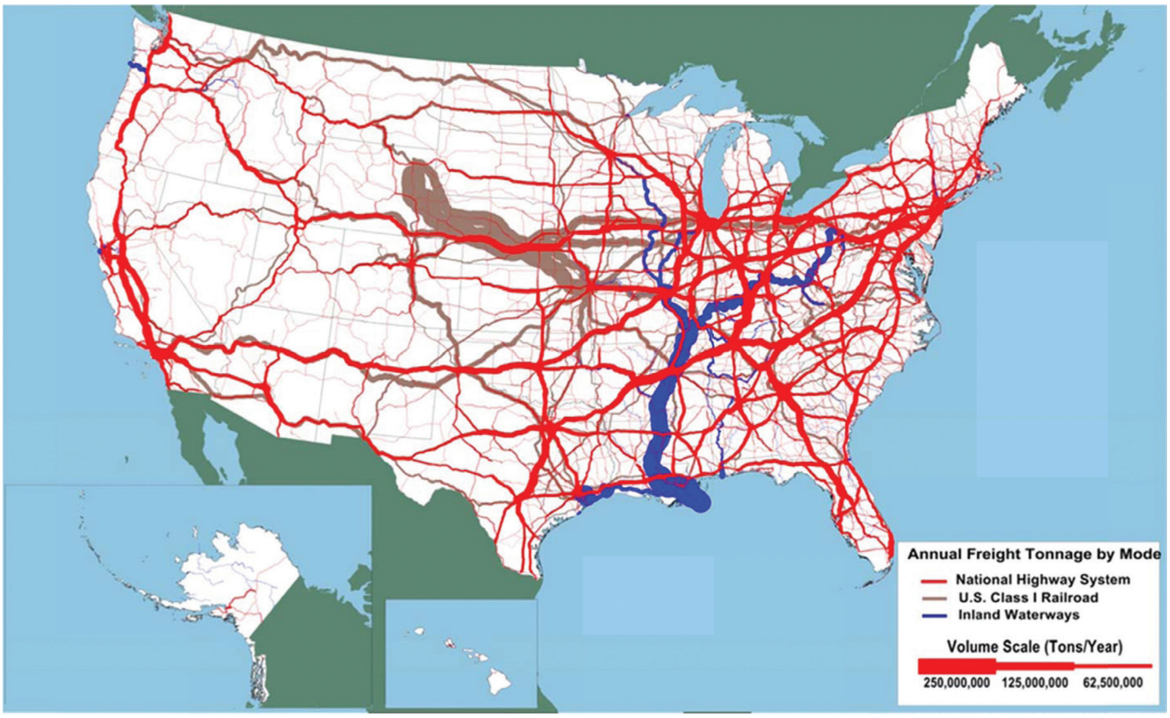
The fact that the railroads are used mainly for long-distances transportation is caused by the prices of truck and rail intermodal transportation. For distances greater than 500 kilometers (km), rail transportation of containers costs about 20% less than road transportation and the cost advantage increases as distance increases. [12]

In U.S., the road and rail transportation do not only compete against each other but they are also complementary connected and take advantage of each other as an intermodal transportation. Therefore they frequently work together to move high-value and time-sensitive cargo. The classic forms of rail intermodal transportation are trailer-on-flatcar and container-on-flatcar and these are spread throughout U.S. The largest concentrations are on routes between Pacific Coast ports and Chicago, southern California and Texas, and Chicago and New York. [11]

3.2. European continent / *Europski kontinent*

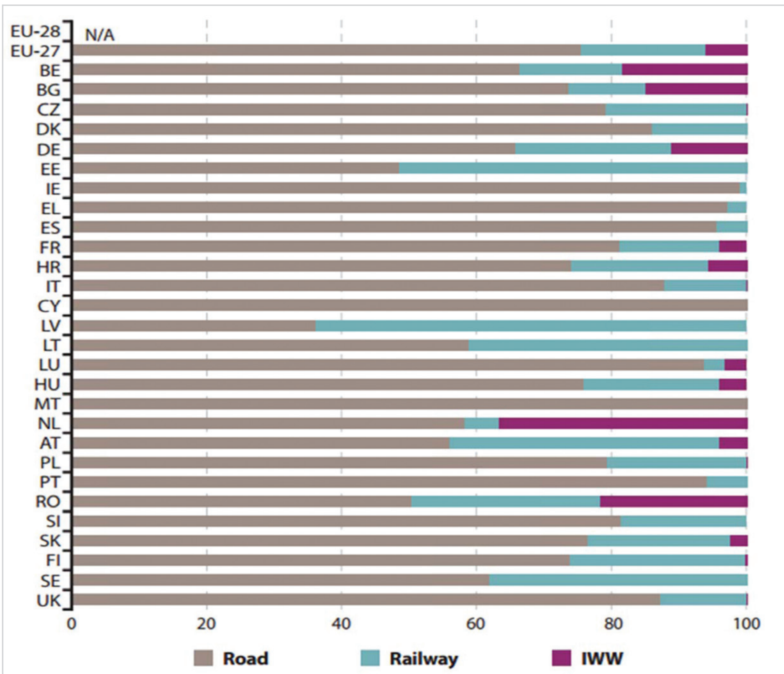
The inland transportation network of Europe consists of three main transportation modes: road, rail and inland waterway. This section focuses mainly on the first two mentioned: road and rail. Nevertheless, as shown in Figure 6, in some of the EU countries (Netherlands 37%, Romania 21%, Belgium 19%, etc.) Inland WaterWay (IWW) transportation plays indisputable role. In EU-27 road transportation represented 76%, railway 18% and inland waterway 6% in 2011.

A comparison between road and rail freight transportation provided by European Comission shows that the quantity of



Source: [11]

Figure 5 Tonnage on highways, railroad and inland waterways
Slika 5. Tonaža na autocestama, željeznicama i unutarnjim plovnim putevima



Source: [13]

Figure 6 Modal split of European inland freight transportation in 2011- % of total inland freight ton-km
Slika 6. Uzorak presjeka prijevoza tereta europskim kopnom tijekom 2011. – postotak kopnenog prijevoza po kilometrima

goods transported by road in the EU-28 equaled nine times the amount transported by rail. [13] EU has one of the world's densest network of communications. In the case of rail and highway networks, for example, EU has considerably more infrastructure per 1,000 km^2 than U.S. This density is the result of many factors, but one of the most important ones is that transportation demand is higher in EU than in the U.S. [14]

3.2.1. Rail transportation / *Prijevoz željeznicom*

Railway network in Europe is part of the Trans-European Transport Networks (TEN-T). TEN-T is supposed to coordinate improvements and projects primary to roads, railways, inland waterways, airports, seaports, inland ports and traffic management systems, providing integrated and intermodal long-distance, high-speed routes. The Trans-European

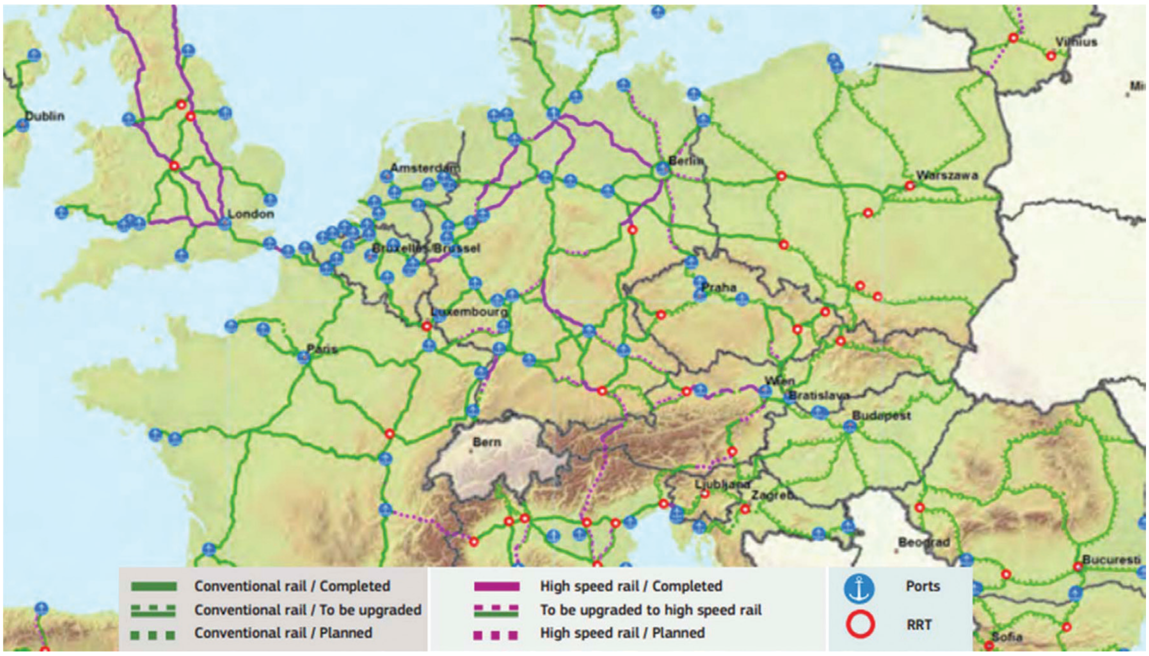
Rail network includes the Trans-European High-Speed Rail Network as well as the Trans-European Conventional Rail Network. [17] In 2010, European freight transportation by rail amounted to 1,589 million tons. In the years 2007-2010, the volume of freight transportation by rail fell by 13% which was mainly caused by lingering economic recession which hit Europe in 2008. Among Member States the largest quantities of goods were transported by German railways (356 million tons in 2010), followed by Poland (249 in 2011), Austria (108) and United Kingdom (100). [13] Figure 7 shows the railway freight network, ports and road-rail terminals (RRT) in the countries of western and central Europe, which are crucial for the connection of the most important European ports with the Slovak Republic (SR).

3.2.2. Ports / *Luke*

European ports are gateways to the European continent and they are definitely crucial for European transportation business and its competitiveness. Seventy four percent of EU goods are shipped through ports. Over 1 200 commercial seaports operate along some 70,000 kilometers of EU´s coast. Therefore, Europe is one of the densiest port regions in the world. In 2011, around 3,7 billion tons of cargo (more than 60,000 port calls of merchant ships) transited through European ports. Bulk traffic represented 70% of it, container traffic 18%, Ro-Ro traffic 7% and the rest was other general cargo. [16] Three most important European ports have been: Rotterdam (NE), Antwerpen (BG) and Hamburg (GE). It is also worth to mention ports in Le Havre (FR), Bremerhaven (GE) and Zeebrugge (BG).

Port of Rotterdam / *Luka Roterdam*

The Port of Rotterdam is one of the main ports and the largest logistic and industrial hubs in Europe. It is the largest seaport of Europe with an annual throughput of 450 million tons of cargo. The port occupies an area of 10,570 ha, the total length of Rotterdam port area is 40 km, maximum berth depth is 23 m, but for container ships it is 19,65 m as can be seen in Table 1. The table also shows all six container terminals of the port of Rotterdam, their parameters (quay length, draught and area), their equipment (gantry cranes, plugs for reefer) and annual capacity in TEUs. [16]



Source: [18]

Figure 7 EU railway freight network, ports and rail-road terminals
Slika 7. Mreža europskog željezničkog prometa, luke i željeznički terminali

Table 1 Rotterdam container terminals - parameters, equipment and capacity
Tablica 1. Roterdamski kontejnerski terminali – parametri, oprema i kapacitet

Terminal	Quay length (m)	Draught (m)	Area (m^2)	Cranes	Reeferplugs	Capacity per year (TEU)
Rotterdam World Gateway	1,700	19.5	1,080,000	14	1,700	2,350,000
APM Terminals Maasvlakte II	1,000 (barge - 500)	19.65 (barge 9.65)	860,000	8 deepsea, 2barge, 2 rail	4,500	2,700,000
Euromax Terminal R´dam	1,500	16.8	840,000	16	2,136	-
APM Terminals Rotterdam	1,600	16.65	1,000,000	14	2,250	3,250,000
ECT Delta Terminal	3,600	16.65	2,650,000	38	3,387	-
ECT City Terminal	1,400	14.1	593,000	9	1,359	-

Source: [16]

3.2.3. Road transportation / *Cestovni prijevoz*

Road transportation is playing a prominent role in the continuous health and growth of Europe's economy. Billions of tons of goods are transported on all road networks by big and heavy trucks. Freight forwarders and logistics companies which specialize in freight transportation focus mostly on customer satisfaction and quality of the services they provide. People expect their goods to be delivered door-to-door as quickly as possible and always on time. This makes truck transportation the only possible mode to meet the demand for such high levels of efficiency and mobility. [19]

Trucking is an essential part of an international trade because it plays at least a little part in almost all of the freight moves. This situation is not about to change despite increasing investment in other modes of transportation. [20] The constant development of road transportation leads to the ability to move even perishable goods from one place to another in refrigerated trucks at prescribed conditions. The use of trucks of any size and capacity is irreplaceable and through the expansion of roads and highways even places which are remote can be easily accessible by road vehicles.

4. MODEL OF FREIGHT TRANSPORTATION BETWEEN EUROPE AND U.S. / *Model prijevoza tereta između Europe i Sjedinjenih Američkih Država*

The following model was developed by the authors and is mainly focused on maritime freight transportation across the Atlantic Ocean between Europe and the U.S. When one wants to transport any shipment by maritime transportation it is usually necessary to complement it with another mode of transportation such as road, railway and/or inland waterway. Therefore some of those modes of inland transportation are implemented into the model. Based on these facts, the model consists of network of maritime shipping lines between the ports and then networks of road and railway transportation on both sides of the Atlantic Ocean.

4.1. Problem description and assumptions / *Opis problema i pretpostavke*

The problem could be described as the selection of routes for each shipment in order to minimize the total transportation costs of all shipments. Each shipment has its origin and destination point of transportation. Therefore the developed model seeks to determine the routing for each origin – destination (O-D) pair of the predefined set of network and at the same time it assigns the volume to each route that minimizes the total transportation costs.

In the model, the points of origin are European cities and points of destination are cities in the U.S. Maritime transportation is considered the main and only line haul mode of transportation between the two continents. The transportation of shipments between the origin cities and the main European ports, and between the main U.S. ports and destination cities can be performed by road or railway. There is no transshipment point between those cities and ports on the same continent. Based on this fact there is only direct transportation between those points of origin (destination) and ports on the same continent.

4.2. Assumptions of the proposed model / *Pretpostavke predloženog modela*

There are several assumptions in the model: (i) there is only one type of commodity and it is heterogeneous, (ii) each O-D demand can be split into the multiple shipments using different routes and/or modes, (iii) there is no time dependency, and (iv) O-D demand is known. Therefore the problem is deterministic in the sense that the demand is known. In comparison, a stochastic version would be the unknown and time dependent demand, which would make problem much more complicated.

4.3. Sets and parameters / *Setovi i parametri*

Define $i \in I$ which is the point of origin (European city) and $j \in J$ which represents the destination (city in the U.S.). Also, define $k \in K$ which is the shipment number. A shipment $k \in K$ will enter the network through an origin point $O(k)$ and exit through a destination point $D(k)$. For each shipment $k \in K$ there is its O-D pair that origins in the city $O(k)$ and directs to the destination city $D(k)$.

The point $m \in M$ is the European port which belongs to the set M- set of European ports. The point $n \in N$ is the U.S port which belongs to the set N - set of U.S. ports.

On the European continent, define $a \in A$ as an European rail operator which belongs to A - set of European rail operators and $b \in B$ as an European truck (road) operator which belongs to B - set of European truck (road) operators. The same is done for the U.S. part of transportation network, therefore $d \in D$ is a U.S. rail operator and $e \in E$ is a U.S. truck (road) operator. Then, define $c \in C$ as a shipping line operating between European and U.S. ports.

Each shipment $k \in K$ has its uniquely associated O-D pair (European city $i \in I$ and U.S. city $j \in J$) and its known demand W_{ijk} (in terms of TEU). Then there are five different cost parameters. The cost to transport one TEU between European city $i \in I$ and European port $m \in M$ via European rail operator $a \in A$ is the cost rate α_{ima} (in \$/TEU). The cost to transport one TEU between European city $i \in I$ and European port $m \in M$ via European truck (road) operator $b \in B$ is the cost rate β_{imb} (in \$/TEU). The cost to transport one TEU between European port $m \in M$ and U.S. port $n \in N$ via shipping line $c \in C$ is the cost rate γ_{mnc} (in \$/TEU). The cost to transport one TEU between U.S. port $n \in N$ and U.S. city $j \in J$ via U.S. rail operator $d \in D$ is the cost rate δ_{njd} (in \$/TEU). The cost to transport one TEU between U.S. port $n \in N$ and U.S. city $j \in J$ via U.S. truck (road) operator $e \in E$ is the cost rate ε_{nje} (in \$/TEU).

Besides cost parameters there are also capacity parameters. The capacity of European port $m \in M$ is O_m (in TEU). The capacity of U.S. port $n \in N$ is P_n (in TEU).

Besides capacities of ports it is also important to consider the capacities of operators on each link of the network. Therefore the capacity of European rail operator $a \in A$ on the link between European city $i \in I$ and European port $m \in M$ is Q_{ima} (in TEU). The capacity of European truck (road) operator $b \in B$ on the link between European city $i \in I$ and European port $m \in M$ is R_{imb} (in TEU). The capacity of shipping line $c \in C$ on the link between European port $m \in M$ and U.S. port $n \in N$ is S_{mnc} (in TEU). The capacity of U.S. rail operator $d \in D$ on the link between U.S. port $n \in N$ and U.S. city $j \in J$ is T_{njd} (in TEU). The capacity of U.S. truck (road) operator $e \in E$ on the link between U.S. port $n \in N$ and U.S. city $j \in J$ is L_{nje} (in TEU).

4.4. Decision variables, constraints and objective function / *Varijable odluka, ograničenja i objektivne funkcije*

If shipment $k \in K$ takes place on the link between European city $i \in I$ and European port $m \in M$ via European rail operator $a \in A$, one defines X_{imak} which is the number of transported TEUs between European city $i \in I$ and European port $m \in M$ via European rail operator $a \in A$ of shipment $k \in K$.

If shipment $k \in K$ takes place on the link between European city $i \in I$ and European port $m \in M$ via European truck (road) operator $b \in B$, one defines Y_{imbk} which is the number of transported TEUs between European city $i \in I$ and European port $m \in M$ via European truck (road) operator $b \in B$ of shipment $k \in K$.

If shipment $k \in K$ takes place on the link between European port $m \in M$ and U.S. port $n \in N$ via shipping line $c \in C$, one defines Z_{mnck} which is the number of transported TEUs between European port $m \in M$ and U.S. port $n \in N$ via shipping line $c \in C$ of shipment $k \in K$.

If shipment $k \in K$ takes place on the link between U.S. port $n \in N$ and U.S. city $j \in J$ via U.S. rail operator $d \in D$, one defines U_{njdk} which is the number of transported TEUs between U.S. port $n \in N$ and U.S. city $j \in J$ via U.S. rail operator $d \in D$ of shipment $k \in K$.

If shipment $k \in K$ takes place on the link between U.S. port $n \in N$ and U.S. city $j \in J$ via U.S. truck (road) operator $e \in E$, one defines V_{njek} which is the number of transported TEUs between U.S. port $n \in N$ and U.S. city $j \in J$ via U.S. truck (road) operator $e \in E$ of shipment $k \in K$.

The model consists of three sets of constraints. Constraints (1) and (2) are the shipment specific origin and destination constraints. They ensure that all transported TEUs of shipment $k \in K$ are equal to demand of shipment $k \in K$. Constraint (1) ensures this consistency for the point of origin $i \in I$ and constraint (2) ensures the same for the point of destination $j \in J$.

Second set of constraints is formulated in (3) and (4). These constraints ensure the conservation of flow in the network. Constraint (3) ensures that all freight going to port $m \in M$ from city $i \in I$ of shipment $k \in K$ has to be equal to all the freight from this shipment $k \in K$ that is going out from this port $m \in M$ Constraint (4) ensures that all freight going from port $n \in N$ to city $j \in J$ of shipment $k \in K$ has to be equal to all freight from this shipment $k \in K$ that is going to this port $n \in N$.

The last set of constraints (5,6,7,8,9,10,11) is the set of capacities. First two constraints (5 and 6) of this set are capacity constraints of ports and the rest are the capacity constraints of operators (rail, road and shipping line).

$$\sum_{m\in M}\sum_{a\in A} X_{imak} + \sum_{m\in M}\sum_{b\in B} Y_{imbk} = W_{ijk} \qquad \forall k \in K \quad (1)$$

$$\sum_{n\in N}\sum_{d\in D} U_{njdk} + \sum_{n\in N}\sum_{e\in E} V_{njek} = W_{ijk} \qquad \forall k \in K \quad (2)$$

$$\sum_{a\in A} X_{imak} + \sum_{b\in B} Y_{imbk} = \sum_{n\in N}\sum_{c\in C} Z_{mnck} \qquad \forall m \in M, \forall k \in K \quad (3)$$

$$\sum_{d\in D} U_{njdk} + \sum_{e\in E} V_{njek} = \sum_{m\in M}\sum_{c\in C} Z_{mnck} \qquad \forall n \in N, \forall k \in K \quad (4)$$

$$\theta \leqq \sum_{n\in N}\sum_{c\in C}\sum_{k\in K} Z_{mnck} \leqq O_m \qquad \forall m \in M \quad (5)$$

$$\theta \leqq \sum_{m\in M}\sum_{c\in C}\sum_{k\in K} Z_{mnck} \leqq P_n \qquad \forall n \in N \quad (6)$$

$$\theta \leqq \sum_{k\in K} X_{imak} \leqq Q_{ima} \quad (7)$$

$$\theta \leqq \sum_{k\in K} Y_{imbk} \leqq R_{imb} \quad (8)$$

$$\theta \leqq \sum_{k\in K} Z_{mnck} \leqq S_{mnc} \quad (9)$$

$$\theta \leqq \sum_{k\in K} U_{njdk} \leqq T_{njd} \quad (10)$$

$$\theta \leqq \sum_{k\in K} V_{njek} \leqq L_{nje} \quad (11)$$

The objective function (12) of the model seeks to minimize the total transportation cost of the whole network between the European cities and the U.S. cities for all shipments. The objective function is represented as follows:

$$\boldsymbol{Min} \sum_{i\in I}\sum_{m\in M}\sum_{a\in A}\sum_{k\in K} \alpha_{ima} * X_{imak} + \sum_{i\in I}\sum_{m\in M}\sum_{b\in B}\sum_{k\in K} \beta_{imb} * Y_{imbk} + \sum_{m\in M}\sum_{n\in N}\sum_{c\in C}\sum_{k\in K} \gamma_{mnc} * Z_{mnck}$$
$$+ \sum_{n\in N}\sum_{j\in J}\sum_{d\in D}\sum_{k\in K} \delta_{njd} * U_{njdk} + \sum_{n\in N}\sum_{j\in J}\sum_{e\in E}\sum_{k\in K} \varepsilon_{nje} * V_{njek} \quad (12)$$

The objective function consists of five parts. The first one represents the total cost of European rail mode of transportation. The second one represents the total cost for European road mode of transportation. The third one is the total cost of maritime transportation between Europe and the U.S. The fourth one is the total cost of U.S. rail mode. Finally the fifth one represents the total cost of U.S. road mode.

Since this is the first attempt to formulate such a problem it may be solved by the branch-and-cut algorithm. As was already mentioned additional dimensions such as time-dependency or stochastic demand would require more sophisticated approaches as meta-heuristics (e.g., genetic algorithms, tabu search, ant colony, etc.).

4.5. The overview of sets and parameters / *Pregled setova i parametara*

The proposed model is complex, therefore it is necessary to explain the inputs. Table 2 provides the definitions of sets and parameters used in the transatlantic multi-mode container routing problem formulation. These sets and parameters enable the creation of constraints and objective function.

Table 2 Definitions of sets and parameters used in the model
Tablica 2. Definicije setova i parametara upotrebljenih u modelu

Set	Definition
$i \in I$	point of origin (European city)
$j \in J$	destination point (city in the United States)
$k \in K$	shipment number
$m \in M$	point of European port
$n \in N$	point of U.S. port
$a \in A$	European rail operator
$b \in B$	European truck (road) operator
$d \in D$	U.S. rail operator
$e \in E$	U.S. truck (road) operator
$c \in C$	shipping line operating between European and U.S. ports
Parameter	**Definition**
W_{ijk}	demand in terms of TEU for each shipment from European city to U.S. city
α_{ima}	transport cost of one TEU between European city and European port via European rail operator
β_{imb}	transport cost of one TEU between European city and European port via European truck operator
γ_{mnc}	transport cost of one TEU between European port and U.S. port via shipping line
δ_{njd}	transport cost of one TEU between U.S. port and U.S. city via U.S. rail operator
ε_{nje}	transport cost of one TEU between U.S. port and U.S. city via U.S. truck operator
O_m	capacity of European port
P_n	capacity of U.S. port
Q_{ima}	capacity of European rail operator on the link between European city and European port
R_{imb}	capacity of European truck operator on the link between European city and European port
S_{mnc}	capacity of shipping line on the link between European port and U.S. port
T_{njd}	capacity of U.S. rail operator on the link between U.S. port and U.S. city
L_{nje}	capacity of U.S. truck operator on the link between U.S. port and U.S. city
X_{imak}	number of transported TEUs between European city and European port via European rail operator
Y_{imbk}	number of transported TEUs between European city and European port via European road operator
Z_{mnck}	number of transported TEUs between European port and U.S. port via shipping line
U_{njdk}	number of transported TEUs between U.S. port and U.S. city via U.S. rail operator
V_{njek}	number of transported TEUs between U.S. port and U.S. city via U.S. road operator

4.6. The General Algebraic Modeling System (GAMS) / *Sustav općeg algebarskog modela*

Branch and cut is a method of combinatorial optimization for solving integer linear programs, that is, linear programming problems where some or all the unknowns are restricted to integer values. Branch and cut involves running a branch and bound algorithm and using cutting planes to tighten the linear programming relaxations. The method solves the linear program without the integer constraint using the regular simplex algorithm. When an optimal solution is obtained, and this solution has a non-integer value for a variable that is supposed to be integer, a cutting plane algorithm may be used to find further linear constraints which are satisfied by all feasible integer points but violated by the current fractional solution. These inequalities may be added to the linear program, such that resolving it will yield a different solution which should be less fractional.

GAMS is specifically designed for modeling linear, nonlinear and mixed integer optimization problems. The system is especially useful with large, complex problems. The program is available for use on personal computers, workstations, mainframes and supercomputers. GAMS allows the user to concentrate on the modeling problem by making the setup simple. The system takes care of the time-consuming details of the specific machine and system software implementation. GAMS lets the user concentrate on modeling. By eliminating the need to think about purely technical machine-specific problems such as address calculations, storage assignments, subroutine linkage, and input-output and flow control, GAMS increases the time available for conceptualizing and running the model, and analyzing the results. GAMS structures good modeling habits itself by requiring concise and exact specification of entities and relationships.

Using GAMS, data are entered only once in familiar list and table form. Models are described in concise algebraic statements which are easy for both humans and machines to read. Whole sets of closely related constraints are entered in one statement. GAMS automatically generates each constraint equation, and lets the user make exceptions in cases where generality is not desired. Statements in models can be reused without having to change the algebra when other instances of the same or related problems arise. The location and type of errors are pinpointed before a solution is attempted. GAMS handles dynamic models involving time sequences, lags and leads and treatment of temporal endpoints. The user can easily program a model to solve for different values of an element and then generate an output report listing the solution characteristics for each case. [21]

5. CONCLUSION / *Zaključak*

Maritime transportation is undeniably one of the most important and one of the most widespread transportation modes in the world. With the increase of the international trade across the continents maritime transportation has developed technologically over the last 20 years. This paper includes the description of intermodal transportation, transatlantic route, inland rail and road transportation in U.S. and in Europe as the complementary modes for maritime transportation. The second part of the paper focuses on mathematical model of freight transportation between Europe and U.S. Transatlantic multi-mode container routing problem (TMMCRP) model is formulated.

The data necessary for running the model are mainly the unit cost, fixed cost of transfer (at nodes) and capacity matrices for each transportation mode and link. Rail and road distances to and from ports as well as maritime distances between the European ports and U.S. ports need to be taken into account in the process of model application. The capacity of railway depends on the railway line, train size, weight load and other parameters. Rail capacity for Europe is in the range of 110-200 TEUs and for U.S. 110-400 TEUs. The capacity of road is considered to be in the range of 110-450 TEUs in Europe and 160-700 TEUs in U.S. Finally, the capacity of liner shipping transportation is assumed to be distributed in a range of 1200-8000 TEUs. For each link and mode, the capacity is randomly generated according to a uniform distribution. The model provides as its output data the volume carried by each segment and modes and the total costs generated by the whole system. Another output of the model is the optimal routing between each O-D pair. The model is designed to optimally route each shipment.

It is essential to mention that the model includes only basic constraints and parameters and they are both time independent. There are many other directions on how the model could be extended. For example, the cost of transfer is fixed regardless of the TEUs. The cost could be changed to unit cost and then multiplied by the number of TEUs transferred. It could also include inland waterborne transportation on the European continent because this mode of transportation is becoming more important. One of the crucial steps for further development of this model is to obtain more accurate input data, such as transportation costs of all modes, capacities of links and nodes of the transportation network.

The proposed formulation of the model belongs to the class of binary (0-1) multi-commodity minimum cost flow problems. The classification is further substantiated by the structure of the physical network in which the collaborative transportation modes operate; that is, the static nodes of the collaborative transportation mode network are fixed transshipment facilities (such as, ports, depots, warehouses, and/or distribution centers) and the static arcs are links in network corresponding to the collaborative transportation modes. The model provides a tool for network optimization in transportation science. It allows users to determine the optimal collaborative routing in a network system that achieves the minimization of costs for a company that ships a single commodity from multiple origins to multiple destinations. The input parameters are the demand, cost parameters and the network data. The model provides as its output data the volume carried by each segment and modes and the total costs generated by the whole system.

Like many economic activities that are intensive in the use of infrastructures, the freight transportation sector is an important component of the economy impacting on development and the welfare of the population. When freight transport systems are efficient, they provide economic opportunities and benefits that result in positive multipliers effects such as better accessibility to markets. When transport systems are deficient in terms of capacity or reliability, they can have an economic costs such as reduced or missed opportunities. [2]

REFERENCES / *Literatura*

[1] DeWitt, Clinger: Intermodal Freight Transportation, Committee on Intermodal Freight Transport, online, <http://onlinepubs.trb.org/onlinepubs/millennium/00061.pdf> [1/2015]

[2] Rodrigue et al. (2013): The Geography of Transport Systems, Hofstra University, Department of Global Studies & Geography, online, <http://people.hofstra.edu/geotrans> [1/2015]

[3] EP (2009): The Evolving Role of EU Seaports in Global Maritime Logistics - Capacities, Challenges and Strategies. European Parliament, Directorate - General for Internal Policies, online, <http://www.europarl.europa.eu/RegData/etudes/etudes/join/2009/419121/IPOL-TRAN_ET(2009)419121_EN.pdf>. [12/2014]

[4] UNCTAD (2013): Review of Maritime Transport 2013. United Nations Conference in Trade and Development, online, <http://unctad.org/en/PublicationsLibrary/rmt2013_en.pdf>. [12/2014]

[5] PPIAF (2014): Public - Private Infrastructure Advisory Facility, online, <http://www.ppiaf.org/freighttoolkit/knowledge-map/ports/intermodal-freight-systems > [1/2015]

[6] UIRR (2014): International Union for Road - Rail Combined Transport, online, <http://www.uirr.com/media-centre/leaflet-and-studies/media centre/61-study-on-infrastructure-capacity-reserves-for-combined-transport-by-2015.html> [1/2015]

[7] EC (2013): European Commission, online, <http://epp.eurostat.ec.europa.eu/portal/page/portal/transport/data/main_tables> [12/2014]

[8] Schmitt et al. (2011). Freight Facts and Figures 2011. Washington, DC: Office of Freight Management and Operations, online, <http://www.ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/docs/11factsfigures/pdfs/fff2011_highres.pdf>.

[9] U. S. Department Of Transportation (2013). Transportation Statistics Annual Report 2012. Washington, DC: Research and Innovative Technology Administration Bureau of Transportation Statistics, online, <http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/tsar_2012.pdf.pdf> [12/2014]

[10] U.S. Department of Transportation. Freight Rail Today. Washington, DC: Federal Railroad Administration, online, <https://www.fra.dot.gov/Page/P0362> [12/2014]

[11] FHWA (2012). Freight Facts and Figures 2012. U.S. Department of Transportation, Federal Higways Administration, Office of Freight Management and Operations, online, <http://www.ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/docs/12factsfigures/pdfs/fff2012_highres.pdf>.

[12] PPIAF (2014). Public - Private Infrastructure Advisory Facility, online, <http://www.ppiaf.org> [12/2014]

[13] EC (2013). Energy, Transport and Environment Indicators. European Commission, Eurostat, online, <http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-DK-13-001/EN/KS-DK-13-001-EN.PDF>.

[14] Huggins (2009). Panorama of transport. Luxembourg: Office for Official Publications of the European Communities, 2009, online, <http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-DA-09-001/EN/KS-DA-09-001-EN.PDF>.

[15] EC (2013). "Europe's Seaports 2030: Challenges Ahead." European Commission, online, <http://europa.eu/rapid/press-release_MEMO-13-448_en.htm>.

[16] Port of Rotterdam (2014). "Containermap", online, <http://www.portofrotterdam.com/en/Business/containers/Documents/Container map.pdf>.

[17] EC (2014). European Commission. Infrastructure - TEN-T - Connecting Europe, online, <http://ec.europa.eu/transport/themes/infrastructure/index_en.htm> (4/6, 2014).

[18] EC (2011). "Trans-European Transport Network: Inland Waterways and Ports." European Commission, online, <http://ec.europa.eu/transport/themes/infrastructure/doc/com(2011)_650_final_2_annex_i_part02.pdf>.

[19] Energy and Transport DG (2006). Road transport policy. Open roads across Europe. Luxembourg: Office for Official Publications of the European Communities (2006), online, <http://ec.europa.eu/transport/road/doc/road_transport_policy_en.pdf>.

[20] Burks et al. (2010). Transportation Research Circular E-C146: Trucking 101. Washington, DC: Transportation Research Board (2010), online, <http://onlinepubs.trb.org/onlinepubs/circulars/ec146.pdf>.

[21] GAMS (2015). The GAMS System. Washington, DC: GAMS Development Corporation, online, <http://onlinepubs.trb.org/onlinepubs/circulars/ec146.pdf>.

[22] Kubíková, S.: Systems for intelligent transport management, Conference proceeding, 3rd International scientific conference Logistika-Ekonomika-Prax 2014, 20. november 2014, Žilina, ISSN 1336-5851

[23] Stopka, O., Kampf, R., Kolář, J., Kubasáková, I.: Identification of appropriate methods for allocation tasks of logistics objects in a certain area, Naše more: znanstveno-stručni časopis za more i pomorstvo, ISSN 0469-6255, Vol. 61, no. 1-2 (2014), pp. 1-6.

[24] Stopka, O., Kampf, R., Kolář, J., Kubasáková, I., Savage, C.: Draft guidelines for the allocation of public logistics centres of international importance, Communications scientific letters of the University of Žilina, ISSN 1335-4205, Vol. 16, no. 2 (2014), pp. 14-19.

[25] Krile, S.: Efficient Heuristic for Non-linear Transportation Problem on the Route with Multiple Ports, Polish Maritime Research, Gdansk, Poland, 2013, Vol. 20, No 4, pp. 80-86, (ISSN: 1233-2585), DOI: 10.2478/pomr-2013-0044.

[26] Krile, S.: Passage Planning with Several Ports of Loading and Discharging, Planiranje plovidbe s više luka ukrcaja i iskrcaja, Naše more (Our Sea), Vol. 60, No 1-2, pp. 21-24, Dubrovnik, 2013. (ISSN: 0469-6255).