

Hugo Mauček

**AN OPTIMAL CONTAINER
TRANSPORTATION MODEL (TEU)
BETWEEN THE EASTERN STATES
OF THE UNITED STATES
AND WESTERN EUROPEAN COUNTRIES**



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I São Paulo I 2025 I



INTERNATIONAL CATALOGING IN PUBLICATION DATA (CIP)

M459o

Mauček, Hugo -

An Optimal Container Transportation Model (TEU)
between the Eastern States of the United States and
Western European Countries / Hugo Mauček. – São
Paulo: Pimenta Cultural, 2025.

Book in PDF

ISBN 978-85-7221-511-4

DOI 10.31560/pimentacultural/978-85-7221-511-4

1. Container transport. 2. Maritime container terminals.
3. Optimization of maritime container transport. 4. Integer
linear programming. 5. Level of development of maritime
container terminals. I. Mauček, Hugo. II. Título.

CDD 387.5

Systematic Catalog Index:

I. Maritime Container Transport

Simone Sales • Librarian • CRB: ES-000814/0

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FOREWORD

I dedicate this book to my wife Tadeja and my daughters Neža and Karina, who always lovingly encouraged and supported me during the writing of this book, enabling me to successfully complete it.

Finally, my greatest thanks go to God, who gave me health and understanding.



Dr Hugo MAUČEC

A handwritten signature in black ink, appearing to read 'Hugo Mauc'.

In Murska Sobota, Slovenia,
September 2025

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SUMMARY

AN OPTIMAL CONTAINER TRANSPORTATION MODEL (TEU) BETWEEN THE EASTERN STATES OF THE UNITED STATES AND WESTERN EUROPEAN COUNTRIES

Containers enable unitization of cargo, which means faster loading and unloading of vehicles, a smaller possibility of losing cargo and stealing shipments, an easier way of storing shipments, and reduced packaging costs. Container shipping has been the fastest growing sector of the maritime industries during the last two decades. The growth of container transport is spurred by economic growth, the process of globalisation, the liberalisation of transport and outsourcing. It has also been spurred by changes in carriers' scheduling strategies and by the development of ports. Container shipping lines are facing several challenges in today's highly competitive environment, one of which is increasing customer demand for greater reliability of container shipments and shipping containers at lower total costs.

The main purpose of this book was to optimize maritime overseas transport routes and reduce the total average price of container transportation between Eastern countries of the United States of America and Western European countries as part of the logistics system in a transnational context, as to define and calculate the development rate of container maritime terminals in the Eastern countries of the United States of America and Western European countries.

In the research, I have modelled six optimisation models of transport. The first optimisation model (Z_1) of container transport by sea from maritime container terminals in the Eastern countries of the USA (PKT/A) to Western European countries (PKT/E) was modelled for optimisation by integer linear programming in the Lingo 14 software tool, where the optimisation criterion was the price of container transport. The second optimization model (Z_2) was modeled for optimization by integer linear programming in the Lingo 14 software tool and with regard to the development rate of maritime container terminals in Western European countries S_r , where the criteria was also optimising the total average cost of container transportation.

As perishable goods are often transported in containers, priority is given to criteria of optimising the time of transport before the criteria of cost. In these models, the objective function remains linear. The third optimisation model (Z_{3T}) was modelled for the integer linear programming of time of transport. The fourth optimization model (Z_{3C}) was modeled afterwards for optimizing the cost of transport, where the results of previous optimization of time (Z_{3T}) were considered. The fifth optimization model (Z_{4T}) was modeled for the integer linear programming of time of transport. The sixth optimization model (Z_{4C}) was modeled afterwards for optimizing the cost of transport with regard to the development rate of maritime container terminals in Western European countries S_r , where the results of previous optimization of container transport time (Z_{4T}) were considered.

By developing and using an optimization model of total numbered integer linear programming, the cost and time of container transport between maritime terminals in the Eastern countries of the United States of America and Western European countries can be significantly reduced. When planning the model, I considered the following elements: 1) transport infrastructure and superstructure, 2) use of intelligent information systems, 3) gross domestic product, 4) transport ecology, 5) cargo flows, 6) innovations, 7) safety and security, and 8) transport energy, the introduction of which in practical terms represents a reduction in the total average price and time of container transportation between container terminals in the Eastern countries of the USA and Western European countries.

From the research conducted in this book, I can conclude different directions. Firstly, the primary hypothesis has been proven with concrete assessments and calculations - by optimizing the flow of merchandise containers between maritime terminals from the Eastern countries of the United States of America and Western European countries on transatlantic shipping routes. The total average price of container transportation is reduced i.e. by 5%. By optimal solution, where the development rate of maritime containers' terminals S_r in Western European countries is involved, I get to even lower common average price of container transportation with regard to classical transport in 2012, where I reduce the common average price of container transportation by 7%.

Secondly, it has been proven that by optimal solution of merchandise containers' flows between maritime terminals from the Eastern countries of the United States of America and Western European countries on transatlantic shipping routes in 2012, where the development rate of maritime containers' terminals S_i in Western European countries is included, the level of common release of Carbon dioxide into environment is reduced by 1%, fuel consumption is reduced by 2%, and energy consumption is reduced by 1% for container ships with a capacity of 9,000 TEU.

Keywords:

Container transport, maritime container terminals, optimization of maritime container transport, integer linear programming.



1

INTRODUCTION

Container transport stems from customer demand for goods (Rodrigue et al., 2009, 2). This customer demand for goods must be continuously met in various geographical markets around the world. Global maritime container liner connections enable customer demand to be met and have a major impact on the development of countries and their economic growth. Existing trends in global markets have triggered large financial investments in the development of maritime container terminals in individual countries and forced container carriers, operators, and companies to cooperate with each other. It is reasonable to optimize and reduce transport costs.

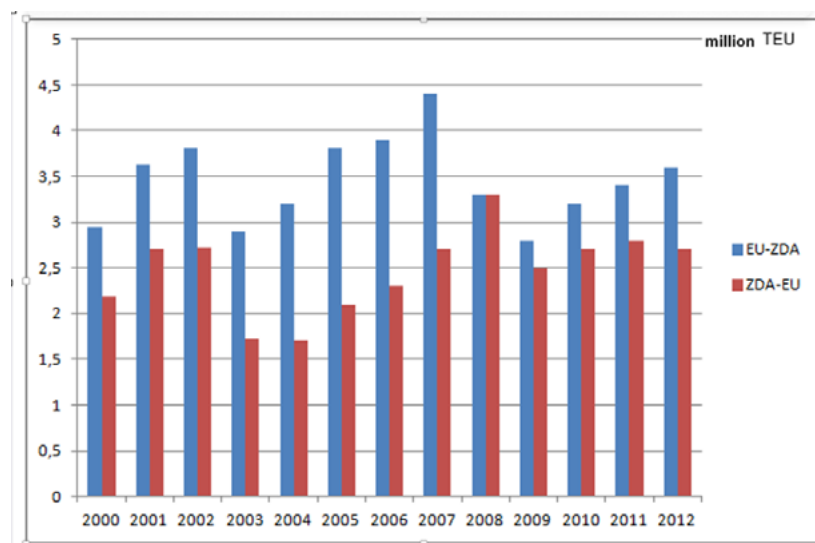
In this book, the cost of container transport is minimized using the integer linear programming method, and at the same time, the time and cost of container transport on transatlantic container liner routes from the maritime container terminals of the Eastern United States to maritime container terminals in Western European countries. Based on the calculated optimal results, new optimization models are developed for container transport on transatlantic container liner services from maritime container terminals in the Eastern United States to maritime container terminals in Western European countries. the level of development of maritime container terminals in the Eastern United States and Western European countries is calculated, the attractiveness of maritime container terminals in Western European countries is defined and calculated, and the impact of container transport optimization models on sustainable development is presented.

1.1 DEFINITION OF THE RESEARCH PROBLEM

Containerization is a rational way of transporting goods. This rational way of handling goods is one of the basic reasons for the globalization of production in the world. Containerization has contributed to increased demand for transport, which has contributed to the further development of containerization on individual continents. Compared to conventional methods of transport, the advantage of using containers is that less packaging is required, there is less damage to goods, and productivity is higher (Hecht and Pawlick, 2007, 13-14). Maritime networks are among the oldest forms of spatial connections. The size of maritime terminals and maritime connections represent processes such as the regionalisation and globalisation of trade flows and business cycles and reveal a certain political economy in the world (Ducret and Notteboom, 2012, 1).

Containerisation has grown since 1956 with the growth of international trade, policy changes, technological developments and globalisation. The annual Review of Maritime Transport (2001-2012) reports published by the United Nations Conference on Trade and Development (UNCTAD) in Geneva show that container flows across the Atlantic Ocean differ in terms of volume in both directions between North America and Europe (see Figure 1). Figure 1 shows that in 2012, 25% more containers were transported in the Europe-North America direction than in the North America-Europe direction.

**Graph 1 - Traffic flows across the Atlantic Ocean in both directions
between North America and Europe (2000-2012)**



Source: Review of Maritime Transport (2001-2012)

After decades of adaptation and expansion of containerisation, global maritime container transport is becoming a reality (Frémont, 2007, 431-442; Rodrigue and Notteboom, 2010, 19-29). The technological revolution of containerisation has gradually produced new forms of relations between countries, regions and port cities, which have been subject to constant pressures such as: transport costs (Limao and Venables, 2001, 451-479), the increasing polr of delivery chains, and the increasing polr of large carriers (Sys, 2009, 259-270; Slack and Fremont, 2009, 23-34). In this context, maritime container terminals compete with each other not only as individual areas that receive ships, but also as important global hubs in global supply chains (Notteboom and Winkelmanns, 2001, 71-89; Hall and Jacobs, 2010, 1103-1115).

Irrational handling, transport, and distribution of containers between the Eastern United States and Western European countries reduces the competitiveness of material goods on the market because it increases the share of external transport costs in the sale price of goods.

The transport of containers between the Eastern United States and Western European countries raises questions about the limited capacity of road infrastructure, safety and security, and social and environmental issues at maritime container terminals. In larger maritime container terminals in the Eastern United States, there are traffic jams and high levels of environmental pollution from exhaust gases.

To date, there has been no scientifically substantiated and transport-oriented research into the possibilities for developing container transport from the Eastern United States to Western European countries. Thus, there is still no established methodology for the optimal transport of containers from container terminals in the Eastern United States to container terminals in Western European countries, which would significantly reduce transport costs and simplify handling and the exchange of transport vehicles.

Accordingly, **the research problem** is defined as follows: For more than fifty years, container transport between the Eastern states of the USA and the countries of Western Europe has been developing intensively. These container flows are relatively fragmented, which leads to inefficient handling and transport of containers between the Eastern United States and Western European countries.

The subject of the research is to investigate and evaluate the most important elements related to container transshipment and transport and to develop a model for container transport on transatlantic container connections between the most important container terminals in the areas under consideration.

The problem and subject of the research relate to three real stochastic research objects, which are: container transport, maritime container terminals in the Eastern United States and in Western European countries.

1.2 OBJECTIVES OF THE BOOK

The main objective of the book is to optimize transoceanic container transport routes between the Eastern United States and Western European countries as part of the logistics system in a transnational context, and to define and calculate the degree of development and attractiveness of maritime container terminals.

The objectives are:

- To develop an optimization model for container transport between the Eastern United States and Western European countries.
- To calculate the degree of development of important maritime container terminals in the Eastern United States and Western European countries and the attractiveness of important maritime container terminals in Western European countries.
- To determine and apply eight important elements of the container transport model, which are derived from the key areas that are most important for carriers in the future and influence the calculation of the degree of development of maritime container terminals (source: ICF International, Long Range Strategic Issues Facing the Transportation Industry, Final Future-focused Research Framework, National Cooperative Highway Research Program, Project 20-80, 2008, Task 2).

1.3 BOOK THESIS

I defined the thesis of the book that it is possible to significantly reduce the cost and time of container transport between maritime container terminals in the Eastern United States and Western Europe by developing and applying optimization models of integer linear programming, taking into account the following elements when designing the model elements: 1) transport infrastructure and transport superstructure, 2) the impact of an intelligent information system, 3) gross domestic product, 4) transport ecology, 5) transport flows, 6) innovation, 7) safety and security, and 8) transport energy, the introduction of which in practical terms represents a reduction in the cost of transporting containers between container terminals in the Eastern United States and Western Europe.

HYPOTHESIS 1:

By optimizing freight container flows, more cost-effective transport chains can be achieved and the time required to transport containers between maritime container terminals in the Eastern United States and Western Europe on transatlantic container lines can be reduced.

HYPOTHESIS 2:

By combining transatlantic container lines between (maritime) container terminals in the Eastern United States and Western European countries, CO₂ emissions into the environment and energy consumption will be reduced.

1.4 EXPECTED ORIGINAL SCIENTIFIC CONTRIBUTIONS

The research conducted in the book could have a significant impact on the national economies and policies of the Eastern United States and Western European countries, as well as on the decisions made by port authorities and freight forwarders (e.g., manufacturing and trading industries), especially with regard to the planning of maritime (shipping) systems. Finally, the findings of this book could also be important at the international level, e.g., in multilateral negotiations (organized by the World Trade Organization, WTO) in connection with the General Agreement on Trade in Services (GATS) regarding international trade in goods and services (in our case, international liner container transport).

1.5 ASSUMPTIONS AND LIMITATIONS

Assumptions and limitations within the scope of the research:

- The study does not include road, rail, and river connections to seaports in the US states and Western European countries.
- The study takes into account both empty and full containers (TEU).
- Maritime container transport across the Atlantic Ocean between North America and Europe is not fully explored in the book due to limited available data.
- The study does not include political decisions made by individual US states and Western European countries, nor does it

include political decisions made by individual port authorities and individual agents.

- Important maritime container terminals in the Eastern states of the USA and in Western European countries are selected on the basis of the largest volume of containers handled.
- The period 2012-2024 for calculating the rate of development of maritime container terminals is selected on the basis of data on global container transshipment at potential container terminals around the world in the period 1970-2024. (source: VICKERMAN, J.: Future Trends and Challenges of the MTS, TranSystems, Washington DC, 2007, Internet, http://www.nauticalcharts.noaa.gov/ocs/hsrp/archive/mar2007/FutureTrends_3-07.pdf, (11 April 2014)).
- The study examines the direction of container flows from Eastern US states to Western European countries, where buyers in Western European countries also pay the cost of container transport in the selling price of goods.

1.6 RESEARCH METHODS

The second chapter uses the methods of description and compilation, analysis and synthesis. The second and third chapters use the methods of analysis and synthesis, induction and deduction, specialisation and generalisation, abstraction and concretisation, and comparison. The third and fourth chapters use the modeling method, the integer linear programming method for minimizing container transport costs, and the integer linear programming method for minimizing the time and cost of container transport from maritime container terminals in the Eastern United States to maritime container terminals in Western Europe.

1.7 ASSESSMENT OF PREVIOUS RESEARCH

By studying numerous available bibliographic units and scientific journals, the following sources were found on the research topic, in which the following was published:

It is clear that the maritime industry includes maritime transport (the shipping industry) and seaports. Some researchers (such as Song, 2012, 9-23) define maritime transport in a broader context to include related land transport. Many studies have been conducted to highlight the importance of optimising container routes by road and rail (Lee, 2011, 1) and visualising the results of management decisions (Lee et al., 2011, 7-21). Recent research has examined the various impacts of port efficiency, competition between ports, and congestion problems. Port efficiency has been investigated by many authors, such as (Notteboom, 2009, 4-60; Heaver 2006, 1-35; Talley, 2007, 500-504; Brooks, 2007, 599-626; Rodriguez et al., 2007, 495-505; Ramos-Real and Tovar, 2010, 231-246).

Research on competition between seaports has, (as noted by Heaver, 2006, 16-29), shifted from "characterizing it as competition for public land (and sea) to competition between alternative logistics systems of which ports are a part." Talley (2007, 502) emphasizes: „A port, especially in a competitive environment, is not only concerned with whether it is efficient (technically and financially), but also with whether it is efficient in providing production." The basis of competitiveness is to ensure an efficient logistics offer as a whole, while achieving a reduction in the total logistics price (or total logistics costs).

In many maritime countries, the interaction between maritime port activities and land congestion has become more pronounced over time, as noted by the authors of the articles (Fan, Wilson, and Tolliver, 2009, 735-749). The problems with container congestion at Eastern coastal ports in the US have been highlighted by (Leachman

and Jula 2011, 609-622; Leachman and Jula 2012, 296-309). (De Borger and De Bruyne, 2011, 1-42) investigated the effects of vertical integration between port activities and land-based congestion. They observed that road traffic flows in the vicinity of maritime cities such as Rotterdam and Antlrp have become increasingly congested due to the expansion of port activities. (Crainic and Kim, 2007, 1-66) discussed the interpretation of congestion in the context of intermodal transport flow models.

To reduce congestion at terminal gates and its economic and environmental impact, various solutions have been proposed and implemented, as noted by the authors (Maguwere, Ivey, Lipinski, and Golias 2010, 1-15). Notteboom (2009) assessed the impact of delays on ship logistics (the logistics of loading ships). (Rodriguez et al., 2007, 495-505) indicated that port terminal costs are influenced by various requerements. (O'Kelly and Bryan, 1998, 605-616) developed a model for positioning transoceanic hubs to show the economic scales produced by inter-hub connections. (Racunica and Wynter, 2005, 453-477; Rodriguez et al., 2007, 485-505) used optimization models of a network of hubs on the example of railway line connections in Europe.

Logistics and supply chain management play an important role in overseas transport. Supply chain optimization models enable the lolst costs for importers of containerized products to regional distribution centers. These models were developed by Leachman and Jula (2011, 992-1004), Leachman and Jula (2012, 296-309).

Fan, Wilson, and Tolliver (2009, 4-7) analyzed the intermodal transport network of containers imported into the US. The model minimizes logistics costs and optimizes maritime shipping and land transport networks in North America under node constraints within the logistics channel. The model includes domestic and international shipping routes and ship sizes with the aim of reducing total logistics costs for container imports and meeting geographical demand.

The model takes into account the following factors in its optimization: ship size, seaport capacity, and market size. The study shows the effects of logistics system constraints in the US on container flows.

Their optimization objective function is as follows:

Minimize total cost =

$$\begin{aligned} & \sum_{e \in E} \sum_{v \in V(e)} \sum_{\pi_e^f \in \Pi_E^f} (WCostA_v^{\pi_e^f} + IPCostA_v^{\pi_e^f}) * anp_{v\pi_e^f} + \sum_{f \in F} \sum_{(ord) \in I^f} URCostR_{ord} * sut_{ord}^f \\ & + \sum_{f \in F} \sum_{(ord) \in I^f} URCostT_{ord} * sut_{ord}^f + \sum_{f \in F} \sum_{(jrbd) \in I^f} CRCost_{jrbd} * sct_{jrbd}^f \end{aligned} \quad (1)$$

The costs in the general equation represent: the cost component $WCostA_v^{\pi_e^f}$ represents the total average costs by sea by ship type $v \in V$ (e) distributed by layers $\pi_e^f \in \Pi_E^f$ costs vessels from the port of departure to the port of destination, $IPCostA_v^{\pi_e^f}$ are the total average costs of the ship $v \in V$ (e) in port necessary for unloading containers, railway delivery costs $URCostR_{jrd}$, $URCostT_{jrd}$ and $CRCost_{jrbd}$ are the costs of transport per TEU for American and Canadian rail carriers. Decision variables $anp_{v\pi_e^f}$ is the number of container ships of different capacities, and the variables sut_{ord}^f , sut_{jrd}^f , sct_{jrbd}^f represent the number of TEUs transported by US and Canadian rail carriers on major rail corridors. Jula and Leachman (2011, 609-622) proposed a mixed integer nonlinear programming model for optimizing the supply chains of importers of containerized goods shipped from Asia to the US. The model determines the cheapest option strategy for importers in terms of port activity costs, transport costs, transshipment costs, and security costs (calculation of total minimum costs). The problem includes the location/allocation problem with risk pooling, route, mode of transport selection, taking into account stochastic demand and random transport time in order to achieve the desired level of satisfaction. The objective function of optimization defined by them is:

$$\sum_m \sum_n \sum_i \left((C_m^S + C_{m,n,i}^N) \delta_{m,n,i} D_n \right) \quad (2)$$

The variables are: n - type of regional distribution center, m - type of entry seaport, i - mode of land transport, D_n - in a national context, the average sales volume for an importer in one lek, including standard deviation, C_m^S - represents the value (L) of cargo storage time in leks, transport costs (C) per loaded unit from the initial to the final seaport, $C_{m,n,i}^N$ - average value (L) and standard deviation (σ) of cargo storage time in weeks and transport costs (C) per loaded unit transported by land.

The results of their research are as follows: 1) high-value goods are influenced by supply chain strategies, which must be attractive, while for lower-value goods, supply chain strategies may be less attractive, 2) in order to achieve the lowest possible total container transport costs, the method of loading and transshipping containers must be adapted to the value of the goods being transported in them.

Lee (2011, 33-161) developed a GIS simulation model for global container transport in North America. The model enables GIS modeling and is a useful tool for mode-split mode and traffic allocation. The interactive model allows the user to optimize the connection, taking into account factors such as cost, distance, and travel time. Lee optimizes and simulates the import of containers from foreign trade partners to locations in the US via the existing North American infrastructure using a GIS system. The research objectives in his study are: 1) visualization of container flows transported to and from the US via North America, 2) implementation of simulation techniques for visual effects based on detailed GIS modeling solutions at the section level and using the example of international intermodal networks, and 3) analysis of potential policy scenarios and infrastructure changes, which are simulated on a large scale. GIS modeling is performed at the micro and macro levels, first using the example of

supply chain simulation and later using the example of multi-supply chain network analysis. His research also shows: 1) how to make use of limited transport resources and 2) how to identify and integrate transport infrastructure (railways, motorways, and river routes) to maritime container ports in North America, including Mexico and Canada. Using GIS visualization of container flow modeling, he displays data on their transport direction and node density, and using the results of simulations of disruption scenarios in seaports, he shows how integrated transport resources can mitigate the impact of disruptions in major distribution channels.

Its dedicated optimization function is as follows:

Minimize

$$\sum_{SEP} \sum_{SEP} (d_s (R^{method} R^{congestion} R^{classification} R^{right\ way})) \quad (3)$$

Under the condition:

$$\frac{V_{st}}{C_{st}} \leq 1 \quad (4)$$

The variable V_{st} represents traffic on a section or node in time period t , C_{st} represents capacity C on a given segment s at time t , P is the route or sequence of segments, d_s is the distance d on segment s , and R is the resistance R on the segment or node.

The results of his research show that linear programming reduces the impact of the resistance of individual networks in the transport of containers by individual transport branches, and that the visualization of their traffic flows improves communication between users and container transport planners.

The method used to solve the optimization problem of container transport between the Eastern United States and Western European countries in this book is first to use the method of integer linear programming, which is characterized by the definition of variables, the notation of the objective function, writing a system of linear inequalities, and using the Lingo 14 computer tool, which gives us the optimal solution. Using integer linear programming, I optimize the total cost of sea container transport in the area under consideration and thus calculate the deswered savings for logistics systems and transport service users.

Since the problems of container transport by sea are not solved in practice solely with the aim of reducing the cost of container transport using the method of integer linear programming, but priority is given to the criterion of transport time over the criterion of transport cost, the method of solving the optimization problem of container transport between the Eastern United States and Western European countries in this book also uses the use of the integer linear programming method, whereby the transport time T and the container transport cost c are minimized. The optimization of container transport by sea to the destinations in question also takes into account the level of development of maritime container terminals in Western European countries S_r .

1.8 CHAPTERS AND SUBCHAPTERS

The results of the research in this book are presented in five interrelated parts.

The first part, **INTRODUCTION**, presents the definition of the research problem, the objectives of the book, assumptions and

limitations, research methods, a review of the literature, and a brief summary of the chapters.

The second part, entitled **OVERVIEW OF MARITIME CONTAINER TRANSPORT**, presents the development of containerisation, the development of container ports, the development of container ships, the container chain and an overview of the development of container transport.

ANALYSIS OF CONTAINER TRANSPORT BETWEEN EASTERN COUNTRIES THE USA AND WESTERN EUROPEAN COUNTRIES is the title of the third part of the book, which lists important maritime container terminals in the Eastern states of the USA and in Western European countries and provides an overview of the volume of container transport from maritime container terminals in the Eastern states of the USA (PKT/A) to maritime container terminals in Western European countries (PKT/E).

The fourth part, entitled **OPTIMIZATION AND OPTIMIZATION MODELS FOR THE TRANSPORT OF CONTAINERS FROM THE EASTERN STATES OF THE USA TO THE COUNTRIES WESTERN EUROPE**, the application of linear integer programming is used to present a model formulation of container transport by sea between maritime container terminals in the Eastern United States (PKT/A) and Western Europe (PKT/E) – transport price optimization; model formulation of container transport by sea between maritime container terminals in the Eastern United States (PKT/A) and Western European countries (PKT/E), taking into account the level of development of maritime container terminals in Western European countries S_r – transport cost optimization; model formulation of container transport by sea between maritime container terminals in the Eastern United States (PKT/A) and Western Europe (PKT/E) – optimisation of transport time and price; model formulation of container transport by sea between maritime container terminals in the Eastern United States (PKT/A) and

Western European countries (PKT/E), taking into account the level of development of maritime container terminals in Western European countries S_r – optimisation of transport time and cost; a projection of the model for container transport from the Eastern United States to Western European countries is presented, along with the results of calculations using the optimization model for container transport from the Eastern United States to Western European countries and the impact of this model on the sustainable development of transport.

The CONCLUSION presents a synthesis of the research results presented in the book, which prove the working hypothesis.



2

OVERVIEW OF MARITIME CONTAINER TRANSPORT

The following subchapters are necessary to outline maritime container transport: 1) the development of containerisation, 2) the development of container ports, 3) the development of container ships, 4) container chain, and 5) outline of container transport development.

2.1 DEVELOPMENT OF CONTAINERISATION

Containerisation is of key importance for multimodal transport. The transfer between different means of transport and intermediate storage increases the risk of damage and theft of goods. Since different goods come in different shapes, lights, dimensions, packaging, and sensitivity, it is very difficult to provide the right transshipment and transport equipment. Broadly universal equipment is usually not as productive, as it often requires a change of tools. Containerization has enabled the standardization of transshipment equipment, transport equipment, and storage space, which has accelerated the logistics process. At the same time, it has adequately protected goods from mechanical and other influences.¹

Containerization is a set of mutually and interdependently organized work resources and technological processes for the automated handling and transport of larger transport units—containers—from the source to the destination (customer). It is the first system that is used globally for „packaging“ and „palletization.“ The containerisation system most comprehensively and universally connects individual piece loads and palletised loads into common cargo units – containers with cargo – and enables the establishment of an uninterrupted transport chain from the raw material base to the

1

ZUPANČIČ, S.: **Economics of Transport**, University of Ljubljana, Faculty of Economics, Ljubljana, 1998, pp. 65-79.

consumer. The main purpose is to transport goods from the manufacturer to the consumer without intermediate transshipment.²

The objectives of containerisation are:³

- to standardize different types of packaging (barrels, packages, bags) into standardized transshipment and transport units,
- safe, fast, and rational handling and transport of goods,
- optimization of the utilization of transport infrastructure and superstructure,
- quantitative and qualitative maximization of the technical, technological, organizational, and economic effects of transport service production processes,
- maximization of the effects of creative, innovative, and operational managers and other participants in the containerization system.

In 1956, McLean developed the idea of standardized containers and truck trailers that were moved by tractors. Loading containers onto semi-trailers onto ships saved space and costs. Later, ships began to carry only containers. A decade later, the first containers arrived in Northern Europe. These were 35' ASA (American Standards) containers, manufactured according to American standards. In other regions of the world, containers of various sizes were used, such as 27' ASA containers. European and Japanese shipowners quickly recognized the benefits of containers and began investing in the new transport technology.

Most containers around the world comply with ISO standards, with 20' and 40' containers being the most commonly used.

2 ZELENIKA, R., JAKOMIN, L.: **Contemporary Transport Systems**, Faculty of Economics, University of Rijeka, Rijeka, 1995, p. 129.

3 Ibid., p. 130.

In recent years, at the request of freight forwarders and shipping companies, larger containers or „Jumbo“ containers with a length of 45' and 48', a width of 8'6" (2.6 m), and a height of 9'6" (2.9 m) have appeared. Larger containers are typically used in the US, as narrow roads in Europe and other continents are a limiting factor for their introduction.

Today, the use of various types of containers in freight transport is growing day by day, mainly due to the advantages of containerisation as the most widespread modern transport technology. It is realistically estimated that the global container fleet currently has more than ten million containers of various types. Today, 80% of freight in the United States and developed European countries is transported in containers. This refers to the container industry, which is not just a specialised industry that produces and maintains the means for working in the containerisation system (i.e. container infrastructure and container superstructure), but also an industry that mass-produces transport services throughout the global transport system and connects all the raw material bases of all global producers and consumers. The most important advantages and economic effects of handling and transporting goods in containers are:⁴

- reduction of freight costs; container transport eliminates the need for transshipment of goods;
- transporting goods in containers enables the protection of goods,
- transporting goods in containers enables faster handling,
- transporting goods in containers significantly reduces storage costs and increases the speed of handling, especially for goods on pallets,

4 ZELENIKA, R.: **Transport Systems, Technology – Organization – Economics – Logistics – Management**, Faculty of Economics, University of Rijeka, Rijeka, 2001, pp. 512-513.

- containerisation enables the full use of standardised means of transport with simple, fast and secure fastening in the means of transport,
- containerisation enables the unification of technical and technological solutions,
- containerisation enables the entire transport chain to have a uniform scheme for handling and transporting goods,
- containerisation means a significant reduction in the time it takes to transport goods from the manufacturer to the consumer,
- containerisation reduces handling and transport costs,
- containerisation significantly simplifies commercial, transport and administrative operations and accelerates electronic data exchange.

When container transport develops into a containerisation system with all the characteristics of dynamic business systems, I see that only then do the full technical, technological, organisational, economic and legal advantages of containerisation come into play. Containerisation also has a very significant impact on maritime transport.

However, in addition to its advantages, containerisation also has disadvantages, such as:⁵

- it requires a large initial investment of capital,
- requires a high degree of specialization, standardization, and automation of the superstructure in all branches of transport, and partly also of the transport infrastructure,

5 Ibid., p. 524.

- requires highly educated, qualified, and very disciplined operational and creative managers, as well as numerous specialized transport experts,
- requires a properly designed and organized integrated transport information system and full coordination of all participants, all work resources, and all procedures of the entire containerization system.

2.2 DEVELOPMENT OF CONTAINER PORTS

The infrastructure of maritime container ports consists of all facilities and equipment located at a specific site that enable the provision of transport services, the maintenance of shipping lanes in coastal waters, and the operation of a signaling system to ensure safe navigation. These include: access channels, operational quays, breakwaters, handling areas, energy, water supply, sewage and telephone networks, and facilities for safe navigation in the port. Container transport infrastructure also includes warehouses, container terminals, customs, free and logistics zones.

Container terminals are precisely defined, usually open spaces with associated facilities and equipment that enable the storage, temporary security, handling, distribution, and transport of containers.

The capacity and type of a container terminal is determined by several interrelated factors arising from the terminal's geo-traffic location, the gravitational area of goods flows, and overall traffic needs. A container terminal can be viewed from various perspectives in terms of the transport process:⁶

6

Cf. JAKOMIN, L., ZELENKA, R., MEDEOT, M.: **Traffic Technology and Transport Systems**, Faculty of Maritime Studies and Transport, University of Ljubljana, Portorož, 2002, p. 151.

- from the perspective of the movement of transport and handling units,
- from the perspective of analyzing the technology used at the terminal,
- from the perspective of information,
- in terms of the frequency of arrivals and departures and the associated rhythm and frequency of operations,
- from the perspective of the scope of business and tasks,
- from the perspective of accessibility or availability of certain forms of transport, etc.

The characteristics of port container terminals are related to the type and generation of the vessel, the number and length of berths, transshipment machinery, activities upon arrival and departure of vessels and land transport, the education and training of the workforce, etc. These activities can be carried out by directly transshipping cargo to/from the vessel, from land transport vehicles, or by depositing cargo at a storage site and subsequently delivering it to the berth. The speed and efficiency of handling activities depend on the capacity (throughput) of the operational quay, the size of the storage area, and the capabilities of the handling machinery.⁷

A port container terminal can be defined as a system because it meets the following conditions:

- it interacts with external entities and its operation enables the existence and functioning of external systems,
- it is a set of technical, technological, organizational, economic, and legal elements that are interrelated,

7 CHOI, Y. S. **Analysis of Combined Productivity of Equipment in Container Terminal**, Korea Maritime Institute, Maritime Review 33, 2003, p. 57-80.

- It consists of individual elements and subsystems that interact and depend on each other continuously,
- operates with the primary objective of transferring containers from ships to land transport and vice versa.

It is essential to understand the characteristics of a port container terminal as a system in order to select the appropriate approach and methodology for terminal management and to establish appropriate work processes, which also represents the development of container transport infrastructure.

A port container terminal is:

- a dynamic system in which changes are constantly taking place (number of ships at anchor and moored, status and number of containers in storage, number and type of land vehicles, number of employees, number and type of handling equipment, etc.),
- a stochastic system, as input/output can only be defined with a certain probability,
- an open system that constantly creates many connections with the environment (container terminals, shipowners, land carriers, economic entities, and others involved in cargo transportation),
- a social system, as its elements are material in nature and connected to people as an integral part of the work process,
- a system aimed at achieving a set goal (the transshipment of containers between individual transport sectors),
- a complex system, as it consists of several elements, many of which represent wholes and can be defined as individual subsystems.

A container terminal most often consists of three entities that have the characteristics of a system. These subsystems differ between individual container terminals, but they all perform the same role. The subsystems of a port container terminal are:

- the berthing or operational quay subsystem,
- the storage subsystem, and
- the handover area subsystem for land transport vehicles.

All three subsystems represent technological and organizational units without which the port container terminal would not be able to perform its basic functions. In addition to the above subsystems, the container terminal occasionally includes additional elements that contribute to the efficiency of its work or increase its market attractiveness. The berthing subsystem (operational quays) includes berths, quay cranes, and loading areas, as well as all related processes. The storage subsystem is directly linked to the berthing and transfer area subsystem. This is an open storage area, the basic purpose of which is to store containers for further shipment by sea or land.

The land vehicle transfer area subsystem is based on the storage subsystem in terms of location and technology. Occasionally, the processes overlap and it is impossible to draw a clear line between the two subsystems.

Each of the aforementioned subsystems has its own purpose as a whole, but in economic terms, they cannot exist as independent elements and offer only their own services. There must be a high degree of connectivity and coordination between them to enable the most efficient operation and development of the port container terminal.

With the globalization of the world economy, the international economic system has also had a major impact on the development and operation of container terminals. Thus, it can be con-

cluded that the international and national economies indirectly influence the technological profile and throughput capacity of a port container terminal.

In most cases, a container terminal is an integral part of the port system. The connection with the port can be very strong or minimal, depending on the organizational form and ownership structure of the port. The operation of the port and the port container terminal is greatly influenced by regional and global liner shipping systems and land transport systems. Liner shipping determines the operation and business of the terminal, as a larger number of liner ship calls facilitates the commercial activity of maritime container terminals in finding new partners and new commodity flows. The geographical position of a maritime container terminal is indirectly dependent on the number of liner connections with the most important global and regional terminals.

The land transport system has a two-way impact on the operations of a port container terminal. Land transport routes determine the size and quality of the potential of the gravitational area, while the number of land transport vehicles, in combination with the business policy of the port or terminal, determines the dimensions of the gravitational hinterland.

The port container terminal is also influenced by many other phenomena in the surrounding area, such as:

- scientific and technical progress,
- location and available space for terminal construction,
- the number and characteristics of container terminals in the immediate and wider vicinity,
- local, national, and regional transport policy, the ownership and management structure of the container terminal, and the policy of the port as a system.

Macroeconomically hinterland is a matter of demand for transport with regard to at the origin, destination, and the entire environment in which service providers carry out their activities. This can be represented by a series of logistics activities, some of which focus on production, others on consumption, often distribution centers. An exception is cargo that is often directly linked to maritime container terminals, but the supply chains are simpler and involve fewer participants.⁸

Seaports seek to help alleviate additional traffic and the complexity of container distribution by improving connections with the hinterland through their facilities. The regionalisation of seaports is seen as a result of the high degree of integration between maritime transport and land transport systems, particularly rail and river transport, which are less prone to congestion than road transport. The development of the global supply chain is increasing pressure on maritime transport, port activities, and inland container distribution. Inland accessibility has become a key factor in the competitiveness of ports. The regionalisation of seaports is strongly dependent on functional interdependence and the joint development of a specific load centre and logistics platform in the hinterland (see Figure 1).

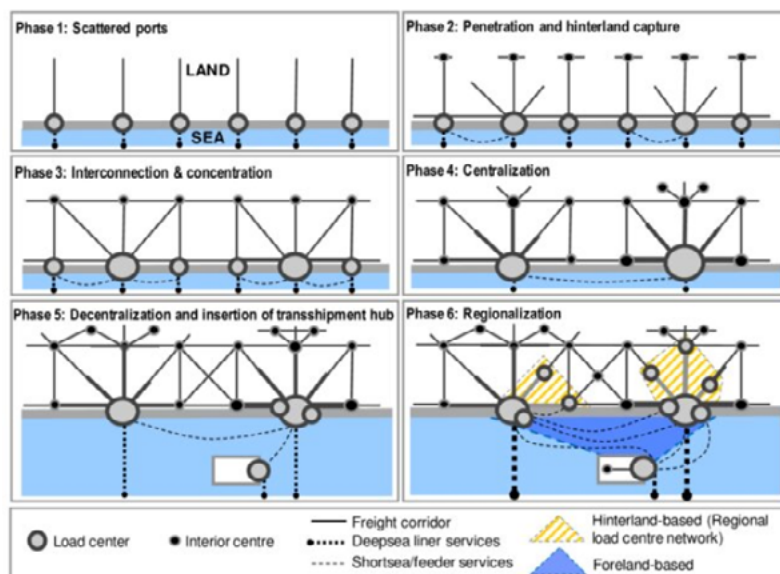
Maritime ports are affected by a wide range of local constraints that hamper their growth and efficiency. The lack of available land for the expansion of maritime ports is one of the most acute and unique problems. This issue has been exacerbated by overseas requirements for the operation of larger ships. Increased maritime traffic can also cause congestion on local roads and rail networks. Environmental constraints and local opposition to seaport development also affect the development of seaports. Global consumption and production are significantly changing the regionalisation of seaports. No single location can currently serve such a complex network

8

Source: Internet, http://people.hofstra.edu/jean-paul_rodrigue/downloads/ashgate-notteboom-rodrigue-draft%20final.pdf, (24 April 2014).

of activities on its own. Globally integrated free trade zones are emerging in the vicinity of many centers as functionally integrated units with their own supply chain.⁹

Figure 1 - Spatial development of the port system



Source: NOTTEBOOM, T., RODRIGUE, J-P (2005): *"Port Regionalization: Towards a New Phase in Port Development"*, *Maritime Policy and Management*, Vol. 32, No. 3, p. 297-313.

The relationship between ports and their hinterland has become the basis for port competitiveness. Global trade depends on maritime and inland connections. Port investments in infrastructure are important because of the expected growth in container traffic, but so are the current demands to achieve results with the growth potential in the hinterland offered by container transport. This has led to the

9 RODRIGUE, J.-P.: **Maritime Transportation: Drivers for the Shipping and Port Industries**, International Transport Forum 2010, Transport and Innovation: Unleashing the Potential, Paper Commissioned for the Experts 'Session on Innovation and the Future of Transport', Paris, January 2010, p. 12.

development of corridors based on rail services that provide connections to inland terminals, which function either as satellite terminals, transshipment centers, or, less frequently, as transmodal facilities.

Satellite terminals are usually located near the port, mainly on the outskirts of the metropolitan area (often less than 100 km away), as they have largely taken over the service function of port facilities. They perform functions that have become too expensive at the port, such as storage (e.g., of empty containers) and distribution. Satellite terminals can also serve as loading centers for local or regional markets, especially where economic density is high. In this case, several terminals form a group with a main port. They are connected by regular train connections or road tractor services. A satellite terminal can also have an important loading function, where the contents of maritime containers are loaded onto trucks.

Loading centers are the main intermodal facilities—loading centers that provide access to well-defined regional markets that include production and consumption functions. This often corresponds to a metropolitan area where different terminals offer simultaneous storage, distribution, and logistics functions. This usually takes place in logistics parks and free trade zones (or foreign zones). The interior of the terminal is therefore a collection or distribution point for the regional market. The larger and more diverse the market, the more important the loading center.

In long-distance container trade, intermediate hubs have begun to grow in importance, with the task of connecting different systems in maritime transport. These hubs are most commonly found along the main shipping routes near the equator, the Suez Canal, the Panama Canal, the Strait of Malacca, and Gibraltar. Many of them enable north-south and east-west connections by sea.

Structure of the global maritime transport system:

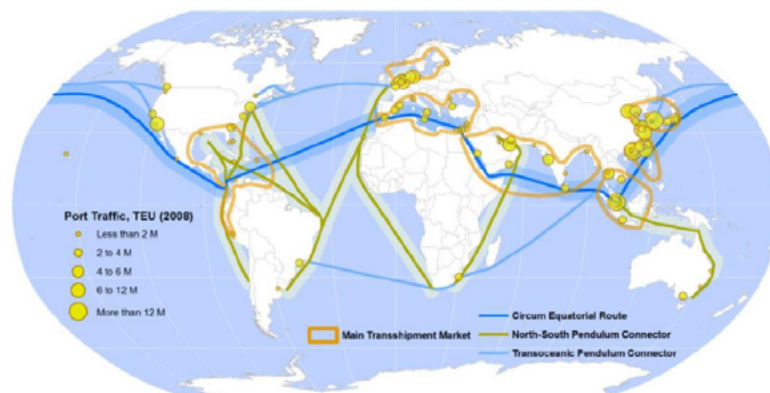
Equatorial route. With the expansion of the Panama Canal, the first connection between the Panama and Suez Canals is expected to take place in 2014. In such an environment, shipping companies may decide to establish equatorial routes in both directions using high-capacity vessels (over 18,000 TEU containers). This connection could contribute significantly to global east-1st freight transport in a cost-effective manner. This does not mean a homogeneous service in the form of multiple port configurations.

North-south connections. These connections reflect existing trade relations, namely for raw materials (oil, minerals, agricultural goods) between South America/North America, Africa/Europe, or Australia/Asia. The reason for this container transport is that there is not enough space to support transoceanic transport services, so cargo is collected and delivered in sequence at ports located at the same latitude. This conventional network will be expanded with transshipment options on the equatorial route.

Transoceanic connections. Three main transoceanic connections are important: the Asia-Europe transpacific connection (via the Indian Ocean) and the transatlantic connection. Industrialisation in Asia (especially China) has given the Asia-Europe and transpacific connections a particularly important role. Growth in the „BRIC“ countries (Brazil, India, and China) is promoting the emergence of a new connection in the southern hemisphere between the east coast of South America, the Cape of Good Hope, and Southeast Asia.

Transshipment market. It is precisely the integration of regional port systems on transoceanic and equatorial routes that enables the creation and development of intermediate hubs. The most important hubs are in Southeast Asia, the Mediterranean, and the Caribbean. These are known as markets because the container transshipment function can be shifted to another port. Therefore, the group of ports defined as „supply“ transshipment markets is important for intermediate stops at ports.

Map 1 - Emerging global maritime container flows



Source: RODRIGUE, J.-P.: *Maritime Transportation: Drivers for the Shipping and Port Industries*, International Transport Forum 2010, *Transport and Innovation: Unleashing the Potential*, Paper Commissioned for the Experts, 'Session on Innovation and the Future of Transport', Paris, January 2010, p. 19.

Table 1 - The ten largest global maritime container terminals in 2012

	Container terminals	Country	Million TEU
1	Shanghai	China	32.53
2	Singapore	Singapore	31.65
3	Hong Kong	China	23.10
4	Shenzhen	China	22.94
5	Busan	South Korea	17.04
6	Ningbo-Zhoushan	China	16.83
7	Guangzhou Harbor	China	14.74
8	Qingdao	China	14.50
9	Jebel Ali	Dubai	13.30
10	Tianjin	China	12.30

Source: Prepared by an author based on data obtained from the Internet, <http://www.worldshipping.org/about-the-industry/global-trade/top-50-world-container-ports>, (11 April 2014).

Map 2 shows the fifty largest maritime container terminals in the world in 2012.

Shipping companies and maritime operators at port terminals represent a very high global industry in terms of both operations and ownership. The maritime industry is already dominated by large ships, associations, takeovers, and strategic alliances, which has an impact on the potential reduction of maritime transport costs. Therefore, there is a growing need to reduce logistics costs on land. In addition to revenue and costs, demand is the main driving force for carriers to integrate their services across the supply chain.

Map 2 - Display of the 50 largest global maritime container terminals in 2012



Source: Internet, <http://vizual-statistix.tumblr.com/image/66724553145> (12 April 2014).

Carriers that traditionally only dealt with the transport of goods are now looking for logistics companies that enable the delivery of goods at the right time, are involved in the supply chain, and provide a logistics system for information management. Shipping

lines are increasingly demanding the selection of a fleet and the improvement of logistics offers that customers want (price, transport time, reliability, frequency of line services, and proximity to markets). Global maritime operators play an important role in the dynamics of maritime container terminal operations, as they ensure the operation of maritime container terminal equipment and also strategically plan financial investments in maritime infrastructure. Both the short and long term are part of their concerns. Short-term problems are related to the capacity and quality of their services, while long-term problems concern issues related to market expansion. Their concerns therefore relate to three areas: port operators at terminals that have expanded into new markets to offer their expertise and increase their revenues (stevedores), shipping companies, and financial holding companies (cf. Table 2).

Table 2 - Global terminal operators

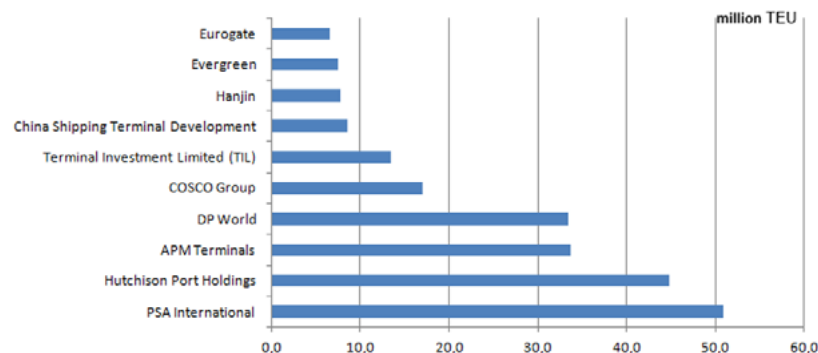
Operators for loading and unloading container ships (stevedores)	Shipping companies (Maritime Shipping Companies)	Financial holdings
Horizontal integration	Vertical integration	Hybrid (vertical or horizontal integration)
Port activities are the primary activity, investments in container terminals for expansion and extension of the scope of production and sales of products, for reducing business risk	Maritime shipping is the primary activity, investments in container terminals are only a support	Financial resources allocated for operations are the most important activity, investments in container terminals for valuation and revenue
Expansion into direct investment	Expansion through direct investments or through the parent company	Expansion through acquisitions, mergers, and reorganizations of assets

PSA International (public), HHLA ¹⁰ (public), Eurogate (private), HPH ¹¹ (private), ICTSI ¹² (private), SSA (private)	APM Terminals (private), COSCO Group (public), MSC ¹³ (private), APL ¹⁴ (private), Hanjin (private), Evergreen (private)	DP World (state asset fund), Ports America (AIG ¹⁵ ; private fund), RREEF (Deutsche Bank; public fund), Macquarie Infrastructure (private fund), Morgan Stanley Infrastructure (private fund)
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Source: RODRIGUE, J.-P.: *Maritime Transportation: Drivers for the Shipping and Port Industries*, International Transport Forum 2010, *Transport and Innovation: Unleashing the Potential*, Paper Commissioned for the Experts, 'Session on Innovation and the Future of Transport', Paris, January 2010, p. 4.

Graph 2 shows the total number of containers handled by container terminals operated by global port operators in 2012.

Graph 2 - Total number of containers handled through maritime container terminals terminals by global port operators in 2012



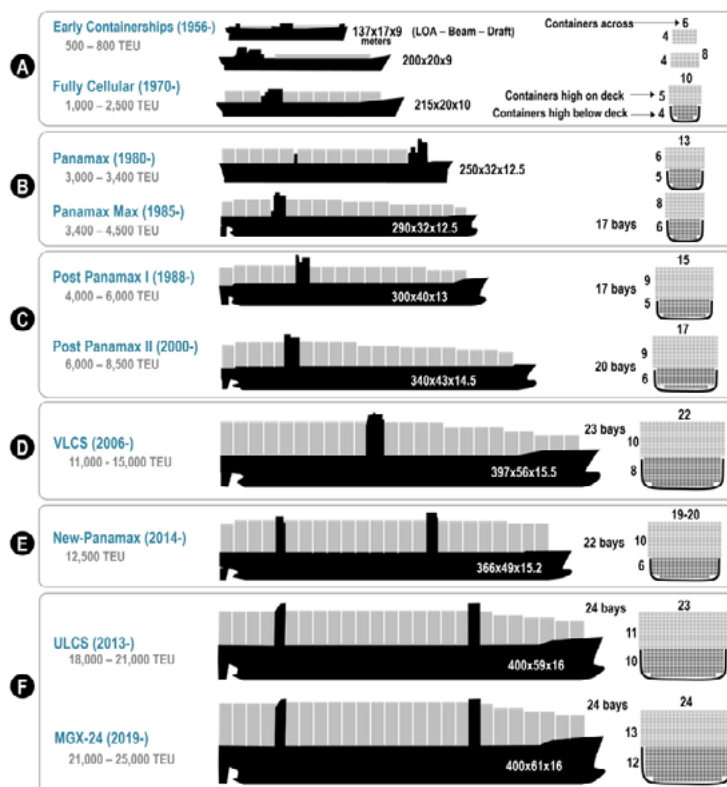
Source: Prepared by an author based on data published on the Internet, <http://www.hellenicshippingnews.com/News.aspx?ElementId=b8560382-8931-42fa-ba9a-300c5adf363f>, (11 April 2014).

- 10 HHLA - Hamburger Hafen und Logistik AG: Container
- 11 HPH - Hutchison Port Holdings
- 12 ICTSI - International Container Terminal Services, Inc.
- 13 MSC - Mediterranean Shipping Company
- 14 APL - American President Lines Ltd.
- 15 AIG - American International Group, Inc.

2.3 DEVELOPMENT OF CONTAINER SHIPS

The first ship to carry only containers is mentioned in the literature as the „Ideal X.“ It sailed from the port of Newark on April 26, 1956, with 58 containers bound for Houston. The same year, the first ship designed exclusively for transporting containers also set sail. The ship „Maxton“ was a converted tanker with a capacity of 60 containers. An overview of the development of container ships from 1956 to 2013 is shown in Figure 2.

Figure 2 - Development of containerships



Source: Internet, <https://transportgeography.org/contents/chapter5/maritime-transportation/evolution-containerships-classes/>, (1 September 2025).

The first container ships designed exclusively for transporting containers appeared in 1968. They had a capacity of 700 TEU. The rapid growth of container transport required ever larger ships, so second-generation ships had a capacity of up to 1,500 TEU (in 1970), third generation up to 3,000 TEU (in 1973), fourth generation up to 4,000 TEU (late 1970s), fifth generation up to 4,500 TEU (in 1985), sixth generation up to 5,500 TEU (in the 1990s). Today, Triple E container ships with a capacity of over 18,000 TEU are already sailing around the world.

Photo 1 - Large container ship „mother ship“



Source: Internet, <http://www.paramountglobalservices.co.uk/upload/container ship.jpg>,
(7 November 2009).

Photo 2 - Smaller container ship – fast „feeder“



*Source: Internet, <http://www.quaysides.co.uk/digi/YSE%20Stena/marcmitchell2.jpg>,
(7 November 2009).*

There are basically two types of container ships, which differ in the way they are loaded and unloaded:¹⁶

Container ships with vertical loading and unloading. This type of container ship is the most common. Cranes installed on piers are used for transshipment. The advantage of this method is primarily the speed of transshipment, but also less damage and space, as containers do not need to be transferred.

These ships can be further divided into subgroups: full container ships (designed only for transporting containers), partial

container ships (ships designed for transporting both containers and conventional general cargo), converted container ships (can be adapted for transporting containers with the help of container cells), conventional merchant ships (designed for transporting conventional cargo and containers. They do not have standardized equipment for securing, placing, and handling containers).

Container ships with horizontal loading and unloading.

Containers are loaded and unloaded through doors at the stern or side using forklifts or tow trucks. Such ships are usually used for various types of cargo and are not specialized for containers only.

Technological advances in shipbuilding mean faster, more economical ships. Given the rapid growth in container transport, there is enough room on the market for both types of ships. Currently, „motherships“ are becoming larger and „feeders“ are becoming faster.¹⁷

2.4 CONTAINER CHAIN

The evaluation of the shipping transport chain refers to the segments necessary for the transport of containers from the sender to the recipient. These segments can be independent segments of the industry. They are presented from the perspective of the carrier and together influence financial performance and return on capital (see Table 3).

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TURK, S.: **Racionalizacija pomorskega (TEU) transporta**, master's thesis, Faculty of Economics, University of Ljubljana, Ljubljana, 2006, p. 69, (unpublished).

Table 3 - Value of the maritime container transport chain and its segments¹⁸

Container shipping industry value chain and segment definition					
	Shipment origination, routing and capacity procurement	Provide containers	Provide and operate vessels	Load and unload shipments	Inland delivery ^a
Key Activities	• Customer sales • Shipment routing • Capacity procurement • Customer service • Billing • Tracking	• Ownership of containers • Storage and maintenance • Repositioning	• Ownership of vessel • Operation of vessel	• Terminal control (ownership or lease) • Terminal operation • Container handling	• Control of trucks • Ownership of railroads • Container handling
Competitor types	• Container carriers • Forwarders / NVOCCs	• Container carriers • Container leasing companies	• Container carriers • Outsourced/ third party • Dry leases • Wet leases	• Container carriers • Captive terminal operators • Third-party terminal operators	• Railroads • TL truckers • Drayage truckers • Container carriers (limited)
Total revenue	\$32 billion	\$8 billion	\$102 billion	\$35 billion	\$28 billion
Historical growth (Revenue '97-'07 CAGR)	10%	11%	7%	11%	7%
Estimated ROCE ^b	50%	9%	3%	25%	34%

Notes: ^a Defined as inland portion of itinerary purchased by customer (e.g., port gate to door); does not include transload market.
^b ROCE = return on capital employed calculated at EBIT (earnings before interest and taxes) divided by net working capital plus book value of plant and equipment.

Source: *INSOMNIA Why challenges facing the world container shipping industry make for more nightmares than they should*, Latest report in a multi-issue series covering value creation in transportation and logistics, *American Shipper*, July 2008, p. 72.

The first segment of the value chain (origin of shipment, line, and order capacity) represents the shipping traffic of the maritime transport industry at the retail level, which includes contractual parties that must pay the costs of transporting containers from door to door. The remaining four segments represent the maritime transport industry at the wholesale level (transport, purchasing, special services). There are a number of competing companies that transport containers by sea, known as liner carriers. At the retail level, liner carriers compete with freight forwarders, who also provide door-to-door container transport. Liner carriers use their own ships for transport,

¹⁸ ROCE - return on capital employed calculated at EBIT (earnings before interest and taxes) divided by net working capital plus book value of plant and equipment - Profit excluding taxes, divided by the net working capital and the sum of the book values of tangible fixed assets;
NVOOC - Non Vessel Owning Ocean Carrier - An organizer of maritime transport that is not a maritime carrier;
CAGR - Compound Annual Growth Rate.

while freight forwarders rely on other companies to provide door-to-door container transport.

The second segment of the value chain (container ownership, storage and maintenance, and return) is particularly characteristic of North America. Container ownership, storage, and maintenance are taken over by third parties, who lease or rent them. 45% of all containers with chassis are leased, while the rest are owned by carriers.

The third segment of the value chain (provision and operation of ships) covers all activities related to the transport of containers from pier to pier (provision of ships either through chartering or direct ownership), fuel supply, and ordering of port pilot services.¹⁹

The fourth segment of the value chain (loading and unloading of ships) refers to the provision and capacity of ships with mooring, loading and unloading of containers from ships and their placement on container platforms in ports. It is estimated that 43% of containers are handled by port cranes, 54% by third-party operators, and 3% by integrated port authorities.

The fifth segment of the value chain (land transport) covers the transport of containers to the end user. The competing groups providing this transport are companies that perform local and national transport by tractor-trailer and rail.²⁰

If I combine all these segments, I obtain the overall structure of container transport prices (see Table 4).

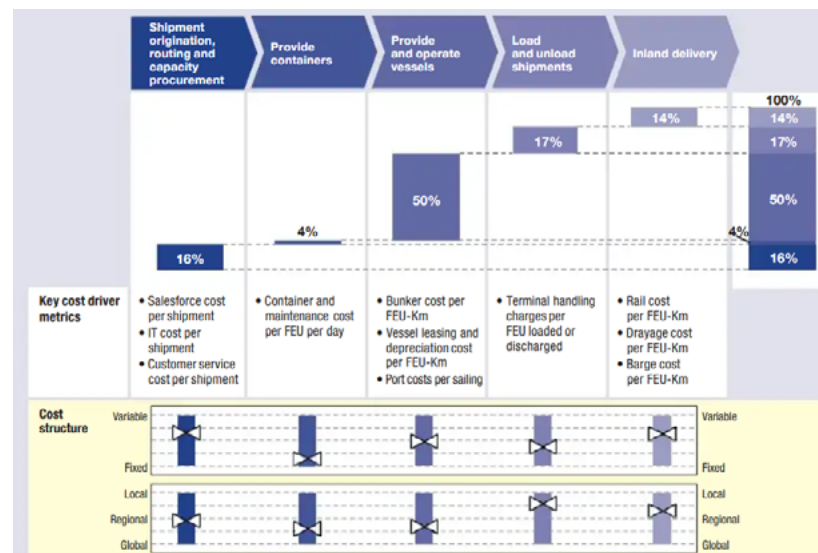
Table 4 shows that almost half of the cost of container transport by sea is accounted for by the costs of loading and unloading ships (17%) and the costs of the origin of the shipment (16%), while

19 Ibid., p. 76.

20 Ibid., p. 77.

the costs of carriers vary depending on the geographical location. Container transport costs are fixed costs because ship schedules are set several months in advance.

Table 4 - Structure of container transport costs by sea²¹



Source: Ibid., p. 72.

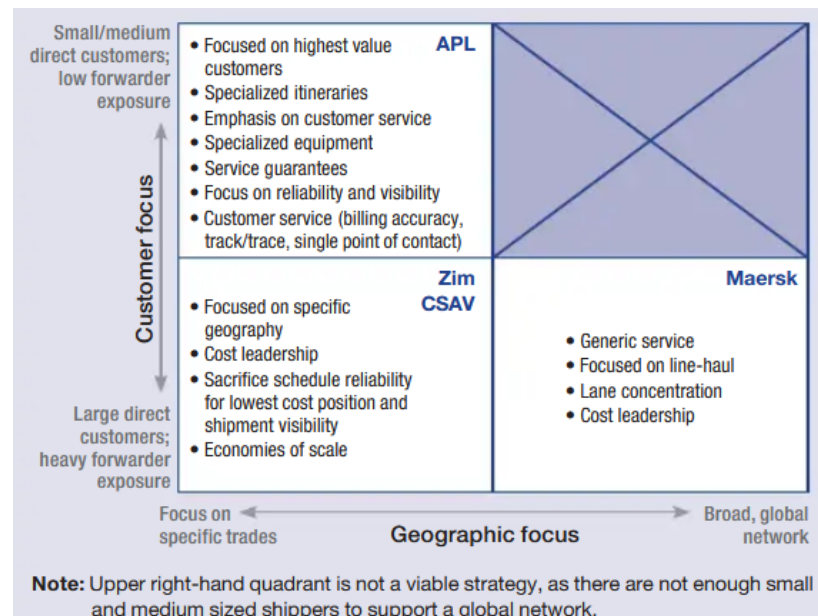
Over a longer period of time, however, all costs are variable, as vessels can be sold or returned to lessors. The fixed part of the costs in the price consists of the costs of information technology, facilities, and container cranes at container terminals. Container rental and repair represent a very high proportion of the fixed costs that the carrier must pay regardless of whether the container is full or empty. The shipping operation is divided approximately 50/50 between fixed and variable costs. Fuel accounts for more than half of the total price structure of all activities. Total land transport accounts for a

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„Forty foot Equivalent Unit“ (40-foot container), 1 FEU= 2 TEU.

large proportion of variable costs, as carriers adapt to user needs for door-to-door delivery.²²

Figure 3 - Matrix of strategic options for container transport by sea



Source: *Ibidem*, p. 78.

The objectives of the largest carriers mentioned above are to build a portfolio in markets where high market shares can be achieved (see Figure 3). In some cases, this means avoiding certain market segments altogether, as it is too difficult to gain a competitive market position. Carriers are thus forced to adapt to geographical conditions and customer needs. With a focus on small and medium-sized customers, this requires more marketing and sales, which increases the average price of transport. There are mainly three market positions for carriers:

- geographically focused in combination with small/medium-sized customers (e.g., APL),
- geographical scope focused on a widely diverse customer structure (e.g., Zim),
- wide geographical coverage and focus on serving large customers (e.g., Maersk).

2.5 OUTLINE OF THE DEVELOPMENT OF CONTAINER TRANSPORT

The growth of container transport, which began fifty years ago, has been impressive and has had far-reaching consequences (globalization would not have been possible without containerization). The use of containers and containerisation marked the beginning of a business cycle that included the following phases: introduction, dispersion and, in the last ten years, the acceptance of container transport as the dominant form of freight transport in the global transport chain. Rapid growth is usually followed by a phase of maturity, where the best market position is achieved and growth slows down. There is growing evidence that the use of containers is entering a phase of maturity, which means that potential growth will be limited in the future and will probably only be related to a market niche.²³

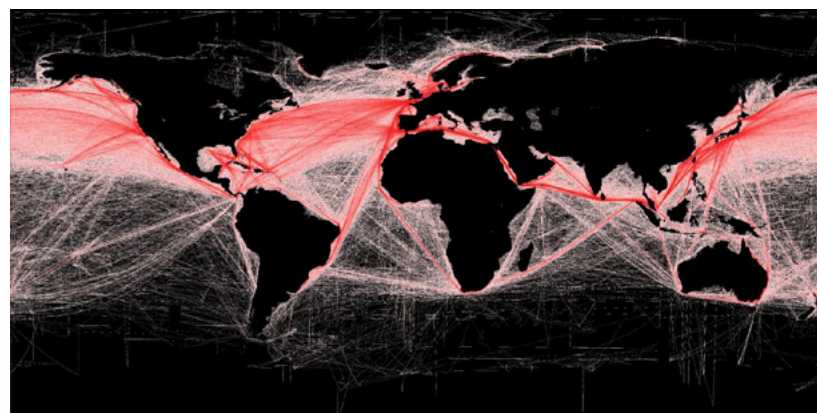
Today, consumption and production markets are flexible and will remain so, as this is the only way they can adapt to the environment and higher oil prices. A similar situation arose after World War II,

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RODRIGUE, J.-P.: **Maritime Transportation: Drivers for the Shipping and Port Industries**, International Transport Forum 2010, Transport and Innovation: Unleashing the Potential, Paper Commissioned for the Experts, 'Session on Innovation and the Future of Transport', Paris, January 2010, p. 14.

when the economic recession led to a decline in long-distance trade, so today consumers and businesses are adapting to higher fuel prices in ways that are less damaging to international trade. Data show that consumers in the US are reducing their demand for services (e.g., restaurants, long-distance travel), but not their consumption of material goods (clothing and toys from China). Many carriers are reducing the speed of their vessels in order to save fuel due to high fuel prices. These carriers will have to adapt to market segments and their customers. The winner among carriers will be the one that achieves a significant position in end-user trade. The geographical location of the industry plays a more important role in this than the common characteristics of carriers. Due to the rise in fuel prices, transport costs will continue to increase in the future.²⁴

Map 3 - Primary transoceanic container freight flows in 2012



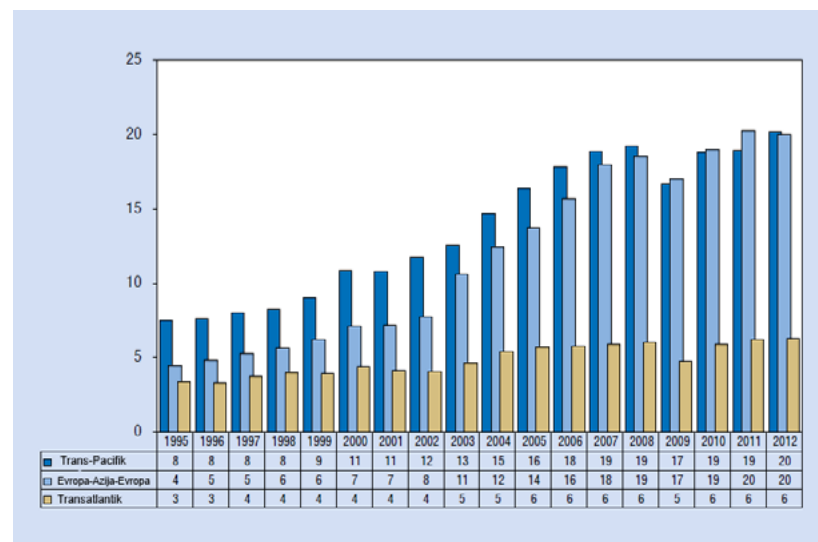
Source: Internet, <https://gcaptain.com/new-satellite-data-reveals-major-uptick-in-global-maritime-traffic/> (1 September 2025)

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INSOMNIA Why challenges facing the world container shipping industry make for more nightmares than they should, Latest report in a multi-issue series covering value creation in transportation and logistics, American Shipper, July 2008, p. 70.

Global container traffic across the oceans is the basis of the supply chain between continents. In 2012, it amounted to 155 million TEU, an increase of 3.2% compared to 2011. The volume of containers decreased mainly in the east-Ist direction, particularly on the Asia-Europe trade route, by 2.6%. This led to a decrease in imports of electrical machinery, metal products, handbags, telecommunications equipment, and textiles²⁵ (see Graph 3).

Graph 3 - Global container traffic by ocean in the period 1995-2012



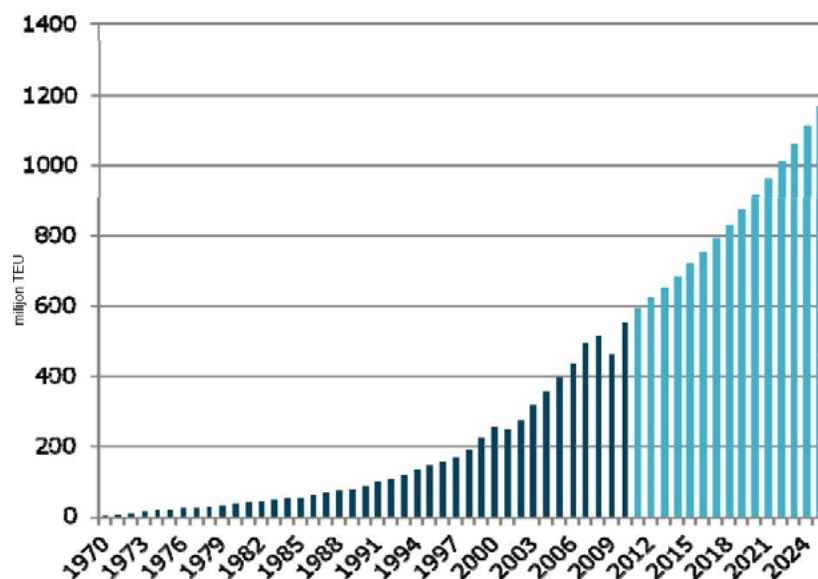
Source: *REVIEW OF MARITIME TRANSPORT 2013, United Nations Conference, New York and Genoa, 2013, p. 24.*

Transpacific container flows in the Asia-North America direction increased by 7.4% in the period 2011-2012, and by 5.2% in the North America-Asia direction. Container flows in the Europe-Asia direction increased by 0.4% in the period 2011-2012, while in

the opposite direction they decreased by 2.6%. Transatlantic container flows between Europe and North America increased by 5.9%, while in the opposite direction, between North America and Europe, they decreased by 6.9%.²⁶

The growth of global container traffic in the period 1970-2012 and the growth forecast until 2024 are shown in Graph 4.

Graph 4 - Global container throughput at maritime container terminals in the period 1970-2012 and growth forecast until 2024



Source: Internet, http://www.nauticalcharts.noaa.gov/ocs/hsrp/archive/mar2007/FutureTrends_3-07.pdf, (11 April 2014).

Graph 4 shows that global container throughput at maritime container terminals will increase by 200% between 2012 and 2024.



3

**ANALYSIS OF CONTAINER
TRANSPORT BETWEEN
THE EASTERN STATES
OF THE USA AND WESTERN
EUROPEAN COUNTRIES**

In analyzing container transport between the Eastern United States and Western European countries, attention should be paid to the following topics: 1) important maritime container terminals in the Eastern United States and Western European countries, and 2) an overview of the volume of container transport from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E).

3.1 MAJOR MARITIME CONTAINER TERMINALS IN THE EASTERN UNITED STATES AND WESTERN EUROPEAN COUNTRIES

The major maritime container terminals in the Eastern United States, through which the largest volume of containers (TEU) is transported, include (cf. Map 4): 1) Boston (Massachusetts) maritime container terminal – PKTB/A, 2) New York (New York) maritime container terminal – PKTN/A, 3) Philadelphia (Pennsylvania) – PKTP/A, 4) Baltimore (Maryland) Maritime Container Terminal – PKTBa/A, 5) Norfolk (Virginia) Maritime Container Terminal – PKTN/A, and 6) Savannah (Georgia) Maritime Container Terminal – PKTS/A.

Map 4 - Major maritime container terminals in the Eastern states USA



Source: Prepared by an author.

Important data on maritime container terminals in the Eastern states of the USA are listed in Table 5.

Table 5 - Important maritime container terminals in the Eastern states of the USA

Maritime container terminal	Capacity (million TEU)	Size (ha)	Transport connection to the interior		
			Road	Rail	River
Boston (Massachusetts) - PKTB/A ²⁷	0.2 ²⁸	34.7	yes	yes	no
New York (New York) - PKTN/A ²⁹	5.5	0	yes	yes	yes
Philadelphia (Pennsylvania) - PKTP/A ³⁰	0.14	56.7 ³¹	yes	yes	yes

27 Internet, <http://www.massport.com/port-of-boston/conley-terminal/terminal-specifications/>, (15 April 2014).

28 Internet, <http://savethecape.org/stcwp1/wp-content/uploads/PDFs/Port%20Capacity%20Report%20Draft120310.pdf>, (15 April 2014).

29 Internet, http://www.nycterminal.com/t3/index.php?id=terminal_overview, (15 April 2014).

30 Internet, <http://www.philaport.com/facilities/packer.htm#>, (15 April 2014).

31 Internet, <http://www.aapa-ports.org/files/SeminarPresentations/WalshJim.pdf>, (25 November 2009).

Baltimore (Maryland) - PKTB/A ³²	0.6 ³³	28	yes	yes	no
Norfolk (Virginia) - PKTN/A ³⁴	0.8	262.2	yes	yes	yes
Savannah (Georgia) - PKTS/A ³⁵	22.5 ³⁶	485.6	yes	yes	no

Source: Prepared by an author.

Among the important Western European maritime container terminals, through which the largest quantity of containers is transported and between which there are transatlantic connections with maritime container terminals in the Eastern states of the United States of America, include: 1) Hamburg (Germany) maritime container terminal – PKTH/E, 2) Rotterdam (Netherlands) – PKTR/E, 3) the Le Havre (France) maritime container terminal – PKTLH/E, and 4) the Antwerp (Belgium) maritime container terminal – PKTA/E.

Map 5 shows the important Western European maritime container terminals under consideration.

- 32 Internet, <http://pobdwerectory.com/terminals.php#intermodal>, (15 April 2014).
- 33 Internet, <http://www.portsamerica.com/portofbaltimore-maryland.html>, (14 April 2014).
- 34 Internet, <http://www.portofvirginia.com/facilities/norfolk-international-terminals.aspx>, (14 April 2014).
- 35 Internet, <http://www.gaports.com/Facilities/GardenCityTerminal/Specifications/tabid/284/Default.aspx>, (15 April 2014).
- 36 Internet, <http://www.gaports.com/portals/2/about/annual%20report/2012/FY2012%20Annual%20Report.pdf>, (14 April 2014).

Map 5 - Major Western European maritime container terminals



Source: Prepared by an author.

Important data on maritime container terminals in Western European countries are listed in Table 6.

Table 6 - Important maritime container terminals in Western European countries

Maritime container terminal	Capacity (million TEU)	Size (ha)	Transport connection		
			Road	Rail	River
Hamburg (Germany) – PKTH/E ³⁷³⁷	13.5	420	yes	yes	yes
Rotterdam (Netherlands) – PKTR/E ³⁸³⁸	125.4	12,426	yes	yes	yes
Le Havre (France) - PKTLH/E ³⁹³⁹	2.2	102	yes	yes	yes
Antwerp (Belgium) - PKTA/E ⁴⁰⁴⁰	15	13,057	yes	yes	yes

Source: Prepared by an author.

37 Internet, <http://www.hafen-hamburg.de/en/article/CTA> and http://www.hk24.de/linkableblob/hhihk24/standortpolitik/downloads/367380/17/data/Port_of_Hamburg_Facts_and_Figures_as_of_May_2012-data.pdf, (14 April 2014).

38 Internet, <http://www.portofrotterdam.com/en/Port/port-statistics/Documents/Port-statistics-2012.pdf>, (14 March 2014).

39 Internet, http://www.worldportsource.com/ports/commerce/FRA_Port_of_Le_Havre_604.php, (14 April 2014).

40 Internet, <http://www.portofantwerp.com/en/containers>, (14 April 2014).

3.2 OVERVIEW OF CONTAINER TRANSPORT VOLUMES FROM MARITIME CONTAINER TERMINALS IN THE EASTERN UNITED STATES (PKT/A) TO MARITIME CONTAINER TERMINALS IN WESTERN EUROPE (PKT/E)

An analysis of the volume of container transport from maritime container terminals in the Eastern United States (PKT/A) to maritime container terminals in Western European countries (PKT/E) is shown in Table 7.

Table 7 - Transported quantity⁴¹ containers in year 2012 from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E)

Maritime container terminals in the Eastern United States	Maritime container terminals in Western European countries				Total TEU volume
	Rotterdam	Antwerp	Hamburg	Le Havre	
<i>Boston</i>					
Quantity in TEU	22,174	33,500	1,921	-	57,595
<i>Trans. cont. price (€/TEU)⁴²</i>	270	268	287	252	
<i>Transport time (days)</i>	1	13	14	12	

41 Internet, http://www.marad.dot.gov/library_landing_page/data_and_statistics/Data_and_Statistics.htm; <http://www.haropaports.com/>; http://www.apl.com/wps/wcm/connect/3a7aa600427564408b2adbdb45abdaff/europe_north_america.html?MOD=AJPERES; http://www.hk24.de/linkableblob/hhihk24/standortpolitik/downloads/367380/17/data/Port_of_Hamburg_Facts_and_Figures_as_of_May_2012-data.pdf, (28 April 2014).

42 Internet, <http://www.kline.com/KAMSurcharges/Surcharges-TransAtlantic-Eastbound.asp>, (28 April 2014).

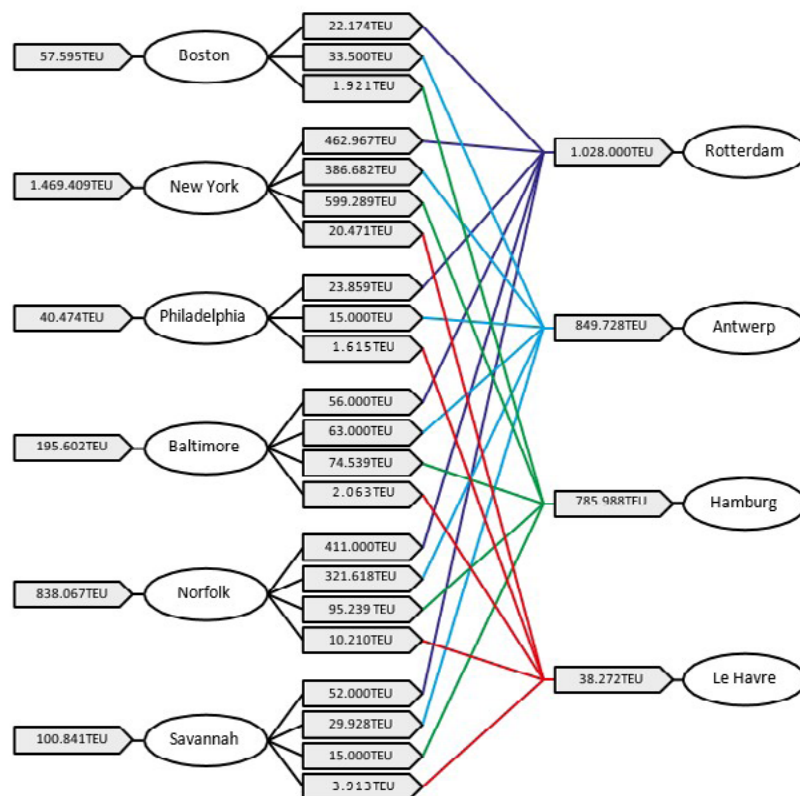
<i>New York</i>					
Quantity TEU	462,967	386,682	599,289	20,471	1,469,409
<i>Trans. cont. price (€/TEU)</i>	<i>282</i>	<i>298</i>	<i>301</i>	<i>266</i>	
<i>Transport time (days)</i>	<i>15</i>	<i>11</i>	<i>13</i>	<i>12</i>	
<i>Philadelphia</i>					
Quantity TEU	23,859	15,000	-	1,615	40,474
<i>Trans. cost (€/TEU)</i>	<i>294</i>	<i>255</i>	<i>330</i>	<i>285</i>	
<i>Transport time (days)</i>	<i>14</i>	<i>14</i>	<i>15</i>	<i>13</i>	
<i>Baltimore</i>					
TEU volume	56,000	63,000	74,539	2,063	195,602
<i>Trans. cost (€/TEU)</i>	<i>305</i>	<i>306</i>	<i>325</i>	<i>285</i>	
<i>Transport time (days)</i>	<i>14</i>	<i>13</i>	<i>15</i>	<i>13</i>	
<i>Norfolk</i>					
Volume TEU	411,000	321,618	95,239	10,210	838,067
<i>Trans. cont. price (€/TEU)</i>	<i>295</i>	<i>296</i>	<i>315</i>	<i>280</i>	
<i>Transport time (days)</i>	<i>17</i>	<i>13</i>	<i>13</i>	<i>10</i>	
<i>Savannah</i>					
Quantity TEU	52,000	29,928	15,000	3,913	100,841
<i>Trans. cont. price (€/TEU)</i>	<i>328</i>	<i>328</i>	<i>344</i>	<i>312</i>	
<i>Transport time (days)</i>	<i>19</i>	<i>15</i>	<i>17</i>	<i>12</i>	
Total quantity received (TEU)	1,028,000	849,728	785,988	38,272	2,701,988
MINIMUM CONTAINER TRANSPORT COST (TEU): 802,736,411 €					

Source: Prepared by an author based on research into container transport across the Atlantic Ocean.

A graphical representation of the volume of containers transported in 2012 from maritime container terminals in the Eastern

United States (PKT/A) to maritime container terminals in Western Europe (PKT/E) is shown in Diagram 1.

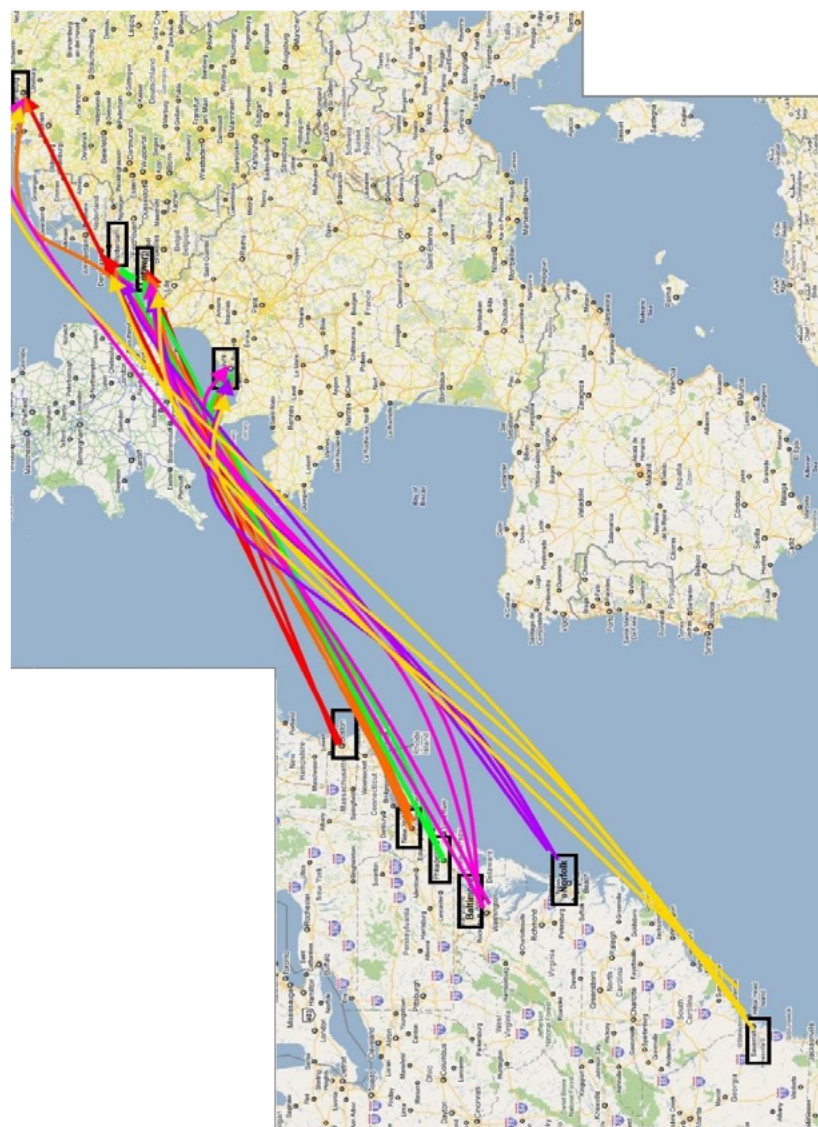
Diagram 1 - Display of the volume of container transport from maritime container terminals in the Eastern United States (PKT/A) to maritime container terminals in Western European countries (PKT/E)



Source: Prepared by an author based on research into container transport across the Atlantic Ocean.

Map 6 shows transatlantic container shipping routes between maritime container terminals in the Eastern United States and maritime container terminals in Western European countries across the Atlantic Ocean in 2012.

Map 6 - Ocean container transport routes between maritime container terminals in the Eastern United States and maritime container terminals in Western European countries across the Atlantic Ocean in 2012



Source: Prepared by an author based on research into container transport across the Atlantic Ocean.

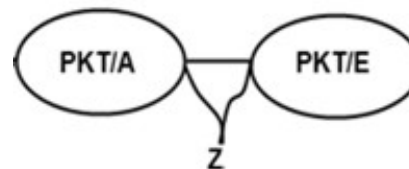


4

**OPTIMIZATION AND
OPTIMIZATION MODELS
FOR CONTAINER TRANSPORT
FROM THE EASTERN UNITED
STATES TO WESTERN EUROPE**

In order to optimally solve the integer problem of container transport from the Eastern United States to Western European countries, attention must be paid to the following topics: 1) model formulation of container transport by sea between maritime container terminals in the Eastern United States (PKT/A) and Western European countries (PKT/E), integer linear programming method, 2) model formulation of container transport by sea between maritime container terminals in the Eastern United States (PKT/A) and Western European countries (PKT/E), taking into account the level of development of maritime container terminals in Western European countries S_r , integer linear programming method, 3) model formulation of container transport by sea between maritime container terminals in the Eastern United States (PKT/A) and Western European countries (PKT/E), integer linear programming method, 4) model formulation of container transport by sea between maritime container terminals in Eastern US states (PKT/A) and Western European countries (PKT/E), taking into account the level of development of maritime container terminals in Western European countries S_r , integer linear programming method, 5) assessment of the level of development of maritime container terminals, 6) projection of the model of container transport from the Eastern United States to Western European countries, 7) results of the new model of container transport from Eastern US states to Western European countries, and 8) impact of the optimization model of container transport from Eastern US states to Western European countries on sustainable transport development.

The model formulation of container transport by sea from the Eastern US to Western European countries is shown as:



PKT/A – Maritime container terminals in the Eastern United States

PKT/E – Maritime container terminals in Western European countries

Z – dedicated variable for container transport prices

4.1 MODEL FORMULATION OF CONTAINER TRANSPORT BY SEA BETWEEN MARITIME CONTAINER TERMINALS IN THE EASTERN UNITED STATES (PKT/A) AND WESTERN EUROPEAN COUNTRIES (PKT/E), INTEGER LINEAR PROGRAMMING METHOD (PRICE OPTIMIZATION)

The problem of optimizing container transport by sea between PKT/A and PKT/E is defined as follows.

Let us denote by x_{ij} the vector of variables, i.e., the number of containers (TEU) that I need to transport from source i - (PKT/A) to consumer j - (PKT/E), and by c_{ij} the vector of transport prices (constants) by number of containers (TEU). I have m origins with capacities a_i units and n consumers with needs b_{ij} units, Z_1 is the transport price [€].

Objective function:

$$Z_1 = \sum_{i=1}^m \sum_{j=1}^n c_{ij} x_{ij} \rightarrow \min \quad [\text{€}] \quad (5)$$

Under the conditions:

$$\sum_{j=1}^n x_{ij} = a_i \quad i=1, 2, \dots, m \quad (6)$$

$$\sum_{i=1}^m x_{ij} = b_j \quad j=1, 2, \dots, n \quad (7)$$

$$x_{ij} \geq 0 \quad i=1, 2, \dots, m \quad j=1, 2, \dots, n \quad (8)$$

4.2 MODEL FORMULATION OF CONTAINER TRANSPORT BY SEA BETWEEN MARITIME CONTAINER TERMINALS IN THE EASTERN UNITED STATES (PKT/A) AND WESTERN EUROPE (PKT/E), TAKING INTO ACCOUNT THE LEVEL OF DEVELOPMENT OF MARITIME CONTAINER TERMINALS IN WESTERN EUROPEAN COUNTRIES S_R , INTEGER LINEAR PROGRAMMING METHOD (PRICE OPTIMIZATION)

The problem of optimizing the transport of containers by sea between PKT/A and PKT/E is defined as follows:

Let us denote by x_{ij} the vector of variables, i.e., the number of containers (TEU) that I need to transport from source i - (PKT/A) to consumer j - (PKT/E), by u_j the vector of attractiveness of maritime container terminals in Western European countries, and by S_{r_j} vector of the degree of development of maritime container terminals in Western European countries. I have m origins with capacities a_i units and n consumers with needs b_j units, Z_2 is the price of transport [€].

Intended function:

$$Z_2 = \sum_{i=1}^m \sum_{j=1}^n u_j S_{r_j} x_{ij} \rightarrow \min \quad [\text{€}] \quad (9)$$

Under the conditions:

$$\sum_{j=1}^n x_{ij} = a_i \quad i=1, 2, \dots, m \quad (10)$$

$$\sum_{i=1}^m x_{ij} = b_j \quad j=1, 2, \dots, n \quad (11)$$

$$x_{ij} \geq 0 \quad i=1, 2, \dots, m \quad j=1, 2, \dots, n \quad (12)$$

4.3 MODEL FORMULATION OF CONTAINER TRANSPORT BY SEA BETWEEN MARITIME CONTAINER TERMINALS IN THE EASTERN UNITED STATES (PKT/A) AND WESTERN EUROPE (PKT/E), INTEGER LINEAR PROGRAMMING METHOD (TIME AND COST OPTIMIZATION)

First, I perform integer linear programming of container transport time and, on this basis (according to the modified profit matrix), optimize the price of container transport.

- a. *In the first phase, integer linear programming of container transport time is performed.*

Let us denote by x_{ij} the vector of variables, i.e., the number of containers (TEU) that I need to transport from source i - (PKT/A) to consumer j - (PKT/E), and by t_{ij} the vector of transport time (constants) by number of containers (TEU). I have m origins with capacities a_i units and n consumers with needs b_j units, Z_{3T} is the total transport time [days].

Objective function:⁴³

$$Z_{3T} = \sum_{i=1}^m \sum_{j=1}^n t_{ij} x_{ij} \rightarrow \min \quad [days] \quad (13)$$

Under the conditions:

$$\sum_{j=1}^n t_{ij} = a_i \quad i = 1, 2, \dots, n \quad (14)$$

$$\sum_{i=1}^m t_{ij} = b_j \quad j = 1, 2, \dots, m \quad (15)$$

$$x_{ij} \geq 0 \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \quad (16)$$

- b. *In the second phase, integer linear programming of container transport prices is performed.*

Let us denote by x_{ij} the vector of variables, i.e., the number of containers (TEU) that I need to transport from source i - (PKT/A) to consumer j - (PKT/E), and by c_{ij} the vector of transport prices (constants) by number of containers (TEU). I have m origins with capacities a_i units and n consumers with needs b_j units, Z_{3c} is the total transport price [€].

Objective function:

$$Z_{3c} = \sum_{i=1}^m \sum_{j=1}^n c_{ij} x_{ij} \rightarrow \min \quad [\text{€}] \quad (17)$$

$$\sum_{j=1}^n x_{ij} = a_i \quad i = 1, 2, \dots, m \quad (18)$$

$$\sum_{i=1}^m x_{ij} = b_j \quad j = 1, 2, \dots, n \quad (19)$$

$$x_{ij} \geq 0 \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \quad (20)$$

In accordance with Hammer, I modify the profit matrix:

$$c_{ij} = \begin{cases} c_{ij} & \text{if } t_{ij} < T \\ 0 & \text{if } t_{ij} \geq T \end{cases} \quad (21)$$

4.4 MODEL FORMULATIONS FOR THE TRANSPORT OF CONTAINERS BY SEA BETWEEN MARITIME CONTAINER TERMINALS IN THE EASTERN UNITED STATES (PKT/A) AND WESTERN EUROPE (PKT/E), TAKING INTO ACCOUNT THE LEVEL OF DEVELOPMENT OF MARITIME CONTAINER TERMINALS IN WESTERN EUROPEAN COUNTRIES S_R , INTEGER LINEAR PROGRAMMING METHOD (OPTIMIZATION OF TIME AND PRICE)

First, I perform integer linear programming of container transport time and, on this basis (according to the modified profit matrix), I optimize the price of container transport.

- a. In the first phase, integer linear programming of container transport time is performed.

Let us denote by x_{ij} the vector of variables, i.e., the number of containers (TEU) that I need to transport from source i - (PKT/A) to consumer j - (PKT/E), and by t_{ij} the vector of transport time (constants) by number of containers (TEU). I have m origins with capacities a_i units and n consumers with needs b_j units, Z_{4T} is the total transport time [days].

Objective function:⁴⁴

$$Z_{4T} = \sum_{i=1}^m \sum_{j=1}^n t_{ij} x_{ij} \rightarrow \min \quad [\text{days}] \quad (22)$$

Under the conditions:

$$\sum_{j=1}^n t_{ij} = a_i \quad i = 1, 2, \dots, n \quad (23)$$

$$\sum_{i=1}^m t_{ij} = b_j \quad j = 1, 2, \dots, m \quad (24)$$

$$i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \quad (25)$$

- b. In the second phase, integer linear programming of container transport prices is performed.

Let us denote by x_{ij} the vector of variables, i.e., the number of containers (TEU) that I need to transport from source i - (PKT/A) to consumer j - (PKT/E), and by c_{ij} the vector of transport costs (constants) by number of containers (TEU), with u_j vector of attractiveness of maritime container terminals in Western European countries and with S_{rj} vector of the degree of development of maritime container terminals in Western European countries. I have m sources with capacities a_i units and n consumers with needs b_j units, Z_{4C} is the transport price [€].

Objective function:

$$Z_{4C} = \sum_{i=1}^m \sum_{j=1}^n u_j S_{rj} x_{ij} \rightarrow \min \quad [\text{€}] \quad (26)$$

$$\sum_{j=1}^n x_{ij} = a_i \quad i = 1, 2, \dots, m \quad (27)$$

$$\sum_{i=1}^m x_{ij} = b_j \quad j = 1, 2, \dots, n \quad (28)$$

$$x_{ij} \geq 0 \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \quad (29)$$

In accordance with Hammer, I modify the profit matrix:

$$c_{ij} = \begin{cases} u_j S_{rj} & \text{if } t_{ij} < T \\ 0 & \text{if } t_{ij} \geq T \end{cases} \quad (30)$$

4.5 ASSESSMENT OF THE LEVEL OF DEVELOPMENT OF MARITIME CONTAINER TERMINALS

The areas listed in Figure 4 are key to establishing a vision for the future development of maritime transport. They will contribute to change and overcoming obstacles, to the development of new innovations and the establishment of a global and national operational structure, which will also contribute to the development of a sustainable society and an efficient transport system.⁴⁵

Since 2007, the World Bank has been compiling the Logistics Performance Index (LPI), which allows for international comparison of the efficiency of certain logistics processes and identification of opportunities for improvement. The Logistics Performance Index shows how approximately 1,000 international logistics professionals in 130 countries assess the efficiency of logistics in a given country in six areas (customs, infrastructure, international shipments, logistics competencies, tracking and tracing, and timeliness). The Logistics Performance Index is derived from a global survey of carriers and freight forwarders. The areas are rated from 0 to 5.⁴⁶ The Logistics Performance Index for 2014 is based on 1,200 indicators.⁴⁷ It is difficult to obtain accurate data for determining the Logistics Performance

45 RODRIGUE, J.-P.: **Maritime Transportation: Drivers for the Shipping and Port Industries**, International Transport Forum 2010, Transport and Innovation: Unleashing the Potential, Paper Commissioned for the Experts 'Session on Innovation and the Future of Transport', Paris, January 2010, p. 2.

46 ARVIS, J., MUSTRA, M., OJALA, L., SHEPHERD, B., SASLOVSKY, D., BUSCH, C., RAJ, A.: **Connecting to Compete 2014, Trade Logistics in the Global Economy, The Logistics Performance Index and Its Indicators**, The International Bank for Reconstruction and Development/The World Bank, Washington, 2014, p. 7. <http://www.worldbank.org/content/dam/Worldbank/document/Trade/LPI2014.pdf>, (14 April 2014).

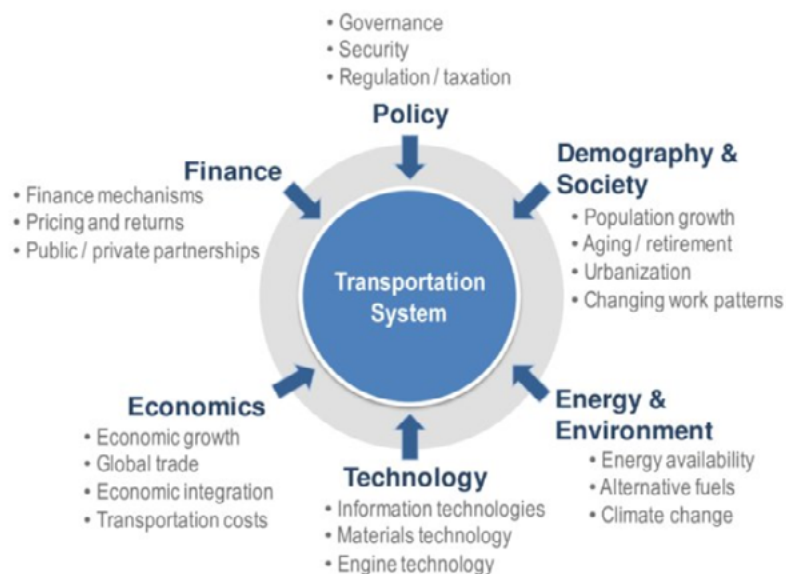
47 Internet, <http://data.worldbank.org/indicator/LP.LPI.OVRL.XQ>, (14 April 2014).

Index, as it is based on theoretical and empirical research and is difficult to measure. The LPI covers the entire supply chain, while the level of development of maritime container terminals S_i shows the importance and influence of maritime container terminals in the transport of containers in global maritime liner container transport and also influences the supply chain. The LPI covers areas similar to the elements used to calculate S_i , maritime transport, the quality of infrastructure in maritime container terminals, traffic flows, transshipments in maritime container terminals, information technology infrastructure, and crime (stolen cargo).

The selected model elements (transport infrastructure and transport superstructure, impact of intelligent information systems, gross domestic product, transport ecology, transport flows, innovation, safety and security, and transport energy) for determining the level of development of maritime container terminals S_i cover approximately 95% of all areas that are also important for determining the indices in the LPI calculation. However, the selected elements of the model can be measured and calculated more accurately than the indicators used to calculate the LPI.

In order for managers to perform important and complex tasks in container transport in a high-quality and competent manner, they must be familiar with the following eight important elements of the container transport model, which are derived from the main areas shown in Figure 4 which are most important for carriers in the future and influence the calculation of the level of development of maritime container terminals in the Eastern United States and Western European countries $S_{(i)}$: 1) transport infrastructure and transport superstructure, 2) the impact of intelligent information systems, 3) gross domestic product, 4) transport ecology, 5) transport flows, 6) innovation, 7) safety and security, and 8) transport energy.

Figure 4 - Impact of important areas on carriers for the future of maritime transport



Source: *ICF International, Long Range Strategic Issues Facing the Transportation Industry, Final Future-focused Research Framework, National Cooperative Highway Research Program, Project 20-80, 2008, Task 2.*

Eight elements of the container transport model (areas) derived from the key areas that are most important for carriers in the future and influence the calculation of the development level of maritime container terminals in the Eastern United States and Western European countries⁴⁸. Were used to determine and calculate the level of development of maritime container terminals S_r . These elements will have a greater and more significant impact than the areas currently used to determine the logistics efficiency index and are more appropriate, more precisely determinable, and more

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See Figure 4, p. 60

measurable (published annual statistics and annual report data) for maritime container terminals. To calculate the level of development of the maritime container terminals S_r in the Eastern United States and Western European countries, statistical data for 2012 are used, and for the calculation of data for 2024, the forecast of global container throughput at maritime container terminals in the period 1970-2024 and the GDP growth for each country until 2024 where the maritime container terminals in question are located. The more accurate the input values of the container transport model elements are, the more accurate the calculation of the development level of maritime container terminals will be. By investing financial resources in the development of model elements, I can influence the competitiveness between maritime container terminals.

The level of development of maritime container terminals S_{r_t} can be defined as follows:

$$S_{r_t} = f_v \sum_{v=1}^p \left(\frac{y_{v,t} - y_{v,t-1}}{y_{v,t}} \right) \quad v=1,2,...,p \quad (31)$$

$$S_{r_i} = f_1 \times S_{r_1} + f_2 \times S_{r_2} + f_3 \times S_{r_3} + f_4 \times S_{r_4} + f_5 \times S_{r_5} + f_6 \times S_{r_6} + f_7 \times S_{r_7} + f_8 \times S_{r_8} \quad (32)$$

$$\sum_{v=1}^p f_v = 1 \quad (33)$$

$$f_v = \frac{r_v}{\sum_{v=1}^p r_v} \quad (34)$$

Where:

- y_v - the state of the value of the container transport model element transport infrastructure and superstructure: $v = 1$
impact of the intelligent information system: $v = 2$
gross domestic product: $v = 3$
transport ecology: $v = 4$
transport flows: $v = 5$
innovations: $v = 6$
safety and security: $v = 7$
transport energy: $v = 8$
- t - year
- f_v - factor influencing individual elements of the container transport model
- r_v - level of development of individual elements of the container transport model
- u - attractiveness of maritime container terminals
- c_v - price of container transport

This study also redefines the concept of the attractiveness of maritime container terminals.

The attractiveness of maritime container terminals - tells us which maritime container terminal generates the largest volume of container traffic transported by sea from maritime container terminals in individual countries

I define the attractiveness of maritime container terminals as follows:

$$u = \frac{c_v}{S_{r_v}} \quad (35)$$

Where:

C_v - transport price per number of containers

S_{rv} - level of development of the maritime container terminal

The attractiveness of maritime container terminals can influence: 1) more flexible maritime line connections, 2) lower transshipment costs for container carriers, 3) companies selling products to save on repositioning costs - adjusting their position to changed market conditions, 4) maritime liner container transport carriers to use large container ships, which bring lower fuel and labor costs to the economy, and 5) the density of hinterland networks between smaller seaports, where container ship utilization is currently between 50% and 70%.⁴⁹ Large container ships will thus be able to transport containers between maritime container terminals with greater attractiveness in order to achieve a high level of utilization.

Level of development of maritime container *terminals* ($S_{r(t)}$) is functionally dependent on the following elements of the container transport model:⁵⁰

- **transport infrastructure and superstructure** ($\Delta y_{1,t}$)

$$S_{r_t} = f_v \sum_{v=1}^p \left(\frac{y_{1,t} - y_{1,t-1}}{y_{1,t}} \right) \quad (36)$$

At level development maritime container terminals (S_{r_t}) element transport infrastructure and superstructure (y_1) influence with the following influencing factor, i.e. the amount investments

49 Balancing the Imbalances in Container Shipping, A.T Kearney, Inc., 2012, p. 1-10. http://www.atkearney.com/documents/10192/254830/Balancing_the_Imbalances_in_Container_Shipping_.pdf/d4a46d4a-d42f-4738-9b37-6343698d1007, (29 December 2012).

50 Cf. Table 8, p. 70.

intended the infrastructure and superstructure of the maritime container terminal in question.

$$y_{1,t} = \sum_{v=1}^p a_{1,t} \quad (37)$$

$$y_{1,t-1} = \sum_{v=1}^p a_{1,t-1} \quad (38)$$

$$S_{r_t} = f_v \left(\frac{\sum_{v=1}^p a_{1,t} - a_{1,t-1}}{\sum_{v=1}^p a_{1,t}} \right) \quad (39)$$

- **impact of the intelligent information system** ($\Delta y_{2,t}$)

$$S_{r_t} = f_v \sum_{v=1}^p \left(\frac{y_{2,t} - y_{2,t-1}}{y_{2,t}} \right) \quad (40)$$

At level of container terminals (S_{r_t}) element impact of the intelligent information system (y_2) influence with the following influencing factor, i.e. amount of investment planned for the development intelligent information system for the maritime container terminal in question.

$$y_{2,t} = \sum_{v=1}^p a_{2,t} \quad (41)$$

$$y_{2,t-1} = \sum_{v=1}^p a_{2,t-1} \quad (42)$$

$$S_{r_t} = f_v \left(\frac{\sum_{v=1}^p a_{2,t} - a_{2,t-1}}{\sum_{v=1}^p a_{2,t}} \right) \quad (43)$$

- **gross domestic product** ($\Delta y_{3,t}$)

$$S_{r_t} = f_v \sum_{v=1}^p \left(\frac{y_{3,t} - y_{3,t-1}}{y_{3,t}} \right) \quad (44)$$

On the level of development of maritime container terminals (S_{r_t}) element gross domestic product (y_3) is influenced by the following influencing factor, i.e. the value of the GDP index for individual country.

$$y_{3,t} = \sum_{v=1}^p a_{3,t} \quad (45)$$

$$y_{3,t-1} = \sum_{v=1}^p a_{3,t-1} \quad (46)$$

$$S_{r_t} = f_v \left(\frac{\sum_{v=1}^p a_{3,t} - a_{3,t-1}}{\sum_{v=1}^p a_{3,t}} \right) \quad (47)$$

- **traffic ecology** ($\Delta y_{4,t}$)

$$S_{r_t} = f_v \sum_{v=1}^p \left(\frac{y_{4,t} - y_{4,t-1}}{y_{4,t}} \right) \quad (48)$$

The degree of development of maritime container terminals (S_{r_t}) element transport ecology (y_4) is influenced by the following influencing factor, i.e. investments aimed at improving nature and environmental protection for the maritime container terminal in question.

$$y_{4,t} = \sum_{v=1}^p a_{4,t} \quad (49)$$

$$y_{4,t-1} = \sum_{v=1}^p a_{4,t-1} \quad (50)$$

$$S_{r_t} = f_v \left(\frac{\sum_{v=1}^p a_{4,t} - a_{4,t-1}}{\sum_{v=1}^p a_{4,t}} \right) \quad (51)$$

▪ **traffic flows** ($\Delta y_{5,t}$)

$$S_{r_t} = f_v \sum_{v=1}^p \left(\frac{y_{5,t} - y_{5,t-1}}{y_{5,t}} \right) \quad (52)$$

The level of development of maritime container terminals (S_{r_t}) is influenced by the traffic element (y_5) with the following influencing factor: container volume.

$$y_{5,t} = \sum_{v=1}^p a_{5,t} \quad (53)$$

$$y_{5,t-1} = \sum_{v=1}^p a_{5,t-1} \quad (54)$$

$$S_{r_t} = f_v \left(\frac{\sum_{v=1}^p a_{5,t} - a_{5,t-1}}{\sum_{v=1}^p a_{5,t}} \right) \quad (55)$$

- **innovations** ($\Delta y_{6,t}$)

$$S_{r_t} = f_v \sum_{v=1}^p \left(\frac{y_{6,t} - y_{6,t-1}}{y_{6,t}} \right) \quad (56)$$

The level of development of maritime container terminals (S_{r_t}) innovation element (y_6) is influenced by the following influencing factor, i.e. the amount of investment planned for the area of innovation in maritime container terminals.

$$y_{6,t} = \sum_{v=1}^p a_{6,t} \quad (57)$$

$$y_{6,t-1} = \sum_{v=1}^p a_{6,t-1} \quad (58)$$

$$S_{r_t} = f_v \left(\frac{\sum_{v=1}^p a_{6,t} - a_{6,t-1}}{\sum_{v=1}^p a_{6,t}} \right) \quad (59)$$

- **safety and security** ($\Delta y_{7,t}$)

$$S_{r_t} = f_i \sum_{v=1}^p \left(\frac{y_{7,t} - y_{7,t-1}}{y_{7,t}} \right) \quad (60)$$

The level of development of maritime container terminals (S_{r_t}) security and security (y_7) is influenced by the following influencing factor, i.e. the amount of investment planned for safety and security for the maritime container terminal in question.

$$y_{7,t} = \sum_{v=1}^p a_{7,t} \quad (61)$$

$$y_{7,t-1} = \sum_{v=1}^p a_{7,t-1} \quad (62)$$

$$S_{r_t} = f_v \left(\frac{\sum_{v=1}^p a_{7,t} - a_{7,t-1}}{\sum_{v=1}^p a_{7,t}} \right) \quad (63)$$

- **traffic energy** ($\Delta y_{8,t}$)

$$S_{r_t} = f_v \sum_{v=1}^p \left(\frac{y_{8,t} - y_{8,t-1}}{y_{8,t}} \right) \quad (64)$$

The level of development of maritime container terminals (S_{r_t}) element traffic energy (y_8) is influenced by the following influencing factor: investments aimed at reducing energy consumption.

$$y_{8,t} = \sum_{v=1}^p a_{8,t} \quad (65)$$

$$y_{8,t-1} = \sum_{v=1}^p a_{8,t-1} \quad (66)$$

$$S_{r_t} = f_v \left(\frac{\sum_{v=1}^p a_{8,t} - a_{8,t-1}}{\sum_{v=1}^p a_{8,t}} \right) \quad (67)$$

4.6 PROJECTION OF THE MODEL FOR CONTAINER TRANSPORT FROM THE EASTERN UNITED STATES TO WESTERN EUROPEAN COUNTRIES

This projection of the container transport model can be divided into two thematic units: 1) planning the elements of the development of the model of container transport from the Eastern states of the USA to the countries of Western Europe, and 2) calculating the degree of development of the elements of the model of container transport from the Eastern states of the USA to the countries of Western Europe.

4.6.1. PLANNING ELEMENTS FOR THE DEVELOPMENT OF A CONTAINER TRANSPORT MODEL FROM EASTERN US STATES TO WESTERN EUROPEAN COUNTRIES

To determine the values of the elements of the container transport model (transport infrastructure, transport superstructure, impact of the intelligent information system, gross domestic product, transport ecology, transport flows, innovation, safety and security, and transport energy), published statistical data from the

ten maritime container terminals under consideration, through which the largest volume of containers was transported in 2012, and are shown in the tables below.

Table 8 - Evaluation of elements of the container transport model
for maritime container terminal New York

Elements of the containers transport model	Input y_{it}		Increase
	2012	2024	$y_{i, 2024}$
1	2	3	4
1. Transport infrastructure and transport superstructure ⁵¹	25 x 10⁹ \$	42 x 10⁹ \$ (value calculated based on 1.7% GDP growth)	17 x 10⁹ \$
2. Impact of intelligent information systems ⁵²	580 x 10⁶ \$	696 x 10⁶ \$ (1.7% GDP growth)	116 x 10⁶ \$
3. Gross domestic product ⁵³	14,991 x 10⁹ \$	25,485 x 10⁹ \$ (value calculated based on 1.7% GDP growth)	10,494 x 10⁹ \$
4. Traffic ecology ⁵⁴	4.9 x 10⁶ \$	8.3 x 10⁶ \$	3.4 x 10⁶ \$ (taking into account 1.7% GDP growth)
5. Traffic flows ⁵⁵	4.2 x 10⁶ TEU	8.4 x 10⁶ TEU	4.2 x 10⁶ TEU

51 Internet, <http://www.panynj.gov/corporate-information/pdf/annual-report-2012.pdf>, (24 April 2014).

52 Internet, <http://www.panynj.gov/corporate-information/pdf/annual-report-2012.pdf>, (24 April 2014).

53 Internet, <http://www.tradingeconomics.com/united-states/gdp>, <https://www.conference-board.org/data/globaloutlook.cfm>, (24 April 2014).

54 Internet, <http://www.panynj.gov/corporate-information/pdf/annual-report-2012.pdf>, (24 April 2014).

55 Internet, http://www.marad.dot.gov/library_landing_page/data_and_statistics/Data_and_Statistics.htm, 24 April 2014. (Based on a 201% growth in global container throughput by 2024, according to the source: Internet, http://www.nauticalcharts.noaa.gov/ocs/hsrp/archive/mar2007/FutureTrends_3-07.pdf, 11 April 2014).

6. Innovation ⁵⁶	2 x 10⁹ \$	3.4 x 10⁹ \$ (1.7% GDP growth)	1.4 x 10⁹ \$
7. Security and safety ⁵⁷	115 x 10⁶ \$	195 x 10⁶ \$ (1.7% GDP growth)	80 x 10⁶ \$
8. Traffic energy ⁵⁸	12 x 10⁶ \$	20 x 10⁶ \$	8 x 10⁶ \$

Source: Prepared by the author based on source material.

Table 9 - Evaluation of elements of the container transport model
for the container terminal Boston

Elements of the container transport model	Input y_{it}		Increase
	2012	2024	y_i 2024
1	2	3	4
1. Transport infrastructure and transport superstructure ⁵⁹	94 x 10⁶ \$	160 x 10⁶ \$ (value calculated based on 1.7% GDP growth)	66 x 10⁶ \$
2. Impact of intelligent information systems ⁶⁰	21 x 10⁶ \$	36 x 10⁶ \$ (value calculated based on GDP)	15 x 10⁶ \$
3. Gross domestic product ⁶¹	14,991 x 10⁹ \$	25,485 x 10⁹ \$ (value calculated based on 1.7% GDP growth)	10,494 x 10⁹ \$

56 Internet, <http://www.panynj.gov/corporate-information/pdf/annual-report-2012.pdf>, (24 April 2014).

57 Internet, http://ec.europa.eu/transport/maritime/studies/doc/2009_04_scanning_containers.pdf, (6 December 2009).

58 Internet, <http://www.panynj.gov/corporate-information/pdf/annual-report-2012.pdf>, (24 April 2014).

59 Internet, https://www.massport.com/media/8006/FY2012_CAFR.pdf, (24 April 2014).

60 Internet, https://www.massport.com/media/8006/FY2012_CAFR.pdf, (24 April 2014).

61 Internet, <http://www.tradingeconomics.com/united-states/gdp>, <https://www.conference-board.org/data/globaloutlook.cfm>, (24 April 2014).

4.	Transport ecology ⁶²	23.1 x 10 ⁶ \$	39.3 x 10 ⁶ \$ (1.7% GDP growth)	16.2 x 10 ⁶ \$
5.	Traffic flows ⁶³	57,602 TEU	115,204 TEU	57,602 TEU
6.	Innovation ⁶⁴	1.5 x 10 ⁶ \$	2.5 x 10 ⁶ \$ (1.7% GDP growth)	1 x 10 ⁶ \$
7.	Security and safety ⁶⁵	61 x 10 ⁶ \$	104 x 10 ⁶ \$	43 x 10 ⁶ \$
8.	Traffic energy ⁶⁶	11 x 10 ⁶ \$	18.7 x 10 ⁶ \$	7.7 x 10 ⁶ \$

Source: Prepared by the author based on source material.

Table 10 - Evaluation of elements of the container transport model
for the container terminal Philadelphia

Elements of the container transport model	Input y_{it}		Increase
	2012	2024	y_i 2024
1	2	3	4
1. Transport infrastructure and transport superstructure ⁶⁷	95 x 10 ⁶ \$	161 x 10 ⁶ \$ (value calculated based on 1.7% GDP growth)	66 x 10 ⁶ \$

62 Internet, https://www.massport.com/media/8006/FY2012_CAFR.pdf, (24 April 2014).

63 Internet, http://www.marad.dot.gov/library_landing_page/data_and_statistics/Data_and_Statistics.htm, 24 April 2014. (Based on a 201% growth in global container throughput by 2024, according to the source: Internet, http://www.nauticalcharts.noaa.gov/ocs/hsrp/archive/mar2007/FutureTrends_3-07.pdf, 11 April 2014).

64 Internet, https://www.massport.com/media/8006/FY2012_CAFR.pdf, (24 April 2014).

65 Internet, http://ec.europa.eu/transport/maritime/studies/doc/2009_04_scanning_containers.pdf, (6 December 2009).

66 Internet, https://www.massport.com/media/8006/FY2012_CAFR.pdf, (24 April 2014).

67 Internet, http://www.philaport.com/news/newsletters/pdfs/29_issue.pdf, (24 April 2014).

2.	Impact of intelligent information systems ⁶⁸	152 x 10⁶ \$	258 x 10⁶ \$ (1.7% growth in GDP value)	106 x 10⁶ \$
3.	Gross domestic product ⁶⁹	14,991 x 10⁹ \$	25,485 x 10⁹ \$ (value calculated based on 1.7% GDP growth)	10,494 x 10⁹ \$
4.	Transport ecology ⁷⁰	36 x 10⁶ \$	61 x 10⁶ \$ (1.7% GDP growth)	25 x 10⁶ \$ (1.7% GDP growth taken into account)
5.	Traffic flows ⁷¹	47,483 TEU	80,721 TEU	33,238 TEU
6.	Innovation ⁷²	42 x 10⁶ \$	71 x 10⁶ \$ (1.7% GDP growth)	29 x 10⁶ \$
7.	Security and safety ⁷³	300 x 10⁶ \$	510 x 10⁶ \$	210 x 10⁶ \$ (1.7% GDP growth taken into account)
8.	Traffic energy ⁷⁴	36 x 10⁶ \$	61 x 10⁶ \$ (1.7% GDP growth)	25 x 10⁶ \$

Source: Prepared by the author based on source material.

- 68 Internet, http://www.philaport.com/news/newsletters/pdfs/29_issue.pdf, (24 April 2014).
- 69 Internet, <http://www.tradingeconomics.com/united-states/gdp>, <https://www.conference-board.org/data/globaloutlook.cfm>, (24 April 2014).
- 70 Internet, http://www.dot.gov/sites/dot.dev/files/docs/TIGER_2013_FactSheets_0.pdf, (24 April 2014).
- 71 Internet, http://www.marad.dot.gov/library_landing_page/data_and_statistics/Data_and_Statistics.htm, 24 April 2014. (Based on a 201% growth in global container throughput by 2024, according to the source: Internet, http://www.nauticalcharts.noaa.gov/ocs/hsrp/archive/mar2007/FutureTrends_3-07.pdf, 11 April 2014).
- 72 Internet, http://www.philaport.com/news/newsletters/pdfs/30_issue.pdf, (24 April 2014).
- 73 Internet, http://www.philaport.com/news/newsletters/pdfs/29_issue.pdf, (24 April 2014).
- 74 Internet, http://www.dot.gov/sites/dot.dev/files/docs/TIGER_2013_FactSheets_0.pdf, (24 April 2014).

Table 11 - Evaluation of elements of the container transport model for maritime container terminal Baltimore

Elements of the container transport model	Input y_{it}		Increase
	2012	2024	y_i 2024
1	2	3	4
1. Transport infrastructure and transport superstructure ⁷⁵	140 x 10 ⁶ \$	238 x 10 ⁶ \$ (value calculated based on 1.7% GDP growth)	98 x 110 ⁶ \$0 ⁽⁶⁾ \$
2. Impact of intelligent information systems ⁷⁶	30 x 10 ⁶ \$	51 x 10 ⁶ \$ (1.7% growth in GDP value)	21 x 10 ⁶ \$
3. Gross domestic product ⁷⁷	14,991 x 10 ⁹ \$	25,485 x 10 ⁹ \$ (1.7% growth in GDP value)	10,494 x 10 ⁹ \$
4. Transport ecology ⁷⁸	1x 10 ⁶ \$	1.7 x 10 ⁶ \$ (1.7% GDP growth)	0.7 x 10 ⁶
5. Traffic flows ⁷⁹	195,602 TEU	391,204 TEU	195,602 TEU

75 Internet, <http://www.pageturnpro.com/The-Daily-Record/49013-Port-of-Baltimore-Report-2013/index.html#/12>, (24 April 2014).

76 Internet, <http://www.pageturnpro.com/The-Daily-Record/49013-Port-of-Baltimore-Report-2013/index.html#/12>, (24 April 2014).

77 Internet, <http://www.tradingeconomics.com/united-states/gdp>, <https://www.conference-board.org/data/globaloutlook.cfm>, (24 April 2014).

78 Internet, http://www.mpa.maryland.gov/_media/client/port-commission/MPCAnnualReport.pdf, (24 April 2014).

79 Internet, http://www.marad.dot.gov/library_landing_page/data_and_statistics/Data_and_Statistics.htm, 24 April 2014. (Based on a 201% growth in global container throughput by 2024, according to the source: Internet, http://www.nauticalcharts.noaa.gov/ocs/hsrp/archive/mar2007/FutureTrends_3-07.pdf, 11 April 2014).

6.	Innovation ⁸⁰	17 x 10 ⁶ \$	29 x 10 ⁶ \$ (1.7% of GDP)	12 x 10 ⁶ \$
7.	Security and safety ⁸¹	4 x 10 ⁶ \$	7 x 10 ⁶ \$ (1.7% GDP growth taken into account)	3 x 10 ⁶ \$
8.	Traffic energy ⁸²	30 x 10 ⁶ \$	51 x 10 ⁶ \$ (1.7% GDP growth)	21 x 10 ⁶ \$

Source: Prepared by the author based on source material.

Table 12 - Evaluation of elements of the container transport model for the container terminal Norfolk

Elements of the container transport model	Input y_{it}		Increase
	2012	2024	y_i 2024
1	2	3	4
1. Transport infrastructure and transport superstructure ⁸³	135 x 10 ⁶ \$	229 x 10 ⁶ \$ (value calculated based on 1.7% GDP growth)	94 x 10 ⁶ \$
2. Impact of intelligent information systems ⁸⁴	12 x 10 ⁶ \$	20 x 10 ⁶ \$ (1.7% growth in GDP)	8 x 10 ⁶ \$

80 Internet, <http://www.pageturnpro.com/The-Daily-Record/49013-Port-of-Baltimore-Report-2013/index.html#/16>, (24 April 2014).

81 Internet, http://www.mpa.maryland.gov/_media/client/port-commission/MPCAnnualReport.pdf, (24 April 2014).

82 Internet, <http://www.pageturnpro.com/The-Daily-Record/49013-Port-of-Baltimore-Report-2013/index.html#/12>, (24 April 2014).

83 Internet, http://www.portofvirginia.com/media/126619/cafr_lb_2013final.pdf, (24 April 2014).

84 Internet, http://www.portofvirginia.com/media/126619/cafr_lb_2013final.pdf, (24 April 2014).

3.	Gross domestic product ⁸⁵	14,991 x 10⁹ \$	25,485 x 10⁹ \$ (1.7% growth in GDP value)	10,494 x 10⁹ \$
4.	Transport ecology ⁸⁶	1.7 x 10⁶ \$	2.9 x 10⁶ \$ (1.7% GDP growth)	1.2 x 10⁶ \$
5.	Traffic flows ⁸⁷	829,063 TEU	1,658,126 TEU	829,063 TEU
6.	Innovation ⁸⁸	13 x 10⁶ \$	22 x 10⁶ \$ (1.7% GDP growth)	9 x 10⁶ \$
7.	Security and safety ⁸⁹	5 x 10⁶ \$	8 x 10⁶ \$	3 x 10⁶ \$ (taking into account 1.7% GDP growth)
8.	Traffic energy ⁹⁰	12 x 10⁶ \$	20 x 10⁶ \$ (1.7% GDP growth)	8 x 10⁶ \$

Source: Prepared by the author based on source material.

85 Internet, <http://www.tradingeconomics.com/united-states/gdp>, <https://www.conference-board.org/data/globaloutlook.cfm>, (24 April 2014).

86 Internet, http://www.portofvirginia.com/media/126619/cafr_lb_2013final.pdf, (24 April 2014).

87 Internet, http://www.marad.dot.gov/library_landing_page/data_and_statistics/Data_and_Statistics.htm, 24 April 2014. (Based on a 201% growth in global container throughput by 2024, according to the source: Internet, http://www.nauticalcharts.noaa.gov/ocs/hsrp/archive/mar2007/FutureTrends_3-07.pdf, 11 April 2014).

88 Internet, http://www.portofvirginia.com/media/126619/cafr_lb_2013final.pdf, (24 April 2014).

89 Internet, http://www.portofvirginia.com/media/126619/cafr_lb_2013final.pdf, (24 April 2014).

90 Internet, http://www.portofvirginia.com/media/126619/cafr_lb_2013final.pdf, (24 April 2014).

Table 13 - Evaluation of elements of the container transport model for the container terminal Savannah

Elements of the container transport model	Input y_{it}		Increase
	2012	2024	y_i 2024
1	2	3	4
1. Transport infrastructure and transport superstructure ⁹¹	22.5 x 10⁶ \$	38.3 x 10⁶ \$ (value calculated based on 1.7% GDP growth)	15.8 x 10⁶ \$
2. Impact of intelligent information systems ⁹²	5 x 10⁶ \$	8.5 x 10⁶ \$ (1.7% GDP growth)	3.5 x 10⁶ \$
3. Gross domestic product ⁹³	14,991 x 10⁹ \$	25,485 x 10⁹ \$ (1.7% growth in GDP value)	10,494 x 10⁹ \$
4. Transport ecology ⁹⁴	4 x 10⁶ \$	6.8 x 10⁶ \$ (1.7% GDP growth)	2.8 x 10⁶ \$
5. Traffic flows ⁹⁵	1,212,020 TEU	2,424,040 TEU	1,212,020 TEU

91 Internet, <http://www.gaports.com/Portals/2/About/Annual%20Report/2013/FY2013AnnualReport.pdf>, (24 April 2014).

92 Internet, <http://www.gaports.com/Portals/2/About/Annual%20Report/2013/FY2013AnnualReport.pdf>, (24 April 2014).

93 Internet, <http://www.tradingeconomics.com/united-states/gdp>, <https://www.conference-board.org/data/globaloutlook.cfm>, (24 April 2014).

94 Internet, <http://www.gaports.com/Portals/2/About/Annual%20Report/2013/FY2013AnnualReport.pdf>, (24 April 2014).

95 Internet, http://www.marad.dot.gov/library_landing_page/data_and_statistics/Data_and_Statistics.htm, 24 April 2014. (Based on a 201% growth in global container throughput by 2024, according to the source: Internet, http://www.nauticalcharts.noaa.gov/ocs/hsrp/archive/mar2007/FutureTrends_3-07.pdf, (24 April 2014).

6.	Innovation ⁹⁶	73 x 10 ⁶ \$	124 x 10 ⁶ \$ (1.7% GDP growth)	51 x 10 ⁶ \$
7.	Security and safety ⁹⁷	3 x 10 ⁶ \$	5.1 x 10 ⁶ \$ (taking into account 1.7% GDP growth)	2.1 x 10 ⁶ \$
8.	Traffic energy ⁹⁸	2 x 10 ⁶ \$	3.4 x 10 ⁶ \$ (1.7% GDP growth)	1.4 x 10 ⁶ \$

Source: Prepared by the author based on source material.

Table 14 - Evaluation of elements of the container transport model for the container terminal Rotterdam

Elements of the container transport model	Input y_{it}		Increase
	2012	2024	y_i 2024
1	2	3	4
1. Transport infrastructure and transport superstructure ⁹⁹	11.6 x 10 ¹² €	13.92 x 10 ¹² € (value calculated based on 1.2% growth in GDP)	2.32 x 10 ¹² €
2. Impact of intelligent information systems ¹⁰⁰	4.4 x 10 ⁶ €	5.28 x 10 ⁶ € (value calculated based on 1.2% growth in GDP)	0.88 x 10 ⁶ €

96 Internet, <http://www.gaports.com/Portals/2/About/Annual%20Report/2013/FY2013AnnualReport.pdf>, (24 April 2014).

97 Internet, <http://www.gaports.com/Portals/2/AnchorAge/pdf/2295GPA.pdf>, (24 April 2014).

98 Internet, <http://www.gaports.com/Portals/2/AnchorAge/pdf/2295GPA.pdf>, (24 April 2014).

99 Internet, <http://www.portofrotterdam.com/en/Port-authority/finance/annual-report/Documents/annualreport-2012.pdf>, (22 April 2014).

100 Internet, <http://www.portofrotterdam.com/en/Port-authority/finance/annual-report/Documents/annualreport-2012.pdf>, (22 April 2014).

3.	Gross domestic product ¹⁰¹	0.7 x 10¹² €	0.84 x 10¹² €	0.14 x 10¹² € (1.2% GDP growth) ¹⁰²
4.	Transport ecology ¹⁰³	626 x 10⁶ €	751 x 10⁶ €	125 x 10⁶ € (1.2% GDP growth taken into account)
5.	Traffic flows ¹⁰⁴	11,866 x 10⁶ TEU	23,732 x 10⁶ TEU	11,866 x 10⁶ TEU
6.	Innovation ¹⁰⁵	12 x 10⁶ €	14.4 x 10⁶ € (1.2% GDP growth)	2.4 x 10⁶ € (1.2% GDP growth)
7.	Security and safety ¹⁰⁶	103 x 10⁶ €	124 x 10⁶ €	21 x 10⁶ € (taking into account 1.2% GDP growth)
8.	Traffic energy ¹⁰⁷	15 x 10⁶ €	18 x 10⁶ € (1.2% growth taken into account)	3 x 10⁶ €

Source: Prepared by the author based on source material.

101 Internet, <http://countryeconomy.com/gdp/netherlands>, (24 April 2014).

102 Internet, <https://www.conference-board.org/data/globaloutlook.cfm>, (23 April 2014).

103 Internet, <http://www.portofrotterdam.com/en/Port-authority/finance/annual-report/Documents/annualreport-2012.pdf>, (22 April 2014).

104 <http://www.portofrotterdam.com/en/Port/port-statistics/Documents/Port-statistics-2012.pdf>, (23 April 2014). - (Based on a 201% growth in global container throughput by 2024, according to the source: Internet, http://www.nauticalcharts.noaa.gov/ocs/hsrp/archive/mar2007/FutureTrends_3-07.pdf, (11 April 2014).

105 Internet, <http://www.portofrotterdam.com/en/Port-authority/finance/annual-report/Documents/annualreport-2012.pdf>, (22 April 2014).

106 Internet, <http://www.portofrotterdam.com/en/Port-authority/finance/annual-report/Documents/annualreport-2012.pdf>, (22 April 2014).

107 Internet, <http://www.portofrotterdam.com/en/Port-authority/finance/annual-report/Documents/annualreport-2012.pdf>, (22 April 2014).

Table 15 - Evaluation of elements of the container transport model for the container terminal in Le Havre

Elements of the container transport model	Input y_{it}		Increase
	2012	2024	y_i 2024
1	2	3	4
1. Transport infrastructure and transport superstructure ¹⁰⁸	28×10^6 €	34×10^6 € (value calculated based on 1.2% GDP growth)	6×10^6 €
2. Impact of intelligent information systems	6×10^5 €¹⁰⁹	7.2×10^5 € (value calculated based on 1.2% growth in GDP)	1.2×10^5 €
3. Gross domestic product ¹¹⁰	2.6×10^{12} €	3.12×10^{12} €	0.52×10^{12} € (1.2% GDP growth) ¹¹¹
4. Transport ecology ¹¹²	6×10^5 €	7.2×10^5 € (1.2% GDP growth)	1.2×10^5 €
5. Traffic flows ¹¹³	2.4×10^6 TEU	2.88×10^6 TEU	0.48×10^6 TEU

108 Internet, http://www.haropaports.com/sites/haropa/files/u21/2014-03-18-gestion_des_dechets_des_navweres_haropa_port_du_havre_sengage_.pdf, (24 April 2014).

109 Internet, <http://www.haropaports.com/en/haropa-port-du-havre-becomes-involved-industry-specialized-waste-collection>, (23 April 2014).

110 Internet; <http://countryeconomy.com/gdp/france>, (23 April 2014).

111 Internet, <https://www.conference-board.org/data/globaloutlook.cfm>, (23 April 2014).

112 Internet, http://www.haropaports.com/sites/haropa/files/u21/2014-03-18-gestion_des_dechets_des_navweres_haropa_port_du_havre_sengage_.pdf, (24 April 2014).

113 Internet, <http://www.haropaports.com/en/our-importexport-solutions>, (23 April 2014) - (based on a 201% increase in global container throughput by 2024, according to the source: Internet, http://www.nauticalcharts.noaa.gov/ocs/hsrp/archive/mar2007/FutureTrends_3-07.pdf, (11 April 2014).

6.	Innovation ¹¹⁴	0.1 x 10⁶ €	0.12 x 10⁶ € (1.2% of GDP)	0.02 x 10⁶ €
7.	Security and safety ¹¹⁵	174 x 10⁶ €	209 x 10⁶ €	35 x 10⁶ € (1.2% GDP growth taken into account)
8.	Traffic energy ¹¹⁶	129 x 10⁶ €	154 x 10⁶ € (value calculated based on 1.2% growth in GDP)	25 x 10⁶ €

Source: Prepared by the author based on source material.

Table 16 - Evaluation of elements of the container transport model for maritime container terminal Antwerp

Elements of the container transport model	Input y_{it}		Increase
	2012	2024	y_i 2024
1	2	3	4
1. Transport infrastructure and transport superstructure ¹¹⁷	248 x 10⁶ €	298 x 10⁶ € (value calculated based on 1.2% GDP growth)	50 x 10⁶ €
2. Impact of intelligent information systems	29 x 10⁶ €¹¹⁸	35 x 10⁶ € (value calculated based on 1.2% GDP growth)	6 x 10⁶ €

114 Internet, http://www.haropaports.com/sites/haropa/files/u21/2014-01-21_leolien_sur_le_port_du_havre_v4_09-01-20141.pdf, (23 April 2014).

115 Internet, <http://www.oecd.org/futures/infrastructureto2030/48368193.pdf>, (23 April 2014).

116 Internet, <http://fr.calameo.com/read/00134416506b57772051d>, (24 April 2014).

117 Internet, http://www.portofantlrp.com/sites/portofantlrp/files/POA-1293_Brochure%20Jaarverslag%202014_UK_0.pdf, (24 April 2014).

118 Internet, http://www.portofantlrp.com/sites/portofantlrp/files/POA-1293_Brochure%20Annual%20Report%202014_UK_0.pdf, (24 April 2014).

3.	Gross domestic product ¹¹⁹	4.8 x 10¹² €	5.8 x 10¹² €	1 x 10¹² €
4.	Transport ecology ¹²⁰	15.4 x 10⁶ €	31.8 x 10⁶ € (1.2% growth in GDP)	16.4 x 10⁶ €
5.	Traffic flows ¹²¹	8.6 x 10⁶ TEU	17.2 x 10⁶ TEU	8.6 x 10⁶ TEU
6.	Innovation ¹²²	20 x 10⁶ €	24 x 10⁶ € (1.2% GDP growth)	4 x 10⁶ €
7.	Security and safety ¹²³	30 x 10⁽⁶⁾ €	36 x 10⁽⁶⁾ €	6 x 10⁽⁶⁾ € (taking into account 1.2% GDP growth)
8.	Traffic energy ¹²⁴	135 x 10⁶ €	162 x 10⁶ € (1.2% GDP growth)	27 x 10⁶ €

Source: Prepared by the author based on source material.

- 119 Internet, <http://countryeconomy.com/gdp/belgium>, (24 April 2014).
- 120 Internet, http://www.portofantlirp.com/sites/portofantlirp/files/POA-1293_Brochure%20Annual%20Report%202014_UK_0.pdf, (24 April 2014).
- 121 <http://www.portofrotterdam.com/en/Port/port-statistics/Documents/Port-statistics-2012.pdf>, (23 April 2014). - (201% growth in global container throughput by 2024 is taken into account, based on source: Internet, http://www.nauticalcharts.noaa.gov/ocs/hsrp/archive/mar2007/FutureTrends_3-07.pdf, (11 April 2014)
- 122 Internet, http://www.portofantlirp.com/sites/portofantlirp/files/POA-1293_Brochure%20Jaarverslag%202014_UK_0.pdf, (24 April 2014).
- 123 Internet, http://www.portofantlirp.com/sites/portofantlirp/files/POA-1293_Brochure%20Jaarverslag%202014_UK_0.pdf, (24 April 2014).
- 124 Internet, http://www.portofantlirp.com/sites/portofantlirp/files/POA-1293_Brochure%20Jaarverslag%202014_UK_0.pdf, (24 April 2014).

Table 17 - Evaluation of elements of the container transport model for the container terminal Hamburg

Elements of the container transport model	Input y_{it}		Increase
	2012	2024	y_i 2024
1	2	3	4
1. Transport infrastructure and transport superstructure ¹²⁵	$212 \times 10^6 \text{ €}$	$214 \times 10^6 \text{ €}$ (value calculated based on 1.2% GDP growth)	$2 \times 10^6 \text{ €}$
2. Impact of intelligent information systems ¹²⁶	$46 \times 10^6 \text{ €}$	$55.2 \times 10^6 \text{ €}$ (value calculated based on 1.2% growth in GDP)	$9.2 \times 10^6 \text{ €}$
3. Gross domestic product ¹²⁷	$3.42 \times 10^{12} \text{ €}$	$4.1 \times 10^{12} \text{ €}$	$0.68 \times 10^{12} \text{ €}$ (1.2% growth)
4. Transport ecology ¹²⁸	$253 \times 10^6 \text{ €}$	$303.6 \times 10^6 \text{ €}$	$50.6 \times 10^6 \text{ €}$ (taking into account 1.2% GDP growth)
5. Traffic flows ¹²⁹	$4.7 \times 10^6 \text{ TEU}$	$9.4 \times 10^6 \text{ TEU}$	$4.7 \times 10^6 \text{ TEU}$

125 Internet, http://www.hamburg-port-authority.de/en/press/Brochures-and-publications/Documents/HPA_AnnualReport_2012.pdf, (23 April 2014).

126 Internet, http://www.hamburg-port-authority.de/en/press/Brochures-and-publications/Documents/HPA_AnnualReport_2012.pdf, (23 April 2014).

127 <https://www.conference-board.org/data/globaloutlook.cfm>, (23 April 2014).

128 Internet, http://www.hamburg-port-authority.de/en/press/Brochures-and-publications/Documents/HPA_AnnualReport_2012.pdf, (23 April 2014).

129 http://www.hamburg-port-authority.de/en/press/Brochures-and-publications/Documents/HPA_AnnualReport_2012.pdf, (23 April 2014). - (201% growth in global container throughput by 2024 is taken into account, based on source: Internet, http://www.nauticalcharts.noaa.gov/ocs/hstp/archive/mar2007/FutureTrends_3-07.pdf, (11 April 2014).

6.	Innovation ¹³⁰	338 x 10 ⁶ €	406 x 10 ⁶ € (1.2% GDP growth)	68 x 10 ⁶ €
7.	Security and safety ¹³¹	17 x 10 ⁶ €	20.4 x 10 ⁶ € (taking into account 1.2% GDP growth)	3.4 x 10 ⁶ €
8.	Traffic energy ¹³²	5.6 x 10 ⁶ €	6.72 x 10 ⁶ € (value calculated based on 1.2% GDP growth)	1.12 x 10 ⁶ €

Source: Prepared by the author based on source material.

4.6.2. CALCULATION OF THE DEGREE OF DEVELOPMENT OF ELEMENTS OF THE MODEL FOR THE TRANSPORT OF CONTAINERS FROM EASTERN US STATES TO WESTERN EUROPEAN COUNTRIES

Let us assume that n interconnected elements are involved in the container transport process elements are involved in the container transport process. With y_{vt} and $y_{v,t-1}$ denote the values of container transport elements (e.g. input, parameter, etc.) of the i -th element of container transport in the period t and t_{-1} . The period t is the year 2024, and the period t_{-1} is the year 2014. The increment of the input value of the i -th element of the container transport model is:¹³³

130 Internet, http://www.hamburg-port-authority.de/en/press/Brochures-and-publications/Documents/HPA_AnnualReport_2012.pdf, (23 April 2014).

131 Internet, http://www.hamburg-port-authority.de/en/press/Brochures-and-publications/Documents/HPA_AnnualReport_2012.pdf, (23 April 2014).

132 Internet, http://www.hamburg-port-authority.de/en/press/Brochures-and-publications/Documents/HPA_AnnualReport_2012.pdf, (23 April 2014).

133 STOJANOVIĆ, D.: **Mathematical Methods in Economics**, Appendix: Growth Matrix, Seventh Revised and Expanded Edition, Savremena administracija, Belgrade, 1988, p. 351.

$$\Delta y_t = y_{vt} - y_{v,t-1} \quad (68)$$

The indwerect growth rate of the i -th container transport element in relation to the j -th is defined as the ratio of the input increment y_{vt} of the i -th container transport element, Δy_{vt} and the input value y_{vt} of the i -th container transport element in period t , or:

$$rvp = \frac{\Delta y_{vt}}{y_{vt}} \quad v, p = 1, 2, \dots, 8. \quad y_{v,t-1} \neq 0 \quad (69)$$

The indwerect growth rate can be expressed in the form of a matrix of container transport element growth:

$$R_t = \begin{bmatrix} r_{11t} & r_{12t} & \dots & \dots & r_{1pt} \\ r_{21t} & r_{22t} & \dots & \dots & r_{2pt} \\ \dots & \dots & \dots & \dots & \dots \\ r_{p1t} & r_{p2t} & \dots & \dots & r_{ppt} \end{bmatrix} \quad t = 1, \dots, T \quad (70)$$

where the elements on the main vertical r_{ppt} denote dwerect ($v = p$), the others ($v \neq p$), indwerect growth rates. The elements in the v row indicate the growth of input in the v element of the container transport model in terms of the sustainable development of container transport relative to the inputs in other elements of the container transport model. The elements in the v column indicate the growth in the value of inputs in all elements of the model relative to the input y_{vt} of that element in the period $t = 22$ years.

From this, I can conclude that each element in the growth matrix is represented by one row and one column, with elements expressing indwerect or relative growth relationships. For example, the first row expresses the growth of the input of the first element of the container transport model relative to the other elements, while

the first column expresses the growth of the other elements relative to the input of the first element. The other rows and columns correspond to the other elements of the container transport model.

Indirect growth rates can also be defined in relation to the inputs y_v of the t -th element of the container transport model in period $t-1$, i.e.:

$$r'_{vpt} = \frac{\Delta y_{vt}}{y_{v,t-1}} \quad v, p = 1, \dots, 8. \quad (71)$$

The growth matrix can also be determined via the external vectors of the model elements. This method of determination is useful for the practical calculation of the growth matrix. Growth vector of model elements:

$$\Delta y_{vt} = (\Delta y_{vt}, \dots, \Delta y_{pt}) \quad (72)$$

and the vector of reciprocal values of the elements of the container transport model in terms of sustainable development:

$$\vec{v} = \left(\frac{1}{y_{1t}}, \dots, \frac{1}{y_{pt}} \right) \quad v, p = 1, \dots, 8. \quad y_{v,t-1} \neq 0 \quad (73)$$

The external growth vector of model element coefficients and reciprocal value vectors define the growth matrix of the container transport model in terms of sustainable development.

$$R_{pt} = \Delta y'_t \times \vec{v} = \begin{bmatrix} \Delta y_{1t} \\ \Delta y_{8t} \end{bmatrix} \begin{pmatrix} \frac{1}{y_t}, \dots, \frac{1}{\Delta y_{8t}} \end{pmatrix} \quad (74)$$

$$R_{pt} = \begin{bmatrix} \frac{\Delta y_{1t}}{y_{1t}} & \dots & \dots & \frac{\Delta y_{1t}}{y_{pt}} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ \frac{\Delta y_{vt}}{y_{vt}} & \dots & \dots & \frac{\Delta y_{vt}}{y_{pt}} \\ \dots & \dots & \dots & \dots \end{bmatrix} = \begin{bmatrix} r_{11t} & \dots & \dots & r_{1pt} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ r_{p1t} & \dots & \dots & r_{ppt} \end{bmatrix} \quad (75)$$

When observing the direct growth rate, the growth of one container transport element is expressed independently of the growth of others. Namely, when defining indirect growth rates, i.e., the growth of the i -th container transport element relative to the v -th; $v, p = 1, \dots, 8$, it is possible to determine the growth structure of container transport elements and express all relations through a growth matrix in a common system. At the same time, by expressing direct and indirect rates, it is possible to monitor changes in the growth intensity of container transport elements and their relations.

Based on the data from Tables 8 to 17, it is possible to define the growth vectors of the elements of the container transport model for maritime container terminals in the Eastern United States 17, it is possible to define the growth vectors of the container transport model elements for maritime container terminals in the Eastern United States and in Western European countries in relation to the current and future values of the container transport model elements in the period 2012/2024.

- For the *New York* maritime container terminal:

$$\Delta y'_{2024} = \begin{bmatrix} 17 \times 10^9 \\ 116 \times 10^6 \\ 10.494 \times 10^9 \\ 3,4 \times 10^6 \\ 4,2 \times 10^6 \\ 1,4 \times 10^9 \\ 80 \times 10^6 \\ 8 \times 10^6 \end{bmatrix} \quad (76)$$

The vector of reciprocal values of the container transport model elements is:

$$1/y_{2024} = (1/42 \times 10^9, 1/696 \times 10^6, 1/24,485 \times 10^9, 1/8.3 \times 10^6, 1/8.4 \times 10^6, 1/3.4 \times 10^9, 1/195 \times 10^6, 1/20 \times 10^6) \quad (77)$$

Product of external vector $\Delta y'_{2024}$ and $\frac{1}{y_{2024}}$ determines the growth matrix of the model elements of container transport for the period from 2012 to 2024, both vertically and horizontally.

$$R_{2024} = \begin{bmatrix} \frac{17 \times 10^9}{42 \times 10^9} & \frac{17 \times 10^9}{696 \times 10^6} & \frac{17 \times 10^9}{25.485 \times 10^9} & \frac{17 \times 10^9}{8.3 \times 10^6} & \frac{17 \times 10^9}{8.4 \times 10^6} & \frac{17 \times 10^9}{3.4 \times 10^9} & \frac{17 \times 10^9}{195 \times 10^6} & \frac{17 \times 10^9}{20 \times 10^6} \\ \frac{116 \times 10^6}{42 \times 10^9} & \frac{116 \times 10^6}{696 \times 10^6} & \frac{116 \times 10^6}{25.485 \times 10^9} & \frac{116 \times 10^6}{8.3 \times 10^6} & \frac{116 \times 10^6}{8.4 \times 10^6} & \frac{116 \times 10^6}{3.4 \times 10^9} & \frac{116 \times 10^6}{195 \times 10^6} & \frac{116 \times 10^6}{20 \times 10^6} \\ \frac{10.494 \times 10^9}{42 \times 10^9} & \frac{10.494 \times 10^9}{696 \times 10^6} & \frac{10.494 \times 10^9}{25.485 \times 10^9} & \frac{10.494 \times 10^9}{8.3 \times 10^6} & \frac{10.494 \times 10^9}{8.4 \times 10^6} & \frac{10.494 \times 10^9}{3.4 \times 10^9} & \frac{10.494 \times 10^9}{195 \times 10^6} & \frac{10.494 \times 10^9}{20 \times 10^6} \\ \frac{3,4 \times 10^6}{42 \times 10^9} & \frac{3,4 \times 10^6}{696 \times 10^6} & \frac{3,4 \times 10^6}{25.485 \times 10^9} & \frac{3,4 \times 10^6}{8.3 \times 10^6} & \frac{3,4 \times 10^6}{8.4 \times 10^6} & \frac{3,4 \times 10^6}{3.4 \times 10^9} & \frac{3,4 \times 10^6}{195 \times 10^6} & \frac{3,4 \times 10^6}{20 \times 10^6} \\ \frac{4,2 \times 10^6}{42 \times 10^9} & \frac{4,2 \times 10^6}{696 \times 10^6} & \frac{4,2 \times 10^6}{25.485 \times 10^9} & \frac{4,2 \times 10^6}{8.3 \times 10^6} & \frac{4,2 \times 10^6}{8.4 \times 10^6} & \frac{4,2 \times 10^6}{3.4 \times 10^9} & \frac{4,2 \times 10^6}{195 \times 10^6} & \frac{4,2 \times 10^6}{20 \times 10^6} \\ \frac{1,4 \times 10^9}{42 \times 10^9} & \frac{1,4 \times 10^9}{696 \times 10^6} & \frac{1,4 \times 10^9}{25.485 \times 10^9} & \frac{1,4 \times 10^9}{8.3 \times 10^6} & \frac{1,4 \times 10^9}{8.4 \times 10^6} & \frac{1,4 \times 10^9}{3.4 \times 10^9} & \frac{1,4 \times 10^9}{195 \times 10^6} & \frac{1,4 \times 10^9}{20 \times 10^6} \\ \frac{80 \times 10^6}{42 \times 10^9} & \frac{80 \times 10^6}{696 \times 10^6} & \frac{80 \times 10^6}{25.485 \times 10^9} & \frac{80 \times 10^6}{8.3 \times 10^6} & \frac{80 \times 10^6}{8.4 \times 10^6} & \frac{80 \times 10^6}{3.4 \times 10^9} & \frac{80 \times 10^6}{195 \times 10^6} & \frac{80 \times 10^6}{20 \times 10^6} \\ \frac{8 \times 10^6}{42 \times 10^9} & \frac{8 \times 10^6}{696 \times 10^6} & \frac{8 \times 10^6}{25.485 \times 10^9} & \frac{8 \times 10^6}{8.3 \times 10^6} & \frac{8 \times 10^6}{8.4 \times 10^6} & \frac{8 \times 10^6}{3.4 \times 10^9} & \frac{8 \times 10^6}{195 \times 10^6} & \frac{8 \times 10^6}{20 \times 10^6} \end{bmatrix} \quad (78)$$

- For the *Boston* maritime container terminal:

$$\Delta y'_{2024} = \begin{bmatrix} 66 \times 10^6 \\ 15 \times 10^6 \\ 10.494 \times 10^9 \\ 16,2 \times 10^6 \\ 57.602 \\ 1 \times 10^6 \\ 43 \times 10^6 \\ 7,7 \times 10^6 \end{bmatrix} \quad (79)$$

The vector of reciprocal values of the container transport model elements is:

$$1/y_{2024} = (1/160 \times 10^6, 1/36 \times 10^6, 1/24,485 \times 10^9, 1/39,3 \times 10^6, 1/115.204, 1/2,5 \times 10^6, 1/104 \times 10^6, 1/18,7 \times 10^6) \quad (80)$$

Product of external vector $\Delta y'_{2024}$ and $\frac{1}{y_{2024}}$ determines the growth matrix of the model elements of container transport for the period from 2012 to 2024, both vertically and horizontally.

$$R_{2024} = \begin{bmatrix} \frac{66 \times 10^6}{160 \times 10^6} & \frac{66 \times 10^6}{36 \times 10^6} & \frac{66 \times 10^6}{24.485 \times 10^9} & \frac{66 \times 10^6}{39,3 \times 10^6} & \frac{66 \times 10^6}{115.204} & \frac{66 \times 10^6}{2,5 \times 10^6} & \frac{66 \times 10^6}{104 \times 10^6} & \frac{66 \times 10^6}{18,7 \times 10^6} \\ \frac{15 \times 10^6}{160 \times 10^6} & \frac{15 \times 10^6}{36 \times 10^6} & \frac{15 \times 10^6}{24.485 \times 10^9} & \frac{15 \times 10^6}{39,3 \times 10^6} & \frac{15 \times 10^6}{115.204} & \frac{15 \times 10^6}{2,5 \times 10^6} & \frac{15 \times 10^6}{104 \times 10^6} & \frac{15 \times 10^6}{18,7 \times 10^6} \\ \frac{10.494 \times 10^9}{160 \times 10^6} & \frac{10.494 \times 10^9}{36 \times 10^6} & \frac{10.494 \times 10^9}{24.485 \times 10^9} & \frac{10.494 \times 10^9}{39,3 \times 10^6} & \frac{10.494 \times 10^9}{115.204} & \frac{10.494 \times 10^9}{2,5 \times 10^6} & \frac{10.494 \times 10^9}{104 \times 10^6} & \frac{10.494 \times 10^9}{18,7 \times 10^6} \\ \frac{16,2 \times 10^6}{160 \times 10^6} & \frac{16,2 \times 10^6}{36 \times 10^6} & \frac{16,2 \times 10^6}{24.485 \times 10^9} & \frac{16,2 \times 10^6}{39,3 \times 10^6} & \frac{16,2 \times 10^6}{115.204} & \frac{16,2 \times 10^6}{2,5 \times 10^6} & \frac{16,2 \times 10^6}{104 \times 10^6} & \frac{16,2 \times 10^6}{18,7 \times 10^6} \\ \frac{57.602}{160 \times 10^6} & \frac{57.602}{36 \times 10^6} & \frac{57.602}{24.485 \times 10^9} & \frac{57.602}{39,3 \times 10^6} & \frac{57.602}{115.204} & \frac{57.602}{2,5 \times 10^6} & \frac{57.602}{104 \times 10^6} & \frac{57.602}{18,7 \times 10^6} \\ \frac{1 \times 10^6}{160 \times 10^6} & \frac{1 \times 10^6}{36 \times 10^6} & \frac{1 \times 10^6}{24.485 \times 10^9} & \frac{1 \times 10^6}{39,3 \times 10^6} & \frac{1 \times 10^6}{115.204} & \frac{1 \times 10^6}{2,5 \times 10^6} & \frac{1 \times 10^6}{104 \times 10^6} & \frac{1 \times 10^6}{18,7 \times 10^6} \\ \frac{43 \times 10^6}{160 \times 10^6} & \frac{43 \times 10^6}{36 \times 10^6} & \frac{43 \times 10^6}{24.485 \times 10^9} & \frac{43 \times 10^6}{39,3 \times 10^6} & \frac{43 \times 10^6}{115.204} & \frac{43 \times 10^6}{2,5 \times 10^6} & \frac{43 \times 10^6}{104 \times 10^6} & \frac{43 \times 10^6}{18,7 \times 10^6} \\ \frac{7,7 \times 10^6}{160 \times 10^6} & \frac{7,7 \times 10^6}{36 \times 10^6} & \frac{7,7 \times 10^6}{24.485 \times 10^9} & \frac{7,7 \times 10^6}{39,3 \times 10^6} & \frac{7,7 \times 10^6}{115.204} & \frac{7,7 \times 10^6}{2,5 \times 10^6} & \frac{7,7 \times 10^6}{104 \times 10^6} & \frac{7,7 \times 10^6}{18,7 \times 10^6} \end{bmatrix} \quad (81)$$

- For the *Philadelphia* maritime container terminal:

$$\Delta y'_{2024} = \begin{bmatrix} 66 \times 10^6 \\ 106 \times 10^6 \\ 10.494 \times 10^9 \\ 25 \times 10^6 \\ 33.238 \\ 29 \times 10^6 \\ 210 \times 10^6 \\ 25 \times 10^6 \end{bmatrix} \quad (82)$$

The vector of reciprocal values of the container transport model elements is:

$$1/y_{2024} = (1/161 \times 10^6, 1/258 \times 10^6, 1/25,485 \times 10^9, 1/61 \times 10^6, 1/80.721, 1/71 \times 10^6, 1/510 \times 10^6, 1/61 \times 10^6) \quad (83)$$

Product of external vector $\Delta y'_{2024}$ and $\frac{1}{y_{2024}}$ determines the growth matrix of the model elements of container transport for the period from 2012 to 2024, both vertically and horizontally.

$$R_{2024} = \begin{bmatrix} 66 \times 10^6 & 66 \times 10^6 & 66 \times 10^5 & 66 \times 10^6 & 66 \times 10^6 & 66 \times 10^6 & 66 \times 10^6 & 66 \times 10^6 \\ 161 \times 10^6 & 258 \times 10^6 & 25.485 \times 10^9 & 39,3 \times 10^3 & 80.721 & 71 \times 10^6 & 510 \times 10^6 & 61 \times 10^6 \\ 106 \times 10^6 & 106 \times 10^6 & 106 \times 10^6 & 106 \times 10^6 & 106 \times 10^6 & 106 \times 10^6 & 106 \times 10^6 & 106 \times 10^6 \\ 161 \times 10^6 & 258 \times 10^6 & 25.485 \times 10^9 & 61 \times 10^6 & 80.721 & 71 \times 10^6 & 510 \times 10^6 & 61 \times 10^6 \\ 10.494 \times 10^9 & 10.494 \times 10^9 & 10.494 \times 10^9 & 10.494 \times 10^9 & 10.494 \times 10^9 & 10.494 \times 10^9 & 10.494 \times 10^9 & 10.494 \times 10^9 \\ 161 \times 10^6 & 258 \times 10^6 & 25.485 \times 10^9 & 61 \times 10^6 & 80.721 & 71 \times 10^6 & 510 \times 10^6 & 61 \times 10^6 \\ 25 \times 10^6 & 25 \times 10^6 & 25 \times 10^6 & 25 \times 10^6 & 25 \times 10^6 & 25 \times 10^6 & 25 \times 10^6 & 25 \times 10^6 \\ 161 \times 10^6 & 258 \times 10^6 & 25.485 \times 10^9 & 61 \times 10^6 & 80.721 & 71 \times 10^6 & 510 \times 10^6 & 61 \times 10^6 \\ 33.238 & 33.238 & 33.238 & 33.238 & 33.238 & 33.238 & 33.238 & 33.238 \\ 161 \times 10^6 & 258 \times 10^6 & 25.485 \times 10^9 & 61 \times 10^6 & 80.721 & 71 \times 10^6 & 510 \times 10^6 & 61 \times 10^6 \\ 29 \times 10^6 & 29 \times 10^6 & 29 \times 10^6 & 29 \times 10^6 & 29 \times 10^6 & 29 \times 10^6 & 29 \times 10^6 & 29 \times 10^6 \\ 161 \times 10^6 & 258 \times 10^6 & 25.485 \times 10^9 & 61 \times 10^6 & 80.721 & 71 \times 10^6 & 510 \times 10^6 & 61 \times 10^6 \\ 210 \times 10^6 & 210 \times 10^6 & 210 \times 10^6 & 210 \times 10^6 & 210 \times 10^6 & 210 \times 10^6 & 210 \times 10^6 & 210 \times 10^6 \\ 161 \times 10^6 & 258 \times 10^6 & 25.485 \times 10^9 & 61 \times 10^6 & 80.721 & 71 \times 10^6 & 510 \times 10^6 & 61 \times 10^6 \\ 25 \times 10^6 & 25 \times 10^6 & 25 \times 10^6 & 25 \times 10^6 & 25 \times 10^6 & 25 \times 10^6 & 25 \times 10^6 & 25 \times 10^6 \\ 161 \times 10^6 & 258 \times 10^6 & 25.485 \times 10^9 & 61 \times 10^6 & 80.721 & 71 \times 10^6 & 510 \times 10^6 & 61 \times 10^6 \end{bmatrix} \quad (84)$$

- For the *Baltimore* maritime container terminal:

$$\Delta y'_{2024} = \begin{bmatrix} 98 \times 10^6 \\ 21 \times 10^6 \\ 10.494 \times 10^9 \\ 0,7 \times 10^6 \\ 195.602 \\ 12 \times 10^6 \\ 3 \times 10^6 \\ 21 \times 10^6 \end{bmatrix} \quad (85)$$

The vector of reciprocal values of the container transport model elements is:

$$1/y_{2024} = (1/238 \times 10^6, 1/51 \times 10^6, 1/25,485 \times 10^9, 1/1,7 \times 10^6, 1/391.204, 1/29 \times 10^6, 1/7 \times 10^6, 1/51 \times 10^6) \quad (86)$$

Product of external vector $\Delta y'_{2024}$ and $\frac{1}{y_{2024}}$ determines the growth matrix of the model elements of container transport for the period from 2012 to 2024, both vertically and horizontally.

$$R_{2024} = \begin{bmatrix} 98 \times 10^6 & 98 \times 10^6 & 98 \times 10^6 & 98 \times 10^6 & 98 \times 10^6 & 98 \times 10^6 & 98 \times 10^6 & 98 \times 10^6 \\ 238 \times 10^6 & 51 \times 10^6 & 25.485 \times 10^9 & 1,7 \times 10^6 & 391.204 & 29 \times 10^6 & 7 \times 10^6 & 51 \times 10^6 \\ 21 \times 10^6 & 21 \times 10^6 & 21 \times 10^6 & 21 \times 10^6 & 21 \times 10^6 & 21 \times 10^6 & 21 \times 10^6 & 21 \times 10^6 \\ 238 \times 10^6 & 51 \times 10^6 & 25.485 \times 10^9 & 1,7 \times 10^6 & 391.204 & 29 \times 10^6 & 7 \times 10^6 & 51 \times 10^6 \\ 10.494 \times 10^9 & 10.494 \times 10^9 & 10.494 \times 10^9 & 10.494 \times 10^9 & 10.494 \times 10^9 & 10.494 \times 10^9 & 10.494 \times 10^9 & 10.494 \times 10^9 \\ 238 \times 10^6 & 51 \times 10^6 & 25.485 \times 10^9 & 1,7 \times 10^6 & 391.204 & 29 \times 10^6 & 7 \times 10^6 & 51 \times 10^6 \\ 0,7 \times 10^6 & 0,7 \times 10^6 & 0,7 \times 10^6 & 0,7 \times 10^6 & 0,7 \times 10^6 & 0,7 \times 10^6 & 0,7 \times 10^6 & 0,7 \times 10^6 \\ 238 \times 10^6 & 51 \times 10^6 & 25.485 \times 10^9 & 1,7 \times 10^6 & 391.204 & 29 \times 10^6 & 7 \times 10^6 & 51 \times 10^6 \\ 195.602 & 195.602 & 195.602 & 195.602 & 195.602 & 195.602 & 195.602 & 195.602 \\ 238 \times 10^6 & 51 \times 10^6 & 25.485 \times 10^9 & 1,7 \times 10^6 & 391.204 & 29 \times 10^6 & 7 \times 10^6 & 51 \times 10^6 \\ 12 \times 10^6 & 12 \times 10^6 & 12 \times 10^6 & 12 \times 10^6 & 12 \times 10^6 & 12 \times 10^6 & 12 \times 10^6 & 12 \times 10^6 \\ 238 \times 10^6 & 51 \times 10^6 & 25.485 \times 10^9 & 1,7 \times 10^6 & 391.204 & 29 \times 10^6 & 7 \times 10^6 & 51 \times 10^6 \\ 3 \times 10^6 & 3 \times 10^6 & 3 \times 10^6 & 3 \times 10^6 & 3 \times 10^6 & 3 \times 10^6 & 3 \times 10^6 & 3 \times 10^6 \\ 238 \times 10^6 & 51 \times 10^6 & 25.485 \times 10^9 & 1,7 \times 10^6 & 391.204 & 29 \times 10^6 & 7 \times 10^6 & 51 \times 10^6 \\ 21 \times 10^6 & 21 \times 10^6 & 21 \times 10^6 & 21 \times 10^6 & 21 \times 10^6 & 21 \times 10^6 & 21 \times 10^6 & 21 \times 10^6 \\ 238 \times 10^6 & 51 \times 10^6 & 25.485 \times 10^9 & 1,7 \times 10^6 & 391.204 & 29 \times 10^6 & 7 \times 10^6 & 51 \times 10^6 \end{bmatrix} \quad (87)$$

- For the *Norfolk* maritime container terminal:

$$\Delta y'_{2024} = \begin{bmatrix} 94 \times 10^6 \\ 8 \times 10^6 \\ 10.494 \times 10^9 \\ 1.2 \times 10^6 \\ 829.063 \\ 9 \times 10^6 \\ 3 \times 10^6 \\ 8 \times 10^6 \end{bmatrix} \quad (88)$$

The vector of reciprocal values of the container transport model elements is:

$$1/y_{2024} = (1/229 \times 10^6, 1/20 \times 10^6, 1/25,485 \times 10^9, 1/2,9 \times 10^6, 1/1,658,126, 1/22 \times 10^6, 1/8 \times 10^6, 1/20 \times 10^6) \quad (89)$$

Product of external vector $\Delta y'_{2024}$ and $\frac{1}{y_{2024}}$ determines the growth matrix of the model elements of container transport for the period from 2012 to 2024, both vertically and horizontally.

$$R_{2024} = \begin{bmatrix} \frac{94 \times 10^6}{229 \times 10^6} & \frac{94 \times 10^6}{20 \times 10^6} & \frac{94 \times 10^6}{25.485 \times 10^9} & \frac{94 \times 10^6}{2,9 \times 10^6} & \frac{94 \times 10^6}{1.658.126} & \frac{94 \times 10^6}{22 \times 10^6} & \frac{94 \times 10^6}{8 \times 10^6} & \frac{94 \times 10^6}{20 \times 10^6} \\ \frac{8 \times 10^6}{229 \times 10^6} & \frac{8 \times 10^6}{20 \times 10^6} & \frac{8 \times 10^6}{25.485 \times 10^9} & \frac{8 \times 10^6}{2,9 \times 10^6} & \frac{8 \times 10^6}{1.658.126} & \frac{8 \times 10^6}{22 \times 10^6} & \frac{8 \times 10^6}{8 \times 10^6} & \frac{8 \times 10^6}{20 \times 10^6} \\ \frac{10.494 \times 10^9}{229 \times 10^6} & \frac{10.494 \times 10^9}{20 \times 10^6} & \frac{10.494 \times 10^9}{25.485 \times 10^9} & \frac{10.494 \times 10^9}{2,9 \times 10^6} & \frac{10.494 \times 10^9}{1.658.126} & \frac{10.494 \times 10^9}{22 \times 10^6} & \frac{10.494 \times 10^9}{8 \times 10^6} & \frac{10.494 \times 10^9}{20 \times 10^6} \\ \frac{1,2 \times 10^6}{229 \times 10^6} & \frac{1,2 \times 10^6}{20 \times 10^6} & \frac{1,2 \times 10^6}{25.485 \times 10^9} & \frac{1,2 \times 10^6}{2,9 \times 10^6} & \frac{1,2 \times 10^6}{1.658.126} & \frac{1,2 \times 10^6}{22 \times 10^6} & \frac{1,2 \times 10^6}{8 \times 10^6} & \frac{1,2 \times 10^6}{20 \times 10^6} \\ \frac{829.063}{229 \times 10^6} & \frac{829.063}{20 \times 10^6} & \frac{829.063}{25.485 \times 10^9} & \frac{829.063}{2,9 \times 10^6} & \frac{829.063}{1.658.126} & \frac{829.063}{22 \times 10^6} & \frac{829.063}{8 \times 10^6} & \frac{829.063}{20 \times 10^6} \\ \frac{9 \times 10^6}{229 \times 10^6} & \frac{9 \times 10^6}{20 \times 10^6} & \frac{9 \times 10^6}{25.485 \times 10^9} & \frac{9 \times 10^6}{2,9 \times 10^6} & \frac{9 \times 10^6}{1.658.126} & \frac{9 \times 10^6}{22 \times 10^6} & \frac{9 \times 10^6}{8 \times 10^6} & \frac{9 \times 10^6}{20 \times 10^6} \\ \frac{3 \times 10^6}{229 \times 10^6} & \frac{3 \times 10^6}{20 \times 10^6} & \frac{3 \times 10^6}{25.485 \times 10^9} & \frac{3 \times 10^6}{2,9 \times 10^6} & \frac{3 \times 10^6}{1.658.126} & \frac{3 \times 10^6}{22 \times 10^6} & \frac{3 \times 10^6}{8 \times 10^6} & \frac{3 \times 10^6}{20 \times 10^6} \\ \frac{8 \times 10^6}{229 \times 10^6} & \frac{8 \times 10^6}{20 \times 10^6} & \frac{8 \times 10^6}{25.485 \times 10^9} & \frac{8 \times 10^6}{2,9 \times 10^6} & \frac{8 \times 10^6}{1.658.126} & \frac{8 \times 10^6}{22 \times 10^6} & \frac{8 \times 10^6}{8 \times 10^6} & \frac{8 \times 10^6}{20 \times 10^6} \end{bmatrix} \quad (90)$$

- For the *Savannah* maritime container terminal:

$$\Delta y'_{2024} = \begin{bmatrix} 15,8 \times 10^6 \\ 3,5 \times 10^6 \\ 10,494 \times 10^9 \\ 2,8 \times 10^6 \\ 1.212.020 \\ 51 \times 10^6 \\ 2,1 \times 10^6 \\ 1,4 \times 10^6 \end{bmatrix} \quad (91)$$

The vector of reciprocal values of the container transport model elements is:

$$1/y_{2024} = (1/38,3 \times 10^6, 1/8,5 \times 10^6, 1/25,485 \times 10^9, 1/6,8 \times 10^6, 1/2.424.040, 1/124 \times 10^6, 1/5,1 \times 10^6, 1/3,4 \times 10^6) \quad (92)$$

Product of external vector $\Delta y'_{2024}$ and $\frac{1}{y_{2024}}$ determines the growth matrix of the model elements of container transport for the period from 2012 to 2024, both vertically and horizontally.

$$R_{2024} = \begin{bmatrix} 15,8 \times 10^6 & 15,8 \times 10^6 & 15,8 \times 10^6 & 15,8 \times 10^6 & 15,8 \times 10^6 & 15,8 \times 10^6 & 15,8 \times 10^6 & 15,8 \times 10^6 \\ 38,3 \times 10^6 & 8,5 \times 10^6 & 25,485 \times 10^9 & 6,8 \times 10^6 & 2,424.040 & 124 \times 10^6 & 5,1 \times 10^6 & 3,4 \times 10^6 \\ 3,5 \times 10^6 & 3,5 \times 10^6 & 3,5 \times 10^6 & 3,5 \times 10^6 & 3,5 \times 10^6 & 3,5 \times 10^6 & 3,5 \times 10^6 & 3,5 \times 10^6 \\ 38,3 \times 10^6 & 8,5 \times 10^6 & 25,485 \times 10^9 & 6,8 \times 10^6 & 2,424.040 & 124 \times 10^6 & 5,1 \times 10^6 & 3,4 \times 10^6 \\ 10,494 \times 10^9 & 10,494 \times 10^9 & 10,494 \times 10^9 & 10,494 \times 10^9 & 10,494 \times 10^9 & 10,494 \times 10^9 & 10,494 \times 10^9 & 10,494 \times 10^9 \\ 38,3 \times 10^6 & 8,5 \times 10^6 & 25,485 \times 10^9 & 6,8 \times 10^6 & 2,424.040 & 124 \times 10^6 & 5,1 \times 10^6 & 3,4 \times 10^6 \\ 2,8 \times 10^6 & 2,8 \times 10^6 & 2,8 \times 10^6 & 2,8 \times 10^6 & 2,8 \times 10^6 & 2,8 \times 10^6 & 2,8 \times 10^6 & 2,8 \times 10^6 \\ 38,3 \times 10^6 & 8,5 \times 10^6 & 25,485 \times 10^9 & 6,8 \times 10^6 & 2,424.040 & 124 \times 10^6 & 5,1 \times 10^6 & 3,4 \times 10^6 \\ 1.212.020 & 1.212.020 & 1.212.020 & 1.212.020 & 1.212.020 & 1.212.020 & 1.212.020 & 1.212.020 \\ 38,3 \times 10^6 & 8,5 \times 10^6 & 25,485 \times 10^9 & 6,8 \times 10^6 & 2,424.040 & 124 \times 10^6 & 5,1 \times 10^6 & 3,4 \times 10^6 \\ 51 \times 10^6 & 51 \times 10^6 & 51 \times 10^6 & 51 \times 10^6 & 51 \times 10^6 & 51 \times 10^6 & 51 \times 10^6 & 51 \times 10^6 \\ 38,3 \times 10^6 & 8,5 \times 10^6 & 25,485 \times 10^9 & 6,8 \times 10^6 & 2,424.040 & 124 \times 10^6 & 5,1 \times 10^6 & 3,4 \times 10^6 \\ 2,1 \times 10^6 & 2,1 \times 10^6 & 2,1 \times 10^6 & 2,1 \times 10^6 & 2,1 \times 10^6 & 2,1 \times 10^6 & 2,1 \times 10^6 & 2,1 \times 10^6 \\ 38,3 \times 10^6 & 8,5 \times 10^6 & 25,485 \times 10^9 & 6,8 \times 10^6 & 2,424.040 & 124 \times 10^6 & 5,1 \times 10^6 & 3,4 \times 10^6 \\ 1,4 \times 10^6 & 1,4 \times 10^6 & 1,4 \times 10^6 & 1,4 \times 10^6 & 1,4 \times 10^6 & 1,4 \times 10^6 & 1,4 \times 10^6 & 1,4 \times 10^6 \\ 38,3 \times 10^6 & 8,5 \times 10^6 & 25,485 \times 10^9 & 6,8 \times 10^6 & 2,424.040 & 124 \times 10^6 & 5,1 \times 10^6 & 3,4 \times 10^6 \end{bmatrix} \quad (93)$$

- For the *Rotterdam* maritime container terminal:

$$\Delta y'_{2024} = \begin{bmatrix} 2,32 \times 10^{12} \\ 0,88 \times 10^6 \\ 0,14 \times 10^{12} \\ 125 \times 10^6 \\ 11.866 \times 10^6 \\ 2,4 \times 10^6 \\ 21 \times 10^6 \\ 3 \times 10^6 \end{bmatrix} \quad (94)$$

The vector of reciprocal values of the container transport model elements is:

$$1/y_{2024} = (1/13.92 \times 10^{12}, 1/5.28 \times 10^6, 1/0.84 \times 10^{12}, 1/751 \times 10^6, 1/23.732 \times 10^6, 1/14.4 \times 10^6, 1/124 \times 10^6, 1/18 \times 10^6) \quad (95)$$

Product of external vector $\Delta y'_{2024}$ and $\frac{1}{y_{2024}}$ determines the growth matrix of the model elements of container transport for the period from 2012 to 2024, both vertically and horizontally.

$$R_{2024} = \begin{bmatrix} \frac{2,32 \times 10^{12}}{13,92 \times 10^{12}} & \frac{2,32 \times 10^{12}}{5,28 \times 10^6} & \frac{2,32 \times 10^{12}}{0,84 \times 10^{12}} & \frac{2,32 \times 10^{12}}{751 \times 10^6} & \frac{2,32 \times 10^{12}}{23.732 \times 10^6} & \frac{2,32 \times 10^{12}}{14,4 \times 10^6} & \frac{2,32 \times 10^{12}}{124 \times 10^6} & \frac{2,32 \times 10^{12}}{18 \times 10^6} \\ \frac{0,88 \times 10^6}{13,92 \times 10^{12}} & \frac{0,88 \times 10^6}{5,28 \times 10^6} & \frac{0,88 \times 10^6}{0,84 \times 10^{12}} & \frac{0,88 \times 10^6}{751 \times 10^6} & \frac{0,88 \times 10^6}{23.732 \times 10^6} & \frac{0,88 \times 10^6}{14,4 \times 10^6} & \frac{0,88 \times 10^6}{124 \times 10^6} & \frac{0,88 \times 10^6}{18 \times 10^6} \\ \frac{0,14 \times 10^{12}}{13,92 \times 10^{12}} & \frac{0,14 \times 10^{12}}{5,28 \times 10^6} & \frac{0,14 \times 10^{12}}{0,84 \times 10^{12}} & \frac{0,14 \times 10^{12}}{751 \times 10^6} & \frac{0,14 \times 10^{12}}{23.732 \times 10^6} & \frac{0,14 \times 10^{12}}{14,4 \times 10^6} & \frac{0,14 \times 10^{12}}{124 \times 10^6} & \frac{0,14 \times 10^{12}}{18 \times 10^6} \\ \frac{125 \times 10^6}{13,92 \times 10^{12}} & \frac{125 \times 10^6}{5,28 \times 10^6} & \frac{125 \times 10^6}{0,84 \times 10^{12}} & \frac{125 \times 10^6}{751 \times 10^6} & \frac{125 \times 10^6}{23.732 \times 10^6} & \frac{125 \times 10^6}{14,4 \times 10^6} & \frac{125 \times 10^6}{124 \times 10^6} & \frac{125 \times 10^6}{18 \times 10^6} \\ \frac{11.866 \times 10^6}{13,92 \times 10^{12}} & \frac{11.866 \times 10^6}{5,28 \times 10^6} & \frac{11.866 \times 10^6}{0,84 \times 10^{12}} & \frac{11.866 \times 10^6}{751 \times 10^6} & \frac{11.866 \times 10^6}{23.732 \times 10^6} & \frac{11.866 \times 10^6}{14,4 \times 10^6} & \frac{11.866 \times 10^6}{124 \times 10^6} & \frac{11.866 \times 10^6}{18 \times 10^6} \\ \frac{2,4 \times 10^6}{13,92 \times 10^{12}} & \frac{2,4 \times 10^6}{5,28 \times 10^6} & \frac{2,4 \times 10^6}{0,84 \times 10^{12}} & \frac{2,4 \times 10^6}{751 \times 10^6} & \frac{2,4 \times 10^6}{23.732 \times 10^6} & \frac{2,4 \times 10^6}{14,4 \times 10^6} & \frac{2,4 \times 10^6}{124 \times 10^6} & \frac{2,4 \times 10^6}{18 \times 10^6} \\ \frac{21 \times 10^6}{13,92 \times 10^{12}} & \frac{21 \times 10^6}{5,28 \times 10^6} & \frac{21 \times 10^6}{0,84 \times 10^{12}} & \frac{21 \times 10^6}{751 \times 10^6} & \frac{21 \times 10^6}{23.732 \times 10^6} & \frac{21 \times 10^6}{14,4 \times 10^6} & \frac{21 \times 10^6}{124 \times 10^6} & \frac{21 \times 10^6}{18 \times 10^6} \\ \frac{3 \times 10^6}{13,92 \times 10^{12}} & \frac{3 \times 10^6}{5,28 \times 10^6} & \frac{3 \times 10^6}{0,84 \times 10^{12}} & \frac{3 \times 10^6}{751 \times 10^6} & \frac{3 \times 10^6}{23.732 \times 10^6} & \frac{3 \times 10^6}{14,4 \times 10^6} & \frac{3 \times 10^6}{124 \times 10^6} & \frac{3 \times 10^6}{18 \times 10^6} \end{bmatrix} \quad (96)$$

- For the *Le Havre* maritime container terminal:

$$\Delta y'_{2024} = \begin{bmatrix} 6 \times 10^6 \\ 1,2 \times 10^5 \\ 0,52 \times 10^{12} \\ 1,2 \times 10^5 \\ 0,48 \times 10^6 \\ 0,02 \times 10^6 \\ 35 \times 10^6 \\ 25 \times 10^6 \end{bmatrix} \quad (97)$$

The vector of reciprocal values of the container transport model elements is:

$$1/y_{2024} = (1/34 \times 10^6, 1/7,2 \times 10^5, 1/3,12 \times 10^{12}, 1/7,2 \times 10^5, 1/2,88 \times 10^6, 1/0,12 \times 10^6, 1/209 \times 10^6, 1/154 \times 10^6) \quad (98)$$

Product of external vector $\Delta y'_{2024}$ and $\frac{1}{y_{2024}}$ determines the growth matrix of the model elements of container transport for the period from 2012 to 2024, both vertically and horizontally.

$$R_{2024} = \begin{bmatrix} \frac{6 \times 10^6}{34 \times 10^6} & \frac{6 \times 10^6}{7,2 \times 10^5} & \frac{6 \times 10^6}{3,12 \times 10^{12}} & \frac{6 \times 10^6}{7,2 \times 10^5} & \frac{6 \times 10^6}{2,88 \times 10^6} & \frac{6 \times 10^6}{0,12 \times 10^6} & \frac{6 \times 10^6}{209 \times 10^6} & \frac{6 \times 10^6}{154 \times 10^6} \\ \frac{1,2 \times 10^5}{34 \times 10^6} & \frac{1,2 \times 10^5}{7,2 \times 10^5} & \frac{1,2 \times 10^5}{3,12 \times 10^{12}} & \frac{1,2 \times 10^5}{7,2 \times 10^5} & \frac{1,2 \times 10^5}{2,88 \times 10^6} & \frac{1,2 \times 10^5}{0,12 \times 10^6} & \frac{1,2 \times 10^5}{209 \times 10^6} & \frac{1,2 \times 10^5}{154 \times 10^6} \\ \frac{0,52 \times 10^{12}}{34 \times 10^6} & \frac{0,52 \times 10^{12}}{7,2 \times 10^5} & \frac{0,52 \times 10^{12}}{3,12 \times 10^{12}} & \frac{0,52 \times 10^{12}}{7,2 \times 10^5} & \frac{0,52 \times 10^{12}}{2,88 \times 10^6} & \frac{0,52 \times 10^{12}}{0,12 \times 10^6} & \frac{0,52 \times 10^{12}}{209 \times 10^6} & \frac{0,52 \times 10^{12}}{154 \times 10^6} \\ \frac{1,2 \times 10^5}{34 \times 10^6} & \frac{1,2 \times 10^5}{7,2 \times 10^5} & \frac{1,2 \times 10^5}{3,12 \times 10^{12}} & \frac{1,2 \times 10^5}{7,2 \times 10^5} & \frac{1,2 \times 10^5}{2,88 \times 10^6} & \frac{1,2 \times 10^5}{0,12 \times 10^6} & \frac{1,2 \times 10^5}{209 \times 10^6} & \frac{1,2 \times 10^5}{154 \times 10^6} \\ \frac{0,48 \times 10^6}{34 \times 10^6} & \frac{0,48 \times 10^6}{7,2 \times 10^5} & \frac{0,48 \times 10^6}{3,12 \times 10^{12}} & \frac{0,48 \times 10^6}{7,2 \times 10^5} & \frac{0,48 \times 10^6}{2,88 \times 10^6} & \frac{0,48 \times 10^6}{0,12 \times 10^6} & \frac{0,48 \times 10^6}{209 \times 10^6} & \frac{0,48 \times 10^6}{154 \times 10^6} \\ \frac{0,02 \times 10^6}{34 \times 10^6} & \frac{0,02 \times 10^6}{7,2 \times 10^5} & \frac{0,02 \times 10^6}{3,12 \times 10^{12}} & \frac{0,02 \times 10^6}{7,2 \times 10^5} & \frac{0,02 \times 10^6}{2,88 \times 10^6} & \frac{0,02 \times 10^6}{0,12 \times 10^6} & \frac{0,02 \times 10^6}{209 \times 10^6} & \frac{0,02 \times 10^6}{154 \times 10^6} \\ \frac{35 \times 10^6}{34 \times 10^6} & \frac{35 \times 10^6}{7,2 \times 10^5} & \frac{35 \times 10^6}{3,12 \times 10^{12}} & \frac{35 \times 10^6}{7,2 \times 10^5} & \frac{35 \times 10^6}{2,88 \times 10^6} & \frac{35 \times 10^6}{0,12 \times 10^6} & \frac{35 \times 10^6}{209 \times 10^6} & \frac{35 \times 10^6}{154 \times 10^6} \\ \frac{25 \times 10^6}{34 \times 10^6} & \frac{25 \times 10^6}{7,2 \times 10^5} & \frac{25 \times 10^6}{3,12 \times 10^{12}} & \frac{25 \times 10^6}{7,2 \times 10^5} & \frac{25 \times 10^6}{2,88 \times 10^6} & \frac{25 \times 10^6}{0,12 \times 10^6} & \frac{25 \times 10^6}{209 \times 10^6} & \frac{25 \times 10^6}{154 \times 10^6} \end{bmatrix} \quad (99)$$

- For the Antwerp maritime container terminal:

$$\Delta y'_{2024} = \begin{bmatrix} 50 \times 10^6 \\ 6 \times 10^6 \\ 1 \times 10^{12} \\ 16,4 \times 10^6 \\ 8,6 \times 10^6 \\ 4 \times 10^6 \\ 6 \times 10^6 \\ 27 \times 10^6 \end{bmatrix} \quad (100)$$

The vector of reciprocal values of the container transport model elements is:

$$1/y_{2024} = (1/298 \times 10^6, 1/35 \times 10^6, 1/5,8 \times 10^{12}, 1/31,8 \times 10^6, 1/17,2 \times 10^6, 1/24 \times 10^6, 1/36 \times 10^6, 1/162 \times 10^6) \quad (101)$$

Product of external vector $\Delta y'_{2024}$ and $\frac{1}{y_{2024}}$ determines the growth matrix of the model elements of container transport for the period from 2012 to 2024, both vertically and horizontally.

$$R_{2024} = \begin{bmatrix} \frac{50 \times 10^6}{298 \times 10^6} & \frac{50 \times 10^6}{7,2 \times 10^5} & \frac{50 \times 10^6}{5,8 \times 10^{12}} & \frac{50 \times 10^6}{31,8 \times 10^6} & \frac{50 \times 10^6}{17,2 \times 10^6} & \frac{50 \times 10^6}{24 \times 10^6} & \frac{50 \times 10^6}{36 \times 10^6} & \frac{50 \times 10^6}{162 \times 10^6} \\ \frac{6 \times 10^6}{298 \times 10^6} & \frac{6 \times 10^6}{35 \times 10^6} & \frac{6 \times 10^6}{5,8 \times 10^{12}} & \frac{6 \times 10^6}{31,8 \times 10^6} & \frac{6 \times 10^6}{17,2 \times 10^6} & \frac{6 \times 10^6}{24 \times 10^6} & \frac{6 \times 10^6}{36 \times 10^6} & \frac{6 \times 10^6}{162 \times 10^6} \\ \frac{1 \times 10^{12}}{298 \times 10^6} & \frac{1 \times 10^{12}}{35 \times 10^6} & \frac{1 \times 10^{12}}{5,8 \times 10^{12}} & \frac{1 \times 10^{12}}{31,8 \times 10^6} & \frac{1 \times 10^{12}}{17,2 \times 10^6} & \frac{1 \times 10^{12}}{24 \times 10^6} & \frac{1 \times 10^{12}}{36 \times 10^6} & \frac{1 \times 10^{12}}{162 \times 10^6} \\ \frac{16,4 \times 10^6}{298 \times 10^6} & \frac{16,4 \times 10^6}{35 \times 10^6} & \frac{16,4 \times 10^6}{5,8 \times 10^{12}} & \frac{16,4 \times 10^6}{31,8 \times 10^6} & \frac{16,4 \times 10^6}{17,2 \times 10^6} & \frac{16,4 \times 10^6}{24 \times 10^6} & \frac{16,4 \times 10^6}{36 \times 10^6} & \frac{16,4 \times 10^6}{162 \times 10^6} \\ \frac{8,6 \times 10^6}{298 \times 10^6} & \frac{8,6 \times 10^6}{35 \times 10^6} & \frac{8,6 \times 10^6}{5,8 \times 10^{12}} & \frac{8,6 \times 10^6}{31,8 \times 10^6} & \frac{8,6 \times 10^6}{17,2 \times 10^6} & \frac{8,6 \times 10^6}{24 \times 10^6} & \frac{8,6 \times 10^6}{36 \times 10^6} & \frac{8,6 \times 10^6}{162 \times 10^6} \\ \frac{4 \times 10^6}{298 \times 10^6} & \frac{4 \times 10^6}{35 \times 10^6} & \frac{4 \times 10^6}{5,8 \times 10^{12}} & \frac{4 \times 10^6}{31,8 \times 10^6} & \frac{4 \times 10^6}{17,2 \times 10^6} & \frac{4 \times 10^6}{24 \times 10^6} & \frac{4 \times 10^6}{36 \times 10^6} & \frac{4 \times 10^6}{162 \times 10^6} \\ \frac{6 \times 10^6}{298 \times 10^6} & \frac{6 \times 10^6}{35 \times 10^6} & \frac{6 \times 10^6}{5,8 \times 10^{12}} & \frac{6 \times 10^6}{31,8 \times 10^6} & \frac{6 \times 10^6}{17,2 \times 10^6} & \frac{6 \times 10^6}{24 \times 10^6} & \frac{6 \times 10^6}{36 \times 10^6} & \frac{6 \times 10^6}{162 \times 10^6} \\ \frac{27 \times 10^6}{298 \times 10^6} & \frac{27 \times 10^6}{35 \times 10^6} & \frac{27 \times 10^6}{5,8 \times 10^{12}} & \frac{27 \times 10^6}{31,8 \times 10^6} & \frac{27 \times 10^6}{17,2 \times 10^6} & \frac{27 \times 10^6}{24 \times 10^6} & \frac{27 \times 10^6}{36 \times 10^6} & \frac{27 \times 10^6}{162 \times 10^6} \end{bmatrix} \quad (102)$$

- For the *Hamburg* maritime container terminal:

$$\Delta y'_{2024} = \begin{bmatrix} 2 \times 10^6 \\ 9,2 \times 10^6 \\ 0,68 \times 10^{12} \\ 50,6 \times 10^6 \\ 4,7 \times 10^6 \\ 68 \times 10^6 \\ 3,4 \times 10^6 \\ 1,12 \times 10^6 \end{bmatrix} \quad (103)$$

The vector of reciprocal values of the container transport model elements is:

$$1/y_{2024} = (1/214 \times 10^6, 1/55,2 \times 10^6, 1/4,1 \times 10^{12}, 1/303,6 \times 10^6, 1/9,4 \times 10^6, 1/406 \times 10^6, 1/20,4 \times 10^6, 1/6,72 \times 10^6) \quad (104)$$

Product of external vector $\Delta y'_{2024}$ and $\frac{1}{y_{2024}}$ determines the growth matrix of the model elements of container transport for the period from 2012 to 2024, both vertically and horizontally.

$$R_{2024} = \begin{bmatrix} 2 \times 10^6 & 2 \times 10^6 & 2 \times 10^6 & 2 \times 10^6 & 2 \times 10^6 & 2 \times 10^6 & 2 \times 10^6 & 2 \times 10^6 \\ 214 \times 10^6 & 55,2 \times 10^6 & 4,1 \times 10^{12} & 303,6 \times 10^6 & 9,4 \times 10^6 & 406 \times 10^6 & 20,4 \times 10^6 & 6,72 \times 10^6 \\ 9,2 \times 10^6 & 9,2 \times 10^6 & 9,2 \times 10^6 & 9,2 \times 10^6 & 9,2 \times 10^6 & 9,2 \times 10^6 & 9,2 \times 10^6 & 9,2 \times 10^6 \\ 214 \times 10^6 & 55,2 \times 10^6 & 4,1 \times 10^{12} & 303,6 \times 10^6 & 9,4 \times 10^6 & 406 \times 10^6 & 20,4 \times 10^6 & 6,72 \times 10^6 \\ 0,68 \times 10^{12} & 0,68 \times 10^{12} & 0,68 \times 10^{12} & 0,68 \times 10^{12} & 0,68 \times 10^{12} & 0,68 \times 10^{12} & 0,68 \times 10^{12} & 0,68 \times 10^{12} \\ 214 \times 10^6 & 55,2 \times 10^6 & 4,1 \times 10^{12} & 303,6 \times 10^6 & 9,4 \times 10^6 & 406 \times 10^6 & 20,4 \times 10^6 & 6,72 \times 10^6 \\ 50,6 \times 10^6 & 50,6 \times 10^6 & 50,6 \times 10^6 & 50,6 \times 10^6 & 50,6 \times 10^6 & 50,6 \times 10^6 & 50,6 \times 10^6 & 50,6 \times 10^6 \\ 214 \times 10^6 & 55,2 \times 10^6 & 4,1 \times 10^{12} & 303,6 \times 10^6 & 9,4 \times 10^6 & 406 \times 10^6 & 20,4 \times 10^6 & 6,72 \times 10^6 \\ 4,7 \times 10^6 & 4,7 \times 10^6 & 4,7 \times 10^6 & 4,7 \times 10^6 & 4,7 \times 10^6 & 4,7 \times 10^6 & 4,7 \times 10^6 & 4,7 \times 10^6 \\ 214 \times 10^6 & 55,2 \times 10^6 & 4,1 \times 10^{12} & 303,6 \times 10^6 & 9,4 \times 10^6 & 406 \times 10^6 & 20,4 \times 10^6 & 6,72 \times 10^6 \\ 68 \times 10^6 & 68 \times 10^6 & 68 \times 10^6 & 68 \times 10^6 & 68 \times 10^6 & 68 \times 10^6 & 68 \times 10^6 & 68 \times 10^6 \\ 214 \times 10^6 & 55,2 \times 10^6 & 4,1 \times 10^{12} & 303,6 \times 10^6 & 9,4 \times 10^6 & 406 \times 10^6 & 20,4 \times 10^6 & 6,72 \times 10^6 \\ 3,4 \times 10^6 & 3,4 \times 10^6 & 3,4 \times 10^6 & 3,4 \times 10^6 & 3,4 \times 10^6 & 3,4 \times 10^6 & 3,4 \times 10^6 & 3,4 \times 10^6 \\ 214 \times 10^6 & 55,2 \times 10^6 & 4,1 \times 10^{12} & 303,6 \times 10^6 & 9,4 \times 10^6 & 406 \times 10^6 & 20,4 \times 10^6 & 6,72 \times 10^6 \\ 1,12 \times 10^6 & 1,12 \times 10^6 & 1,12 \times 10^6 & 1,12 \times 10^6 & 1,12 \times 10^6 & 1,12 \times 10^6 & 1,12 \times 10^6 & 1,12 \times 10^6 \\ 214 \times 10^6 & 55,2 \times 10^6 & 4,1 \times 10^{12} & 303,6 \times 10^6 & 17,2 \times 10^6 & 406 \times 10^6 & 20,4 \times 10^6 & 6,72 \times 10^6 \end{bmatrix} \quad (105)$$

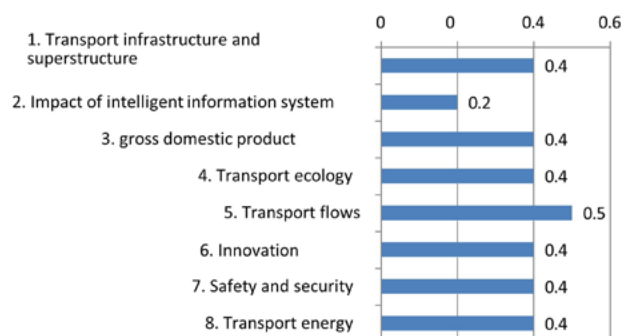
Table 18 shows the growth matrix of the container transport model elements for the New York maritime container terminal for the period 2012-2024.

Table 18 - Growth matrix of container transport model elements
for the New York maritime container terminal for the period 2012-2024

	1	2	3	4	5	6	7	8
1	0.4	24.42	0.0007	2,048	2,024	5	87	850
2	0.003	0	4.7×10^{-6}	14	14	0.034	0.6	5.8
3	250	150,775	0.4	1.3×10^6	1.2×10^6	3,086	53,815	524,700
4	8×10^{-4}	0.005	1.4×10^{-7}	0.4	0.4	1	0.02	0.2
5	0.0001	0.006	1.7×10^{-7}	0	0.5	1.2	0.02	0.006
6	0.03	2	6×10^{-5}	169	167	0.4	7	70
7	0.002	0.1	3.3×10^{-6}	10	10	23	0.4	4
8	2×10^{-4}	0.01	3.3×10^{-7}	1	1	0.002	0.04	0.4

Source: Prepared by the author based on source material.

Graph 5 - Direct growth rates of container transport model elements
for the New York maritime container terminal in the period 2009-2015

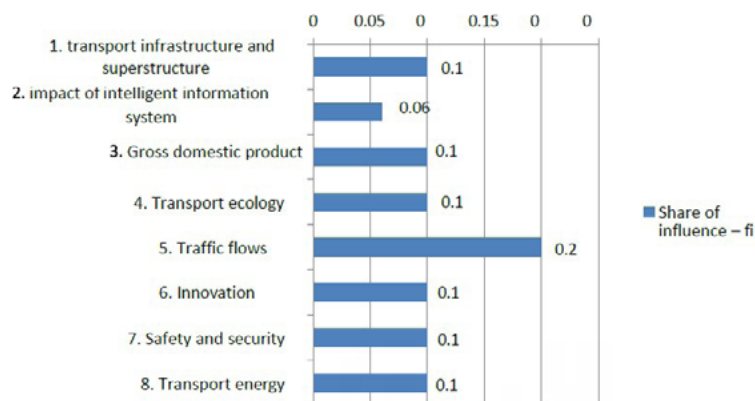


Source: Prepared by the author based on source material.

Graph 5 shows that the highest level of development in the period from 2012 to 2024 at the New York maritime container terminal is in the element of traffic flows, with a value of 0.5; follow by the elements of transport infrastructure and superstructure, gross domestic product, transport ecology, innovation, safety and security, and transport energy with a value of 0.4; the element of the impact of an intelligent information system has a value of 0.2.

The calculated influence factors of individual elements of the container transport model for the New York maritime container terminal are shown in Graph 6.

Graph 6 - Influence factors of individual elements of the container transport model for the New York Maritime Container Terminal for the period 2012-2024



Source: Prepared by the author based on source material.

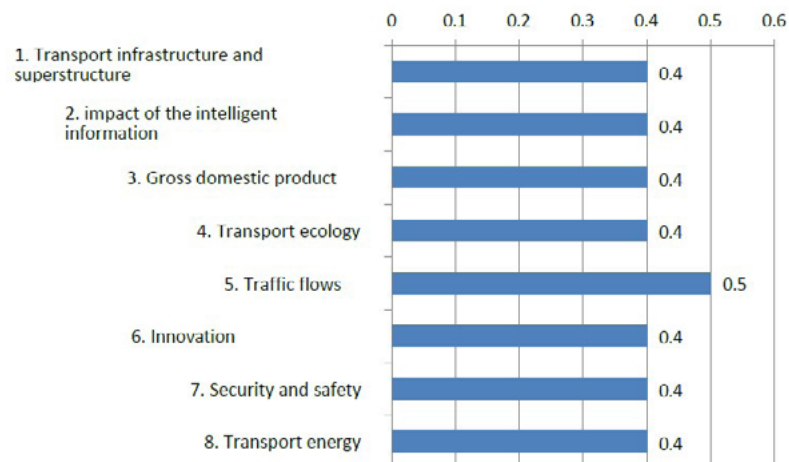
Table 19 shows the growth matrix of the container transport model elements for the Boston maritime container terminal in the period 2012-2024.

**Table 19 - Growth matrix of container transport model elements
for the Boston maritime container terminal in the period 2012-2024**

1	0.4	1.8	2.6×10^{-6}	1.7	573	26.4	0.6	3.5
2	0.1	0.4	5.9×10^{-7}	0.4	130	6	0.1	0.8
3	65,587	219,500	0.4	267,022	9.1×10^7	4.2×10^6	100,903	561,176
4	0.1	0.45	6.4×10^{-7}	0.4	141	6.5	0	0.9
5	0.0004	0.002	2.3×10^{-9}	0.001	0.5	0.02	5.5×10^{-4}	0.003
6	0.006	0.03	4×10^{-8}	0.03	8.7	0.5	0.01	0.05
7	0.3	1	1.7×10^{-6}	1	373	172	0.4	2.3
8	0.04	0.2	3×10^{-7}	0.2	67	3	0.1	0.4

Source: Prepared by the author based on source material.

**Graph 7 - Direct growth rates of elements of the container transport model
for the Boston maritime container terminal in the period 2012-2024**

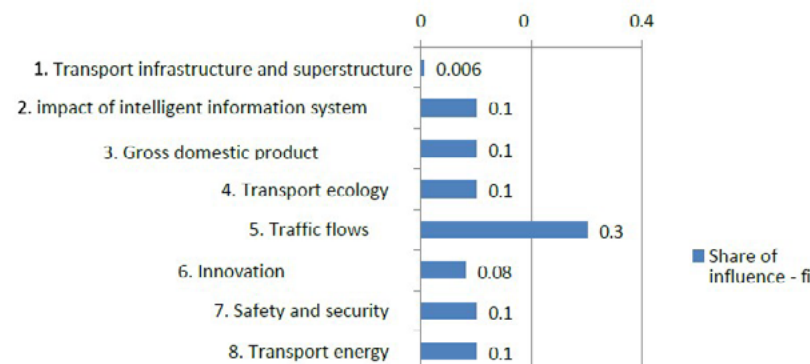


Source: Prepared by the author based on source material.

Graph 7 shows that the highest level of development in the period from 2012 to 2024 at the Boston maritime container terminal is in the element of traffic flows, with a value of 0.5; follow by the elements of transport infrastructure and superstructure, gross domestic product, transport ecology, innovation, safety and security, transport energy, and the impact of the intelligent information system with a value of 0.4.

The calculated impact factors of individual elements of the container transport model for the Boston maritime container terminal are shown in Graph 8.

Graph 8 - Influence factors of individual elements of the container transport model for Boston maritime container terminal in the period 2012-2024



Source: Prepared by the author based on source material.

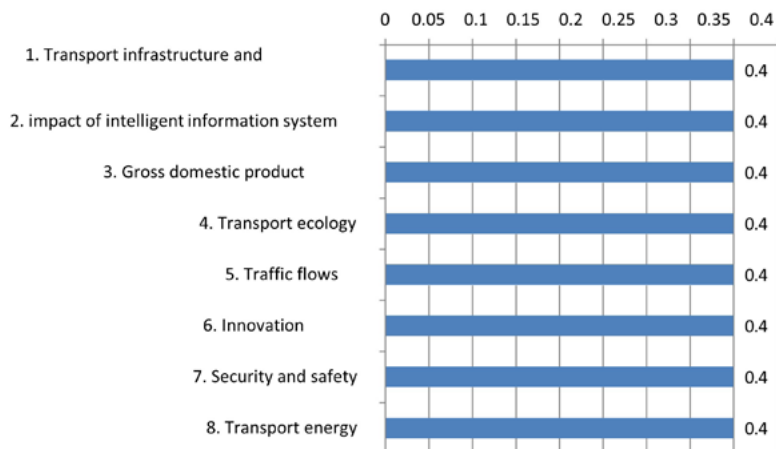
Table 20 shows the growth matrix of the container transport model elements for the Philadelphia maritime container terminal in the period 2012-2024.

**Table 20 - Growth matrix of container transport model elements
for the Philadelphia seaport container terminal in the period 2012-2024**

1	0.4	0	2.6×10^{-6}	1	818	0.9	0.1	1.1
2	0.7	0.4	4.2×10^{-6}	1.7	1,313	1.5	0.2	1.7
3	65,180	40,674	0.4	172,032	130×10^6	147,803	20,576	172,033
4	0.2	0	9.8×10^{-7}	0.4	310	0.4	0.05	0.4
5	2×10^{-4}	1.3×10^{-4}	1.3×10^{-9}	5×10^{-3}	0.4	4.7×10^{-4}	5.5×10^{-5}	5.4×10^{-4}
6	0.2	0.1	1.1×10^{-6}	0.5	359	0.4	0.06	0.5
7	1.3	0.8	8.2×10^{-6}	3.4	2,602	2.9	0.4	3.4
8	0.15	0.09	9.8×10^{-7}	0.4	310	0.35	0.05	0.4

Source: Prepared by the author based on source material.

**Graph 9 - Direct growth rates of elements of the container transport model
for maritime container terminal Philadelphia in time period 2012-2024**

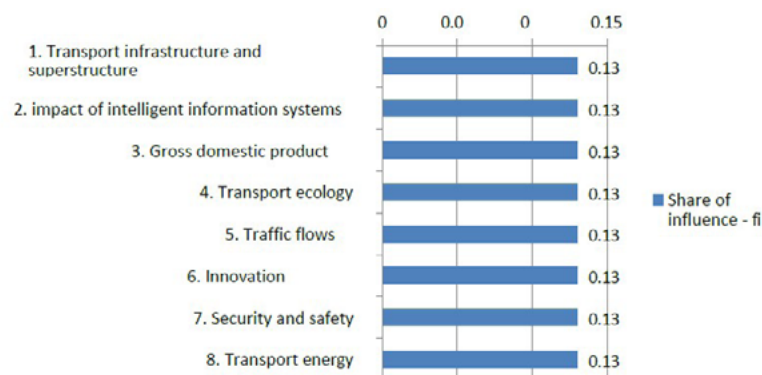


Source: Prepared by the author based on source material.

Graph 9 shows that the elements of the container transport model have a development level of 0.4 in the period from 2012 to 2024 at the Boston maritime container terminal.

The calculated impact factors of individual elements of the container transport model for the Philadelphia maritime container terminal are shown in Graph 10.

Graph 10 - Factors influencing individual elements of the container transport model for maritime container terminal Philadelphia in time period 2012-2024



Source: Prepared by the author based on source material.

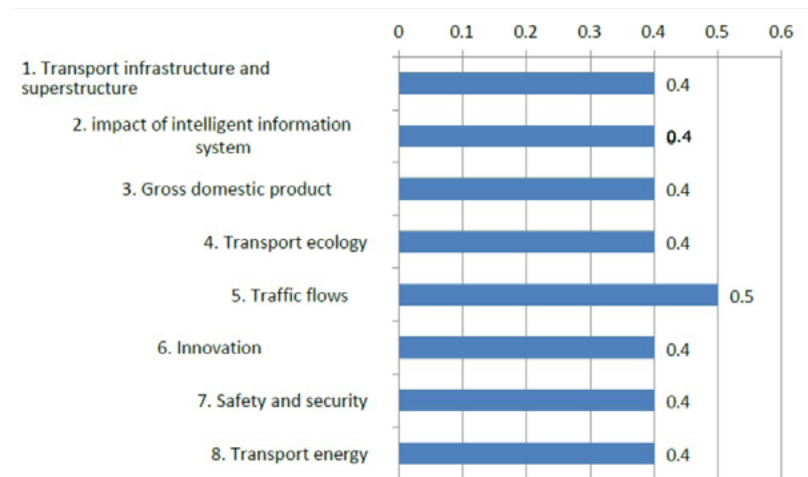
Table 21 shows the growth matrix of the container transport model elements for the Baltimore maritime container terminal in the period 2012-2024.

Table 21 - Growth matrix of container transport model elements for the Baltimore maritime container terminal in the period 2012-2024

1	0.4	1.9	3.8×10^{-6}	57	251	3.4	14	1.9
2	0.09	0.4	8.2×10^{-7}	12.4	53.7	0	3	0.4
3	44,092	205,765	0.4	6.2×10^6	2.7×10^6	361,862	1.5×10^6	205,765
4	3×10^{-3}	13×10^{-3}	2.7×10^{-8}	0.4	1,789	0.02	0	0.01
5	8.2×10^{-4}	4×10^{-3}	7.7×10^{-9}	0.1	0.5	0.01	0.03	4×10^{-3}
6	0.05	0.2	4.7×10^{-7}	7	30.7	0.4	1.7	0.2
7	0.01	0.06	1.2×10^{-7}	1.8	7.7	0	0.4	0.05
8	0.01	0.4	8.2×10^{-7}	12	54	0.7	3	0.4

Source: Prepared by the author based on source material.

Graph 11 - Direct growth rates of container transport model elements for Baltimore maritime container terminal for the period 2012-2024

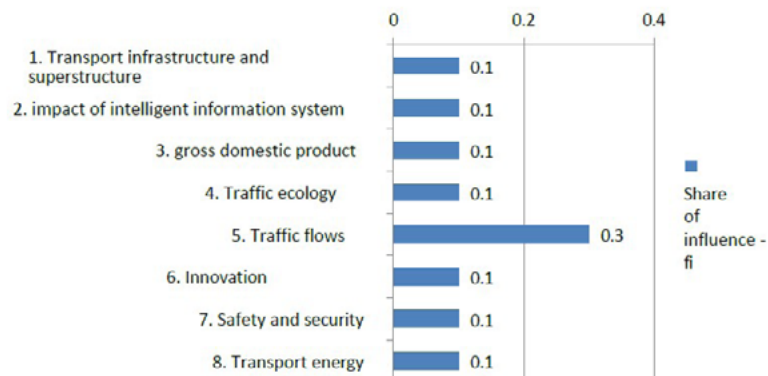


Source: Prepared by the author based on source material.

Graph 11 shows that the highest level of development in the period from 2012 to 2024 at the Baltimore maritime container terminal is in the transport flows element, with a value of 0.5; follow by the elements of transport infrastructure and superstructure, gross domestic product, transport ecology, innovation, safety and security, transport energy, and the impact of an intelligent information system, with a value of 0.4.

The calculated impact factors of individual elements of the container transport model for the Baltimore maritime container terminal are shown in Figure 12.

Graph 12 - Influence factors of individual elements of the container transport model for Baltimore maritime container terminal in the period 2012-2024



Source: Prepared by the author based on source material.

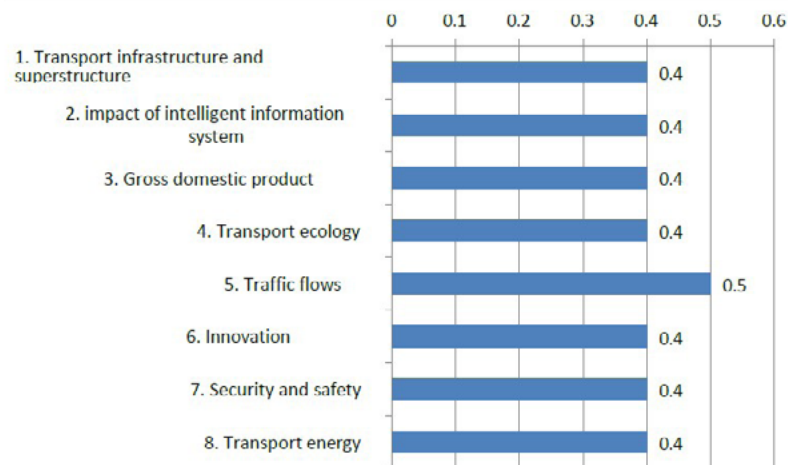
Table 22 shows the growth matrix of the container transport model elements for the Norfolk maritime container terminal in the period 2012-2024.

Table 22 - Growth matrix of container transport model elements for the Norfolk maritime container terminal in the period 2012-2024

1	0.4	4.7	3.7×10^{-6}	3	56.7	4.3	11.8	4.7
2	0.03	0.4	3.1×10^{-7}	2.7	4.8	0.4	1	0.4
3	45,825	524,700	0.4	3.6×10^6	6.3×10^6	477,000	1.3×10^6	524,700
4	5×10^{-3}	0.06	4.7×10^{-8}	0.4	0.7	0.05	0.15	0.06
5	4×10^{-3}	0.04	3.3×10^{-8}	0.3	0.5	0.04	0	0.04
6	0.03	0.45	3.5×10^{-7}	3	5.4	0.4	1.1	0.5
7	0.01	0.15	1.2×10^{-7}	1	1.8	0	0.4	0.15
8	0.03	0.4	3.1×10^{-7}	2.8	4.8	0.4	1	0.4

Source: Prepared by the author based on source material.

Graph 13 - Direct growth rates of container transport model elements for Norfolk maritime container terminal for the period 2012-2024

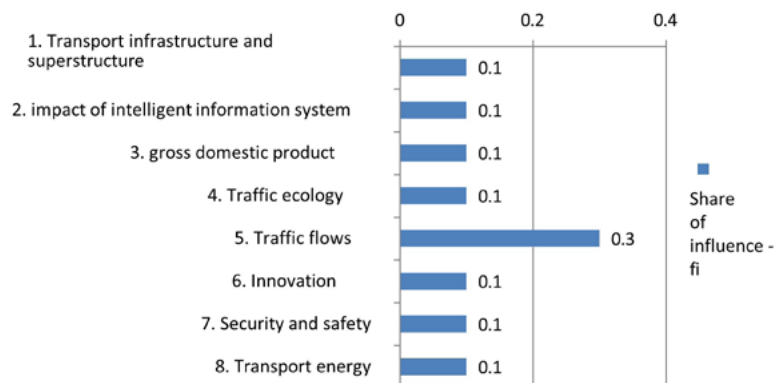


Source: Prepared by the author based on source material.

Graph 13 shows that the highest level of development in the period from 2012 to 2024 at the Norfolk maritime container terminal is in the transport flows element, with a value of 0.5; follow by the elements of transport infrastructure and superstructure, gross domestic product, transport ecology, innovation, safety and security, transport energy, and the impact of an intelligent information system, with a value of 0.4.

The calculated impact factors of individual elements of the container transport model for the Norfolk maritime container terminal are shown in Graph 14.

Graph 14 - Influence factors of individual elements of the container transport model for Norfolk maritime container terminal in the period 2012-2024



Source: Prepared by the author based on source material.

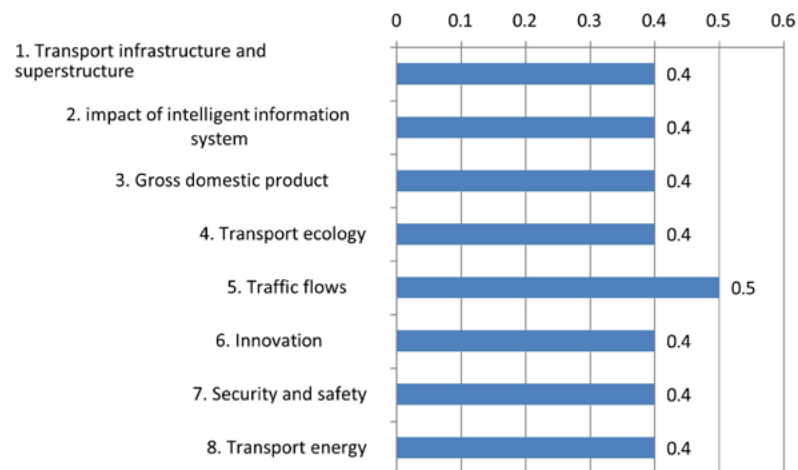
Table 23 shows the growth matrix of the container transport model elements for the Savannah maritime container terminal in the period 2012-2024.

Table 23 - Growth matrix of container transport model elements for the Savannah maritime container terminal in the period 2012-2024

1	0.4	1.9	6.2×10^{-7}	2	6.5	0.1	3	4.6
2	0.1	0.4	1.4×10^{-7}	0.5	1.4	0.03	0.7	1
3	273,995	1.2×10^6	0.4	1.5×10^6	4.3	84,629	1.9×10^6	3×10^6
4	0.1	0.3	1×10^{-7}	0.4	1.2	0.02	0.5	0.8
5	0.03	0	4.8×10^{-8}	0	0.5	0.0	0.2	0.4
6	1.3	6	2×10^{-6}	7.5	21	0.4	10	15
7	0.05	0	8.2×10^{-8}	0	0.5	0.02	0.4	0.6
8	0.04	0	5.5×10^{-8}	0.2	0.6	0.01	0.3	0.4

Source: Prepared by the author based on source material.

**Graph 15 - Direct growth rates of container transport model elements
for the the Savannah maritime container terminal in the period 2012-2024**

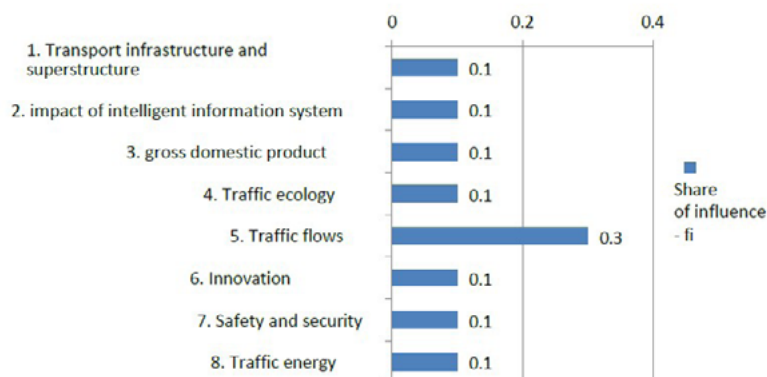


Source: Prepared by the author based on source material.

Graph 15 shows that the highest level of development in the period from 2012 to 2024 at the Savannah maritime container terminal is in the element of traffic flows, with a value of 0.5; follow by the elements of transport infrastructure and superstructure, gross domestic product, transport ecology, innovation, safety and security, transport energy, and the impact of the intelligent information system, with a value of 0.4.

The calculated impact factors of individual elements of the container transport model for the Savannah maritime container terminal are shown in Figure 16.

Graph 16 - Impact factors of individual elements of the container transport model for the Savannah maritime container terminal in the period 2012-2024



Source: Prepared by the author based on source material.

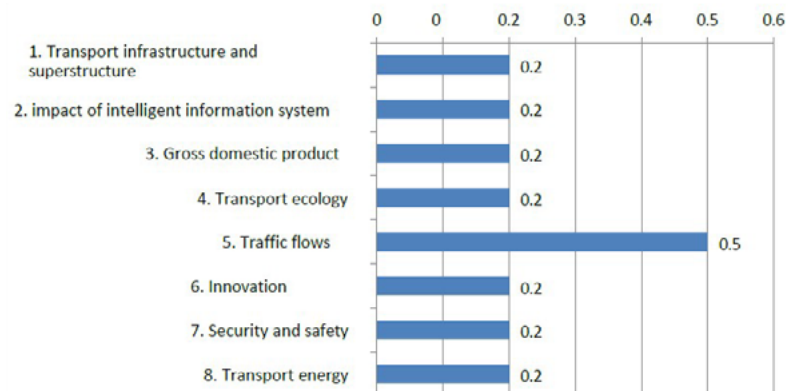
Table 24 shows the growth matrix of the container transport model elements for the Savannah maritime container terminal in the period 2012-2024.

Table 24 -Growth matrix of container transport model elements for the Rotterdam maritime container terminal in the period 2012-2024

1	0.2	0.4×10^6	2.8	3,089	378	161,111	18,710	128,890
2	6.3×10^{-8}	0.2	1×10^{-6}	1×10^{-3}	3.7×10^{-5}	0.06	0.01	0.05
3	0.01	26,515	0.2	186	5.9	9,722	1,129	7,778
4	8.9×10^{-6}	21	1.5×10^{-4}	0.2	5×10^{-3}	8.7	1	7
5	8.5×10^{-4}	2,247	0.01	16	0.5	824	96	659
6	1.7×10^{-7}	0.5	2.9×10^{-6}	3×10^{-3}	1×10^{-4}	0.2	0.02	0.1
7	1.5×10^{-6}	43.9	2.5×10^{-5}	0.03	8.8×10^{-4}	1.5	0.2	1.2
8	2.2×10^{-7}	0.6	3.6×10^{-6}	4×10^{-3}	1.3×10^{-4}	0.2	0.07	0.2

Source: Prepared by the author based on source material.

**Graph 17 - Direct growth rates of elements of the container transport model
for maritime container terminal Rotterdam in time period 2012-2024**

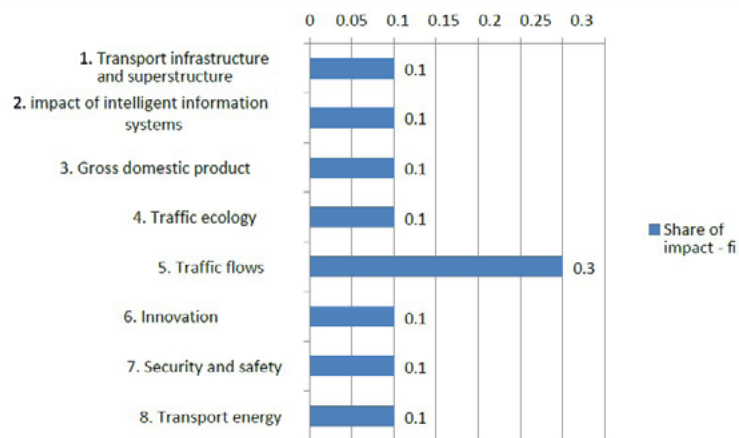


Source: Prepared by the author based on source material.

Graph 17 shows that the highest level of development in the period from 2012 to 2024 in the Rotterdam maritime container terminal is in the transport flows element, with a value of 0.5; follow by the elements of transport infrastructure and superstructure, gross domestic product, transport ecology, innovation, safety and security, transport energy, and the impact of the intelligent information system, with a value of 0.2.

The calculated impact factors of individual elements of the container transport model for the Rotterdam maritime container terminal are shown in Graph 18.

Graph 18 - Impact factors of individual elements of the container transport model for the Rotterdam maritime container terminal container terminal Rotterdam in time period 2012-2024



Source: Prepared by the author based on source material.

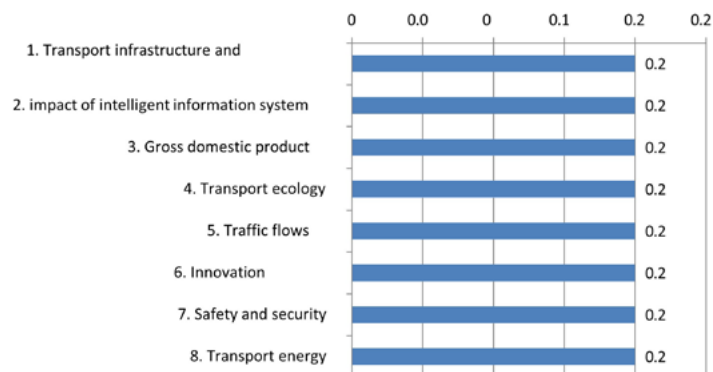
Table 25 shows the growth matrix of the container transport model elements for the Le Havre maritime container terminal for the period 2012-2024.

Table 25 - Growth matrix of container transport model elements for the Le Havre maritime container terminal in the period 2012-2024

1	0.2	8.3	1.9×10^{-6}	8.3	2	50	0.03	0.04
2	4×10^{-3}	0.2	3.8×10^{-8}	0.16	0.04	1	5.7×10^{-4}	7.8×10^{-4}
3	15,294	722,222	0.2	722,222	180,556	4.3×10^6	2,488	3,377
4	0.04	0.2	3.8×10^{-8}	0.2	5×10^{-3}	8.7	1	7
5	0.01	0.7	1.5×10^{-7}	0.7	0.2	4	2×10^{-3}	3×10^{-3}
6	0.7	0.03	6.4×10^{-9}	0.03	0.01	0.2	9.6×10^{-6}	1.3×10^{-4}
7	1	49	1×10^{-5}	49	12	292	0.2	0.2
8	0.7	35	8×10^{-6}	35	8.7	208	0.1	0.2

Source: Prepared by the author based on source material.

Graph 19 - Direct growth rates of container transport model elements for Le Havre maritime container terminal for the period 2012-2024

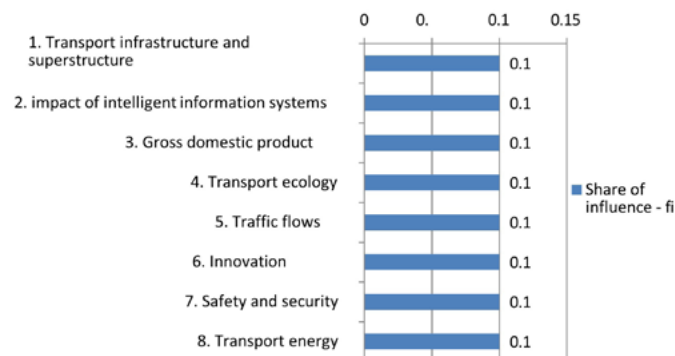


Source: Prepared by the author based on source material.

Graph 19 shows that all elements of the container transport model at the Le Havre maritime container terminal have a development level of 0.2 for the period 2012-2024.

The calculated impact factors of individual elements of the container transport model for the Le Havre maritime container terminal are shown in Graph 20.

Graph 20 - Influence factors of individual elements of the container transport model for Le Havre seaport container terminal for the period 2012-2024



Source: Prepared by the author based on source material.

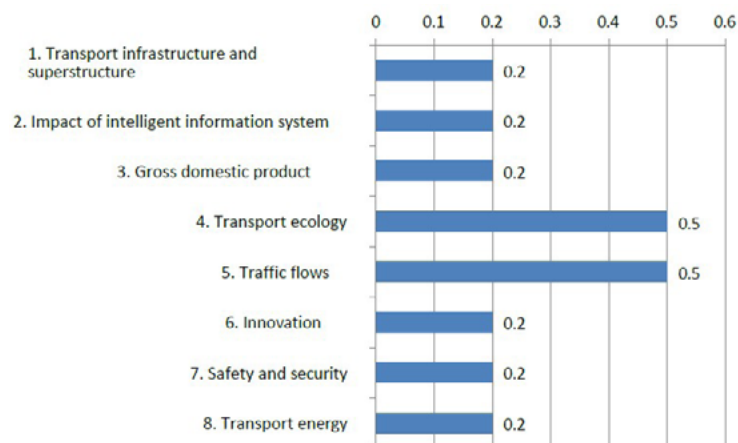
Table 26 shows the growth matrix of the container transport model elements for the Antwerp maritime container terminal in the period 2012-2024.

Table 26 - Growth matrix of container transport model elements
for the Antwerp maritime container terminal in the period 2012-2024

1	0.2	69	8.6×10^{-6}	1	3	2	1.4	0.3
2	0.02	0.2	1×10^{-6}	0.2	0.3	0.3	0.2	0.04
3	3,356	28,571	0.2	31,447	58,140	41,667	27,778	6,173
4	0.06	0.5	2.8×10^{-6}	0.5	1	0.7	0.5	0.1
5	0.02	0.2	1.5×10^{-6}	0.3	0.5	0.4	0.2	0.05
6	0.01	0	6.9×10^{-7}	0	0	0.2	0.1	0.02
7	0.02	0.2	1×10^{-6}	0.2	0.3	0.3	0.2	0.04
8	0	0.8	4.7×10^{-6}	0.8	1.6	1	0.8	0.2

Source: Prepared by the author based on source material.

Graph 21 - Direct growth rates of elements of the container transport model
for the Antwerp maritime container terminal in the period 2012-2024

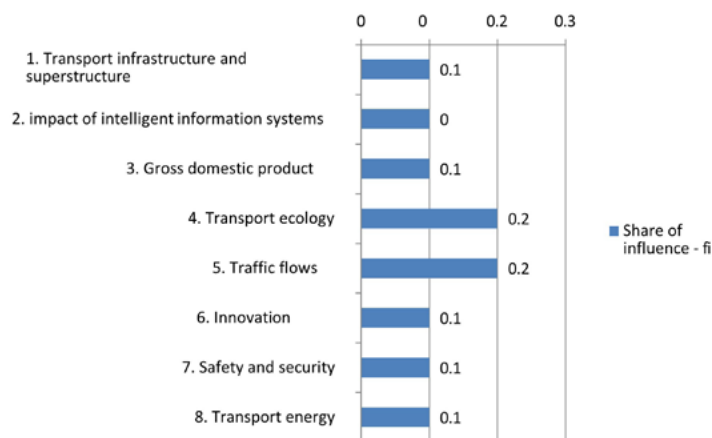


Source: Prepared by the author based on source material.

Graph 21 shows that the highest level of development in the period from 2012 to 2024 at the Antwerp maritime container terminal is in the elements of traffic flows and traffic ecology, with a value of 0.5; follow by the elements of transport infrastructure and superstructure, gross domestic product, innovation, safety and security, transport energy, and the impact of an intelligent information system, with a value of 0.2.

The calculated impact factors of the individual elements of the container transport model for the Antwerp maritime container terminal are shown in Graph 22.

Graph 22 - Impact factors of individual elements of the container transport model for the Antwerp maritime container terminal in the period 2012-2024



Source: Prepared by the author based on source material.

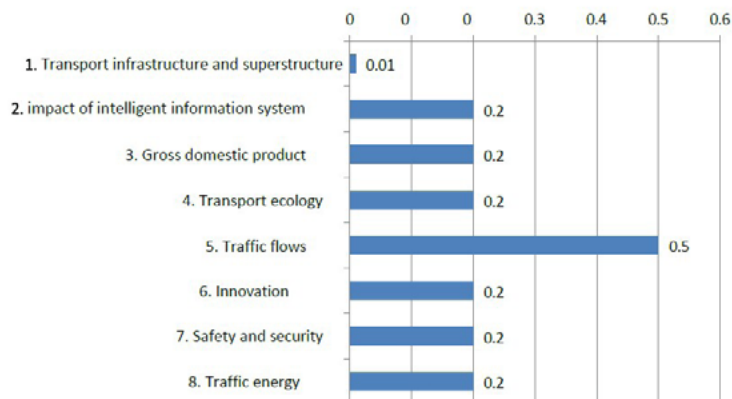
Table 27 shows the growth matrix of the container transport model elements for the Hamburg maritime container terminal in the period 2012-2024.

**Table 27 - Growth matrix of container transport model elements
for the Hamburg seaport container terminal in the period 2012-2024**

1	0.01	0	4.9×10^{-7}	1×10^{-3}	0.2	4×10^{-3}	0.1	0.3
2	0.04	0.2	2.2×10^{-6}	0.03	1	0.02	0.5	1.4
3	3,178	12,319	0.2	2,240	72,340	1,675	333,333	101,190
4	0.2	0.9	1.2×10^{-5}	0.2	5	0.1	2.5	8
5	0.02	0.1	1.1×10^{-6}	0.01	0.5	0.01	0	0.7
6	0.3	1.2	1.7×10^{-5}	0.2	72	0.2	3	10
7	0.02	0.1	8.3×10^{-7}	0.01	0	0.01	0.2	0.5
8	5×10^{-3}	0.02	2.4×10^{-7}	4×10^{-3}	0.1	3×10^{-3}	0.05	0.2

Source: Prepared by the author based on source material.

**Graph 23 - Dwerect growth rates of elements of the container transport model
for the Hamburg maritime container terminal in the period 2012-2024**

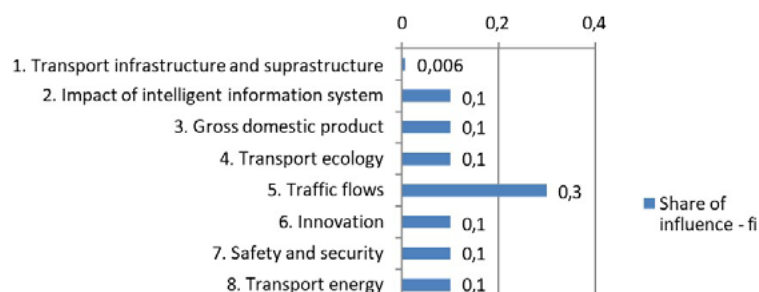


Source: Prepared by the author based on source material.

Graph 23 shows that the highest level of development in the period from 2012 to 2024 in the Hamburg maritime container terminal is in the transport flows element, with a value of 0.5; follow by gross domestic product, innovation, safety and security, transport energy, and the impact of intelligent information systems with a value of 0.2, and transport infrastructure and superstructure with a value of 0.01.

The calculated impact factors of the individual elements of the container transport model for the Hamburg maritime container terminal are shown in Graph 24.

Graph 24 - Influence factors of individual elements of the container transport model for the Hamburg seaport container terminal for the period 2012-2024



Source: Prepared by the author based on source material.

The data used to calculate the development rate of the maritime container terminals in question in the Eastern United States and Western European countries for the period 2012-2024 are shown in Table 28.



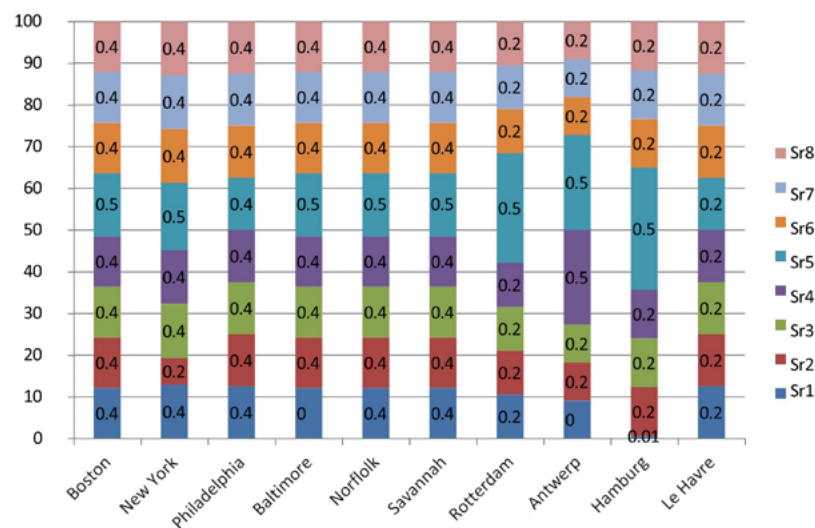
Table 28 - Data for calculating the degree of development of maritime container terminals

Pomorski kontejnerski terminali	f ₁	Sr ₁	f ₂	Sr ₂	f ₃	Sr ₃	f ₄	Sr ₄	f ₅	Sr ₅	f ₆	Sr ₆	f ₇	Sr ₇	f ₈	Sr ₈	Sr
Boston	0,08	0,4	0,08	0,4	0,08	0,4	0,08	0,4	0,1	0,5	0,08	0,4	0,08	0,4	0,08	0,4	0,3
New York	0,1	0,4	0,06	0,2	0,1	0,4	0,1	0,4	0,2	0,5	0,1	0,4	0,1	0,4	0,1	0,4	0,4
Philadelphia	0,13	0,4	0,13	0,4	0,13	0,4	0,13	0,4	0,13	0,4	0,13	0,4	0,13	0,4	0,13	0,4	0,4
Baltimore	0,1	0,4	0,1	0,4	0,1	0,4	0,1	0,4	0,3	0,5	0,1	0,4	0,1	0,4	0,1	0,4	0,4
Norfolk	0,1	0,4	0,1	0,4	0,1	0,4	0,1	0,4	0,3	0,5	0,1	0,4	0,1	0,4	0,1	0,4	0,4
Savannah	0,1	0,4	0,1	0,4	0,1	0,4	0,1	0,4	0,3	0,5	0,1	0,4	0,1	0,4	0,1	0,4	0,4
Rotterdam	0,1	0,2	0,1	0,2	0,1	0,2	0,1	0,2	0,3	0,5	0,1	0,2	0,1	0,2	0,1	0,2	0,3
Antwerp	0,1	0,2	0,1	0,2	0,1	0,2	0,2	0,5	0,2	0,5	0,1	0,2	0,1	0,2	0,1	0,2	0,3
Hamburg	0,006	0,01	0,1	0,2	0,1	0,2	0,1	0,2	0,3	0,5	0,1	0,2	0,1	0,2	0,1	0,2	0,3
Le Havre	0,1	0,2	0,1	0,2	0,1	0,2	0,1	0,2	0,1	0,2	0,1	0,2	0,1	0,2	0,1	0,2	0,2

Source: Prepared by an author based on data from Tables 8 to 17.

Graph 25 shows the shares of the development level of individual elements of the container transport model for the maritime container terminals in the Eastern United States and Western European countries.

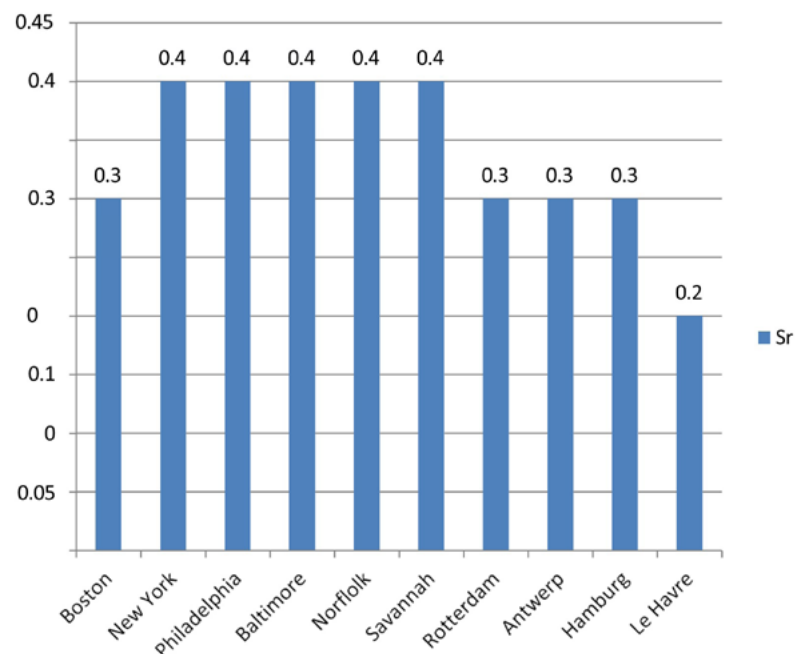
Graph 25 - Shares of individual elements of transport containers



Source: Prepared by an author based on data from Table 28.

The stages of development of the maritime container terminals in question in the Eastern United States and in Western European countries are shown in Graph 26.

Graph 26 - Levels of development of maritime container terminals (S_r)



Source: Prepared by an author based on data from Table 28.

The maritime container terminals with the highest level of development in the period 2012-2024 are New York, Philadelphia, Baltimore, Norfolk, and Savannah, with a value of 0.4. They are followed by the maritime container terminals of Boston, Rotterdam, Antwerp, and Hamburg with a value of 0.3, and the maritime container terminal of Le Havre with a value of 0.2. If, at the end of the time horizon, there is a negative increase in the value of the elements of the container transport model, then the value of the development level of maritime container terminals may also be negative.

The calculated attractiveness (u) of maritime container terminals in Western European countries in the period 2012-2024 is shown in Table 29.

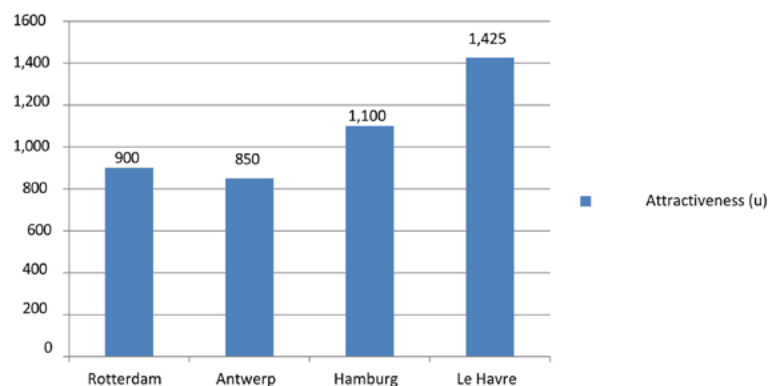
**Table 29 - Attractiveness (u) of maritime container terminals
in Western European countries**

Maritime container terminals	Average price c_j (€) ¹³⁴	S_{r_j}	Attractiveness (u_j) (€)
Rotterdam	270	0.3	90
Antwerp	255	0.3	850
Hamburg	330	0.3	1,100
Le Havre	285	0.2	1,425

Source: Prepared by an author based on data published on the Internet, http://www.kline.com/KAMSurcharges/Surcharges_TransAtlantic-Eastbound.asp, (22 April 2014).

Graph 27 shows the attractiveness of the maritime container terminals in Western European countries in the period 2012-2024.

**Graph 27 - Attractiveness of maritime container terminals
in Western European countries**



Source: Prepared by the author based on source material.

The Antwerp seaport container terminal will be the most attractive in the 2012-2024 period, follow by the seaport container terminals in Rotterdam, Hamburg, and Le Havre.

The 2012 container transport optimization model shows that the largest number of containers is transported across the Atlantic Ocean from maritime container terminals in the Eastern United States to the maritime container terminals of Rotterdam, Antwerp, Hamburg, and Le Havre.

There is a close link between the container transport optimisation model and the level of development of maritime container terminals, which affects the attractiveness of maritime container terminals. Maritime container terminals in the Eastern United States will achieve a higher level of development in the period 2012-2024 than maritime container terminals in Western European countries. The level of development of maritime container terminals in Western European countries over a given period of time can influence the optimisation of transport time and container transport costs on transatlantic liner routes.

4.7 RESULTS OF THE NEW MODEL FOR TRANSPORTING CONTAINERS FROM EASTERN US STATES TO WESTERN EUROPEAN COUNTRIES

The optimal solution for container transport from PKT/A to PKT/E in 2012 is shown below for the six optimization models performed.

- a. *The optimal solution for container transport from PKT/A to PKT/E in 2012 for the first optimization model*

The optimal solution for transporting containers from PKT/A to PKT/E in 2012 for the first optimization model is calculated using the integer linear programming method.

$$Z_1 = 270 x_{11} + 268 x_{12} + 287 x_{13} + 252 x_{14} + 282 x_{21} + 298 x_{22} + 301 x_{23} + 266 x_{24} + 294 x_{31} + 255 x_{32} + 330 x_{33} + 285 x_{34} + 305 x_{41} + 306 x_{42} + 325 x_{43} + 285 x_{44} + 295 x_{51} + 296 x_{52} + 315 x_{53} + 280 x_{54} + 328 x_{61} + 328 x_{62} + 344 x_{63} + 312 x_{64} \rightarrow \min$$

under the following conditions:

$$x_{11} \geq 0, x_{12} \geq 0, x_{13} \geq 0, x_{14} \geq 0, x_{21} \geq 0, x_{22} \geq 0, x_{23} \geq 0, x_{24} \geq 0, x_{31} \geq 0, x_{32} \geq 0, x_{33} \geq 0, x_{34} \geq 0, x_{41} \geq 0, x_{42} \geq 0, x_{43} \geq 0, x_{44} \geq 0, x_{51} \geq 0, x_{52} \geq 0, x_{53} \geq 0, x_{54} \geq 0, x_{61} \geq 0, x_{62} \geq 0, x_{63} \geq 0, x_{64} \geq 0$$

$$x_{11} + x_{12} + x_{13} + x_{14} = 57.595$$

$$x_{21} + x_{22} + x_{23} + x_{24} = 1.469.409$$

$$x_{31} + x_{32} + x_{33} + x_{34} = 40.474$$

$$x_{41} + x_{42} + x_{43} + x_{44} = 195.602$$

$$x_{51} + x_{52} + x_{53} + x_{54} = 838.067$$

$$x_{61} + x_{62} + x_{63} + x_{64} = 100.841$$

$$x_{11} + x_{21} + x_{31} + x_{41} + x_{51} + x_{61} = 1.028.000$$

$$x_{12} + x_{22} + x_{32} + x_{42} + x_{52} + x_{62} = 849.728$$

$$x_{13} + x_{23} + x_{33} + x_{43} + x_{53} + x_{63} = 785.988$$

$$x_{14} + x_{24} + x_{34} + x_{44} + x_{54} + x_{64} = 38.272$$

Table 30 - Optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the first optimization model

Maritime container terminals in Eastern US states	Maritime container terminals in Western European countries				Total TEU volume
	Rotterdam	Antwerp	Hamburg	Le Havre	
<i>Boston</i>					
Quantity in TEU	-	57,595	-	-	57,595
<i>Trans. cost (€/TEU)¹⁹⁵</i>	270	268	287	252	
<i>Transport time (days)</i>	13	13	14	12	
<i>New York</i>					
Quantity TEU	784,262	-	685,147	-	1,469,409
<i>Trans. cont. price (€/TEU)</i>	282	298	301	266	
<i>Transport time (days)</i>	15	11	13	12	
<i>Philadelphia</i>					
Quantity TEU	-	40,474	-	-	40,474
<i>Trans. cost (€/TEU)</i>	294	255	330	285	
<i>Transport time (days)</i>	14	14	15	13	
<i>Baltimore</i>					
Quantity TEU	-	157,330	-	38,272	195,602
<i>Trans. cont. price (€/TEU)</i>	305	306	325	285	
<i>Transport time (days)</i>	14	13	15	13	
<i>Norfolk</i>					
Quantity TEU	243,738	594,329	-	-	838,067
<i>Trans. cont. price (€/TEU)</i>	295	296	315	280	
<i>Transport time (days)</i>	17	13	13	10	

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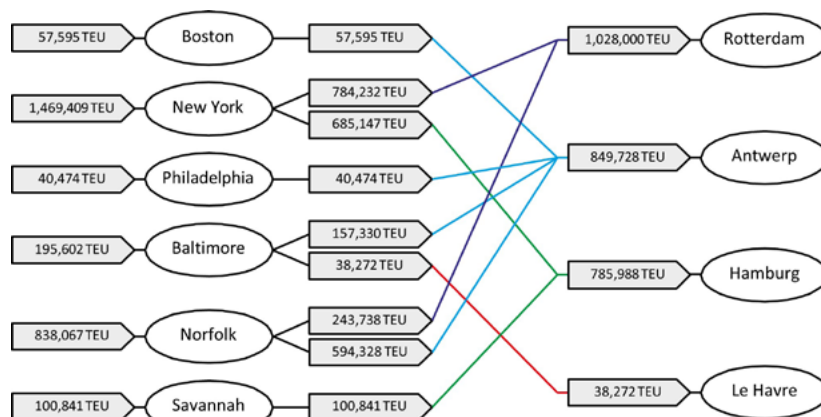
Internet, <http://www.kline.com/KAMSurcharges/Surcharges-TransAtlantic-Eastbound.asp>, (28 April 2014).
Transport cost data calculated as €0.045/TEU * distance between maritime container terminals in km

Savannah					
Quantity TEU	-	-	100,841	-	100,841
Trans. cost (€/TEU)	328	328	344	312	
Transport time (days)	19	15	17	12	
Total quantity received TEU	1,028,000	849,728	785,988	38,272	2,701,988
MINIMUM CONTAINER TRANSPORT COST (TEU): 794,711,359 €					

Source: Prepared by an author based on calculations in the Lingo 14 software tool.

The optimal solution for transporting containers from maritime container terminals in the Eastern United States (PKT/A) to maritime container terminals in Western Europe (PKT/E) using the linear programming method from Table 30 is shown in Diagram 2.

Diagram 2 - Optimal solution for transporting containers from seaport container terminals in the Eastern United States (PKT/A) to seaport container terminals in Western European countries (PKT/E) for the first optimization model



Source: Prepared by the author based on source material.

The minimum total average cost of transporting containers from maritime container terminals in the Eastern United States (PKT/A) to maritime container terminals in Western Europe (PKT/E) in 2012, calculated using the integer linear programming method,

is $Z_1 = 794,711,359$ €, which would save 8,025,052 € (1%) compared to the conventional method of container transport, where the total average cost of container transport by sea is 802,736,411 € (Table 7).

b. *Optimal solution for container transport from PKT/A to PKT/E in 2012 for the second optimization model*

The optimal solution for transporting containers from PKT/A to PKT/E in 2012 for the second optimization model is calculated using the integer linear programming method, taking into account the level of development of maritime container terminals S_r in Western European countries.

$$\begin{aligned} Z_2 = & 900 \times 0.3 x_{11} + 850 \times 0.3 x_{12} + 1,100 \times 0.3 x_{13} + 1,425 \times 0.2 x_{14} + \\ & 900 \times 0.3 x_{21} + 850 \times 0.3 x_{22} + 1,100 \times 0.3 x_{23} + 1,425 \times 0.2 x_{24} + \\ & 900 \times 0.3 x_{31} + 850 \times 0.3 x_{32} + 1,100 \times 0.3 x_{33} + 1,425 \times 0.2 x_{34} + \\ & 900 \times 0.3 x_{41} + 850 \times 0.3 x_{42} + 1,100 \times 0.3 x_{43} + 1,425 \times 0.2 x_{44} + \\ & 900 \times 0.3 x_{51} + 850 \times 0.3 x_{52} + 1,100 \times 0.3 x_{53} + 1,425 \times 0.2 x_{54} + \\ & 900 \times 0.3 x_{61} + 850 \times 0.3 x_{62} + 1,100 \times 0.3 x_{63} + 1,425 \times 0.2 x_{64} \rightarrow \min \end{aligned}$$

under the conditions:

$$\begin{aligned} x_{11} \geq 0, x_{12} \geq 0, x_{13} \geq 0, x_{14} \geq 0, x_{21} \geq 0, x_{22} \geq 0, x_{23} \geq 0, x_{24} \geq 0, x_{31} \geq 0, \\ x_{32} \geq 0, x_{33} \geq 0, x_{34} \geq 0, x_{41} \geq 0, x_{42} \geq 0, x_{43} \geq 0, x_{44} \geq 0, x_{51} \geq 0, x_{52} \geq 0, \\ x_{53} \geq 0, x_{54} \geq 0, x_{61} \geq 0, x_{62} \geq 0, x_{63} \geq 0, x_{64} \geq 0 \end{aligned}$$

$$\begin{aligned} x_{11} + x_{12} + x_{13} + x_{14} &= 57.595 \\ x_{21} + x_{22} + x_{23} + x_{24} &= 1.469.409 \\ x_{31} + x_{32} + x_{33} + x_{34} &= 40.474 \\ x_{41} + x_{42} + x_{43} + x_{44} &= 195.602 \\ x_{51} + x_{52} + x_{53} + x_{54} &= 838.067 \\ x_{61} + x_{62} + x_{63} + x_{64} &= 100.841 \\ x_{11} + x_{21} + x_{31} + x_{41} + x_{51} + x_{61} &= 1.028.000 \\ x_{12} + x_{22} + x_{32} + x_{42} + x_{52} + x_{62} &= 849.728 \\ x_{13} + x_{23} + x_{33} + x_{43} + x_{53} + x_{63} &= 785.988 \\ x_{14} + x_{24} + x_{34} + x_{44} + x_{54} + x_{64} &= 38.272 \end{aligned}$$

Table 31 shows the optimal solution for transporting containers from maritime container terminals in the Eastern United States (PKT/A) to maritime container terminals in Western European countries (PKT/E) using the integer linear programming method and taking into account the level of development of maritime container terminals S_r in Western European countries.

Table 31 - Optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the second optimization model

Maritime container terminals in Eastern US states	Maritime container terminals in Western European countries				Total TEU volume
	Rotterdam	Antwerp	Hamburg	Le Havre	
<i>Boston</i>					
Quantity in TEU	19,323	-	-	38,272	57,595
<i>Trans. cont. price (€/TEU)¹³⁶</i>	270	255	330	285	
<i>Transport time (days)</i>	13	13	14	12	
<i>New York</i>					
Quantity TEU	29,295	654,126	785,988	-	1,469,409
<i>Trans. cont. price (€/TEU)</i>	270	255	330	285	
<i>Transport time (days)</i>	15	11	13	12	
<i>Philadelphia</i>					
Volume TEU	40,474	-	-	-	40,474
<i>Trans. cost (€/TEU)</i>	270	255	330	285	
<i>Transport time (days)</i>	14	14	15	13	
<i>Baltimore</i>					
Quantity TEU	-	195,602	-	-	195,602
<i>Trans. cont. price (€/TEU)</i>	270	255	330	285	
<i>Transport time (days)</i>	14	13	15	13	

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Internet, <http://www.kline.com/KAMSurcharges/Surcharges-TransAtlantic-Eastbound.asp>, (28 April 2014). The transport price includes the level of development S_r of maritime container terminals in Western European countries

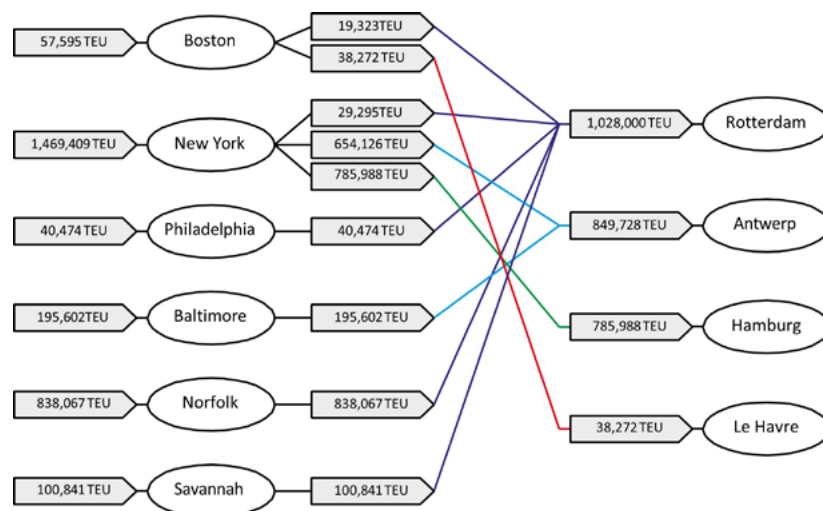
Norfolk					
Quantity TEU	838,067	-	-	-	838,067
Trans. cont. price (€/TEU)	270	255	330	285	
Transport time (days)	17	13	13	10	
Savannah					
Quantity TEU	100,841	-	-	-	100,841
Trans. cost (€/TEU)	270	255	330	285	
Transport time (days)	19	15	17	12	
Total quantity received (TEU)	1,028,000	849,728	785,988	38,272	2,701,988
MINIMUM CONTAINER TRANSPORT COST (TEU): 764,524,200 €					

Source: Prepared by a author based on calculations in the Lingo 14 software tool.

Minimum total average price of container transport from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) in 2012 using the linear programming method and taking into account the level of development of maritime container terminals S_r in Western European countries is $Z_2 = 764,524,200$ €, which would save 38,212,211 € (5%) compared to the conventional method container transport, where the total average price of container transport by sea is 802,736,411 € (Table 7).

The optimal solution for container transport from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) using the linear integer programming method and taking into account the level of development of maritime container terminals S_r in Western European countries is shown in Diagram 3.

Diagram 3 - The optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the second optimization model



Source: Prepared by the author based on source material.

- c. Optimal solution for transporting containers from PKT/A to PKT/E in 2012 for the third and fourth optimization models

The optimal solution for transporting containers from PKT/A to PKT/E in 2012 for the third and fourth optimization models is calculated using the integer linear programming method and the northlst corner method.

- c1. Optimization of container transport time from PKT/A to PKT/E in 2012

$$\begin{aligned}
 Z_{3T} = & 13 x_{11} + 13 x_{12} + 14 x_{13} + 12 x_{14} + 15 x_{21} + 11 x_{22} + 13 x_{23} + \\
 & 12 x_{24} + 14 x_{31} + 14 x_{32} + 15 x_{33} + 13 x_{34} + 14 x_{41} + 13 x_{42} + \\
 & 15 x_{43} + 13 x_{44} + 17 x_{51} + 13 x_{52} + 13 x_{53} + 10 x_{54} + 19 x_{61} + \\
 & 15 x_{62} + 17 x_{63} + 12 x_{64} \rightarrow \min
 \end{aligned}$$

under the conditions:

$$\begin{aligned} x_{11} \geq 0, x_{12} \geq 0, x_{13} \geq 0, x_{14} \geq 0, x_{21} \geq 0, x_{22} \geq 0, x_{23} \geq 0, x_{24} \geq 0, x_{31} \geq 0, \\ x_{32} \geq 0, x_{33} \geq 0, x_{34} \geq 0, x_{41} \geq 0, x_{42} \geq 0, x_{43} \geq 0, x_{44} \geq 0, x_{51} \geq 0, x_{52} \geq 0, \\ x_{53} \geq 0, x_{54} \geq 0, x_{61} \geq 0, x_{62} \geq 0, x_{63} \geq 0, x_{64} \geq 0 \end{aligned}$$

$$x_{11} + x_{12} + x_{13} + x_{14} = 57.595$$

$$x_{21} + x_{22} + x_{23} + x_{24} = 1.469.409$$

$$x_{31} + x_{32} + x_{33} + x_{34} = 40.474$$

$$x_{41} + x_{42} + x_{43} + x_{44} = 195.602$$

$$x_{51} + x_{52} + x_{53} + x_{54} = 838.067$$

$$x_{61} + x_{62} + x_{63} + x_{64} = 100.841$$

$$x_{11} + x_{21} + x_{31} + x_{41} + x_{51} + x_{61} = 1.028.000$$

$$x_{12} + x_{22} + x_{32} + x_{42} + x_{52} + x_{62} = 849.728$$

$$x_{13} + x_{23} + x_{33} + x_{43} + x_{53} + x_{63} = 785.988$$

$$x_{14} + x_{24} + x_{34} + x_{44} + x_{54} + x_{64} = 38.272$$

Table 32 - Optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the third optimization model

Maritime container terminals in Eastern US states	Maritime container terminals in Western European countries				Total TEU volume
	Rotterdam	Antwerp	Hamburg	Le Havre	
<i>Boston</i>					
Quantity TEU	57,595	-	-	-	57,595
Transport time (days)	13	13	14	12	
<i>New York</i>					
Quantity TEU	619,681	849,728	-	-	1,469,409
Transport time (days)	15	11	13	12	
<i>Philadelphia</i>					
Volume TEU	40,474	-	-	-	40,474
Transport time (days)	14	14	15	13	

Baltimore					
Volume TEU	195,602	-	-	-	195,602
Transport time (days)	14	13	15	13	
Norfolk					
Quantity TEU	52,079	-	785,988	-	838,067
Transport time (days)	17	13	13	10	
Savannah					
Quantity TEU	62,569	-	-	38,272	100,841
Transport time (days)	19	15	17	12	
Total quantity received (TEU)	1,028,000	849,728	785,988	38,272	2,701,988
TOTAL CONTAINER TRANSPORT TIME (TEU): 19 days					

Source: Prepared by the author based on source material.

c2. Optimization of container transport costs from PKT/A to PKT/E in 2012

Optimal solution for transporting containers from PKT/A to PKT/E in 2012:

$$Z_{3C} = 270 \times 57,595 + 268 \times 0 + 287 \times 0 + 252 \times 0 + 282 \times 619,681 + 298 \times 849,728 + 301 \times 0 + 266 \times 0 + 294 \times 40,474 + 255 \times 0 + 313 \times 0 + 278 \times 0 + 305 \times 195,602 + 306 \times 0 + 325 \times 0 + 285 \times 0 + 295 \times 52,079 + 296 \times 0 + 315 \times 785,988 + 280 \times 0 + 328 \times 62,569 + 328 \times 0 + 344 \times 0 + 312 \times 38,272$$

under the conditions:

$$\begin{aligned} x_{11} \geq 0, x_{12} \geq 0, x_{13} \geq 0, x_{14} \geq 0, x_{21} \geq 0, x_{22} \geq 0, x_{23} \geq 0, x_{24} \geq 0, x_{31} \geq 0, \\ x_{32} \geq 0, x_{33} \geq 0, x_{34} \geq 0, x_{41} \geq 0, x_{42} \geq 0, x_{43} \geq 0, x_{44} \geq 0, x_{51} \geq 0, x_{52} \geq 0, \\ x_{53} \geq 0, x_{54} \geq 0, x_{61} \geq 0, x_{62} \geq 0, x_{63} \geq 0, x_{64} \geq 0 \end{aligned}$$

$$x_{11} + x_{12} + x_{13} + x_{14} = 57.595$$

$$x_{21} + x_{22} + x_{23} + x_{24} = 1.469.409$$

$$x_{31} + x_{32} + x_{33} + x_{34} = 40.474$$

$$X_{41} + X_{42} + X_{43} + X_{44} = 195.602$$

$$X_{51} + X_{52} + X_{53} + X_{54} = 838.067$$

$$X_{61} + X_{62} + X_{63} + X_{64} = 100.841$$

$$X_{11} + X_{21} + X_{31} + X_{41} + X_{51} + X_{61} = 1.028.000$$

$$X_{12} + X_{22} + X_{32} + X_{42} + X_{52} + X_{62} = 849.728$$

$$X_{13} + X_{23} + X_{33} + X_{43} + X_{53} + X_{63} = 785.988$$

$$X_{14} + X_{24} + X_{34} + X_{44} + X_{54} + X_{64} = 38.272$$

Table 33 - Optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the third optimization model

Maritime container terminals in Eastern US states	Maritime container terminals in Western European countries				Total TEU volume
	Rotterdam	Antwerp	Hamburg	Le Havre	
<i>Boston</i>					
Quantity TEU	57,595	-	-	-	57,595
Trans. cost (€/TEU) ¹³⁷	270	268	287	252	
<i>New York</i>					
Quantity TEU	619,681	849,728	-	-	1,469,409
Trans. cont. price (€/TEU)	282	298	301	266	
<i>Philadelphia</i>					
Quantity TEU	40,474	-	-	-	40,474
Trans. cost (€/TEU)	294	255	330	285	
<i>Baltimore</i>					
Quantity TEU	195,602	-	-	-	195,602
Trans. cost (€/TEU)	305	306	325	285	
<i>Norfolk</i>					
Quantity TEU	52,079	-	785,988	-	838,067
Trans. cont. price (€/TEU)	295	296	315	280	

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Internet, <http://www.kline.com/KAMSurcharges/Surcharges-TransAtlantic-Eastbound.asp>, (28 April 2014). Transport cost calculated as €0.045/TEU * distance between maritime container terminals in km

<i>Savannah</i>					
Quantity TEU	62,569	-	-	38,272	100,841
<i>Trans. cont. price (€/TEU)</i>	<i>328</i>	<i>328</i>	<i>344</i>	<i>312</i>	
Total quantity received TEU	1,028,000	849,728	785,988	38,272	2,701,988
MINIMUM CONTAINER TRANSPORT COST (TEU): 810,490,623 €					

Source: Prepared by the author based on source material.

c3. *Optimization of container transport time from PKT/A to PKT/E in 2012*

$$\begin{aligned}
 Z_{3T} = & 13 x_{11} + 13 x_{12} + 14 x_{13} + 12 x_{14} + 15 x_{21} + 11 x_{22} + 13 x_{23} + \\
 & 12 x_{24} + 14 x_{31} + 14 x_{32} + 15 x_{33} + 13 x_{34} + 14 x_{41} + 13 x_{42} + \\
 & 15 x_{43} + 13 x_{44} + 17 x_{51} + 13 x_{52} + 13 x_{53} + 10 x_{54} + 15 x_{62} + \\
 & 17 x_{63} + 12 x_{64} \rightarrow \min
 \end{aligned}$$

under the conditions:

$$\begin{aligned}
 & x_{11} \geq 0, x_{12} \geq 0, x_{13} \geq 0, x_{14} \geq 0, x_{21} \geq 0, x_{22} \geq 0, x_{23} \geq 0, x_{24} \geq 0, x_{31} \geq 0, \\
 & x_{32} \geq 0, x_{33} \geq 0, x_{34} \geq 0, x_{41} \geq 0, x_{42} \geq 0, x_{43} \geq 0, x_{44} \geq 0, x_{51} \geq 0, x_{52} \geq 0, \\
 & x_{53} \geq 0, x_{54} \geq 0, x_{62} \geq 0, x_{63} \geq 0, x_{64} \geq 0
 \end{aligned}$$

$$x_{11} + x_{12} + x_{13} + x_{14} = 57.595$$

$$x_{21} + x_{22} + x_{23} + x_{24} = 1.469.409$$

$$x_{31} + x_{32} + x_{33} + x_{34} = 40.474$$

$$x_{41} + x_{42} + x_{43} + x_{44} = 195.602$$

$$x_{51} + x_{52} + x_{53} + x_{54} = 838.067$$

$$x_{62} + x_{63} + x_{64} = 100.841$$

$$x_{11} + x_{21} + x_{31} + x_{41} + x_{51} = 1.028.000$$

$$x_{12} + x_{22} + x_{32} + x_{42} + x_{52} + x_{62} = 849.728$$

$$x_{13} + x_{23} + x_{33} + x_{43} + x_{53} + x_{63} = 785.988$$

$$x_{14} + x_{24} + x_{34} + x_{44} + x_{54} + x_{64} = 38.272$$

Table 34 - Optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the third optimization model

Maritime container terminals in Eastern US states	Maritime container terminals in Western European countries				Total TEU volume
	Rotterdam	Antwerp	Hamburg	Le Havre	
<i>Boston</i>					
Quantity TEU	57,595	-	-	-	57,595
<i>Transport time (days)</i>	<i>13</i>	<i>13</i>	<i>14</i>	<i>12</i>	
<i>New York</i>					
Quantity TEU	682,250	787,159	-	-	1,469,409
<i>Transport time (days)</i>	<i>15</i>	<i>11</i>	<i>13</i>	<i>12</i>	
<i>Philadelphia</i>					
Volume TEU	40,474	-	-	-	40,474
<i>Transport time (days)</i>	<i>14</i>	<i>14</i>	<i>15</i>	<i>13</i>	
<i>Baltimore</i>					
Volume TEU	195,602	-	-	-	195,602
<i>Transport time (days)</i>	<i>14</i>	<i>13</i>	<i>15</i>	<i>13</i>	
<i>Norfolk</i>					
Quantity TEU	52,079	-	785,988	-	838,067
<i>Transport time (days)</i>	<i>17</i>	<i>13</i>	<i>13</i>	<i>10</i>	
<i>Savannah</i>					
Quantity TEU	-	62,569	-	38,272	100,841
<i>Transport time (days)</i>	<i>19</i>	<i>15</i>	<i>17</i>	<i>12</i>	
Total quantity received (TEU)	1,028,000	849,728	785,988	38,272	2,701,988
TOTAL CONTAINER TRANSPORT TIME (TEU): 17 days					

Source: Prepared by the author based on source material.

c3. *Optimisation of container transport costs from PKT/A to PKT/E in 2012*

Optimal solution for container transport from PKT/A to PKT/E in 2012:

$$Z_{3C} = 270 \times 57,595 + 268 \times 0 + 287 \times 0 + 252 \times 0 + 282 \times 815,283 + 298 \times 654,126 + 301 \times 0 + 266 \times 0 + 294 \times 40,474 + 255 \times 0 + 330 \times 0 + 285 \times 0 + 305 \times 0 + 306 \times 195,602 + 325 \times 0 + 285 \times 0 + 295 \times 52,079 + 296 \times 0 + 315 \times 785,988 + 280 \times 0 + 328 \times 62,569 + 328 \times 0 + 344 \times 0 + 312 \times 38,272$$

under the conditions:

$$x_{11} \geq 0, x_{12} \geq 0, x_{13} \geq 0, x_{14} \geq 0, x_{21} \geq 0, x_{22} \geq 0, x_{23} \geq 0, x_{24} \geq 0, x_{31} \geq 0, x_{32} \geq 0, x_{33} \geq 0, x_{34} \geq 0, x_{41} \geq 0, x_{42} \geq 0, x_{43} \geq 0, x_{44} \geq 0, x_{51} \geq 0, x_{52} \geq 0, x_{53} \geq 0, x_{54} \geq 0, x_{62} \geq 0, x_{63} \geq 0, x_{64} \geq 0$$

$$x_{11} + x_{12} + x_{13} + x_{14} = 57.595$$

$$x_{21} + x_{22} + x_{23} + x_{24} = 1.469.409$$

$$x_{31} + x_{32} + x_{33} + x_{34} = 40.474$$

$$x_{41} + x_{42} + x_{43} + x_{44} = 195.602$$

$$x_{51} + x_{52} + x_{53} + x_{54} = 838.067$$

$$x_{62} + x_{63} + x_{64} = 100.841$$

$$x_{11} + x_{21} + x_{31} + x_{41} + x_{51} = 1.028.000$$

$$x_{12} + x_{22} + x_{32} + x_{42} + x_{52} + x_{62} = 849.728$$

$$x_{13} + x_{23} + x_{33} + x_{43} + x_{53} + x_{63} = 785.988$$

$$x_{14} + x_{24} + x_{34} + x_{44} + x_{54} + x_{64} = 38.272$$

Table 35 - Optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the third optimization model

Maritime container terminals in Eastern US states	Maritime container terminals in Western European countries				Total TEU volume
	Rotterdam	Antwerp	Hamburg	Le Havre	
<i>Boston</i>					
Quantity TEU	57,595	-	-	-	57,595
<i>Trans. cont. price (€/TEU)¹³⁸</i>	<i>270</i>	<i>268</i>	<i>287</i>	<i>252</i>	
<i>New York</i>					
Quantity TEU	682,250	787,159	-	-	1,469,409
<i>Trans. cont. price (€/TEU)</i>	<i>282</i>	<i>298</i>	<i>301</i>	<i>266</i>	
<i>Philadelphia</i>					
Quantity TEU	40,474	-	-	-	40,474
<i>Trans. cost (€/TEU)</i>	<i>294</i>	<i>255</i>	<i>330</i>	<i>285</i>	
<i>Baltimore</i>					
Quantity TEU	195,602	-	-	-	195,602
<i>Trans. cost (€/TEU)</i>	<i>305</i>	<i>306</i>	<i>325</i>	<i>285</i>	
<i>Norfolk</i>					
Quantity TEU	52,079	-	785,988	-	838,067
<i>Trans. cont. price (€/TEU)</i>	<i>295</i>	<i>296</i>	<i>315</i>	<i>280</i>	
<i>Savannah</i>					
Quantity TEU	-	62,569	-	38,272	100,841
<i>Trans. cont. price (€/TEU)</i>	<i>328</i>	<i>328</i>	<i>344</i>	<i>312</i>	
Total quantity received TEU	1,028,000	849,728	785,988	38,272	2,701,988
MINIMUM CONTAINER TRANSPORT COST (TEU): 809,489,519 €					

Source: Prepared by the author based on source material.

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Internet, <http://www.kline.com/KAMSurcharges/Surcharges-TransAtlantic-Eastbound.asp>, (28 April 2014). Transport cost calculated as €0.045/TEU * distance between maritime container terminals in km

c4. Optimization of container transport time from PKT/A to PKT/E in 2012

The North-West Corner method was also used to optimize container transport time from PKT/A to PKT/E in 2012.

Table 36 - Optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the third optimization model

Maritime container terminals in Eastern US states	Maritime container terminals in Western European countries				Total TEU volume
	Rotterdam	Antwerp	Hamburg	Le Havre	
<i>Boston</i>					
Quantity TEU	57,595	-	-	-	57,595
<i>Transport time (days)</i>	<i>13</i>	<i>13</i>	<i>14</i>	<i>12</i>	
<i>New York</i>					
Quantity TEU	970,405	499,004	-	-	1,469,409
<i>Transport time (days)</i>	<i>15</i>	<i>11</i>	<i>13</i>	<i>12</i>	
<i>Philadelphia</i>					
Quantity TEU	-	40,474	-	-	40,474
<i>Transport time (days)</i>	<i>14</i>	<i>14</i>	<i>15</i>	<i>13</i>	
<i>Baltimore</i>					
Quantity TEU	-	195,602	-	-	195,602
<i>Transport time (days)</i>	<i>14</i>	<i>13</i>	<i>15</i>	<i>13</i>	
<i>Norfolk</i>					
Quantity TEU	-	114,648	723,419	-	838,067
<i>Transport time (days)</i>	<i>17</i>	<i>13</i>	<i>13</i>	<i>10</i>	
<i>Savannah</i>					
Quantity TEU	-	-	62,569	38,272	100,841
<i>Transport time (days)</i>	<i>19</i>	<i>15</i>	<i>17</i>	<i>12</i>	
Total quantity received (TEU)	1,028,000	849,728	785,988	38,272	2,701,988
TOTAL CONTAINER TRANSPORT TIME (TEU): 17 days					

Source: Prepared by the author based on source material.

c5. Optimization of container transport prices from PKT/A to PKT/E in 2012

The optimization of container transport prices from PKT/A to PKT/E in 2012 was carried out on the basis of previously obtained data using the north1st corner method.

$$Z_{3C} = 270 \times 57,595 + 268 \times 0 + 287 \times 0 + 252 \times 0 + 282 \times 970,405 + 298 \times 499,004 + 301 \times 0 + 266 \times 0 + 294 \times 0 + 255 \times 40,474 + 330 \times 0 + 285 \times 0 + 305 \times 0 + 306 \times 195,602 + 325 \times 0 + 285 \times 0 + 295 \times 52,079 + 296 \times 114,648 + 315 \times 723,419 + 280 \times 0 + 328 \times 0 + 328 \times 0 + 344 \times 62,569 + 312 \times 38,272$$

Table 37 - Optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the third optimization model

Maritime container terminals in Eastern US states	Maritime container terminals in Western European countries				Total TEU volume
	Rotterdam	Antwerp	Hamburg	Le Havre	
<i>Boston</i>					
Quantity TEU	57,595	-	-	-	57,595
<i>Trans. cost (€/TEU)</i> ¹³⁹	<i>270</i>	<i>268</i>	<i>287</i>	<i>252</i>	
<i>New York</i>					
Quantity TEU	970,405	499,004	-	-	1,469,409
<i>Trans. cost (€/TEU)</i>	<i>282</i>	<i>298</i>	<i>301</i>	<i>266</i>	
<i>Philadelphia</i>					
Quantity TEU	-	40,474	-	-	40,474
<i>Trans. cost (€/TEU)</i>	<i>294</i>	<i>255</i>	<i>330</i>	<i>285</i>	
<i>Baltimore</i>					
Quantity TEU	-	195,602	-	-	195,602
<i>Trans. cost (€/TEU)</i>	<i>305</i>	<i>306</i>	<i>325</i>	<i>285</i>	

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Internet, <http://www.kline.com/KAMSurcharges/Surcharges-TransAtlantic-Eastbound.asp>, (28 April 2014).
Transport cost data calculated as €0.045/TEU * distance between maritime container terminals in km

Norfolk					
Quantity TEU	-	114,648	723,419	-	838,067
Trans. cost (€/TEU)	295	296	315	280	
Savannah					
Quantity TEU	-	-	62,569	38,272	100,841
Trans. cost (€/TEU)	328	328	344	312	
Total quantity received TEU	1,028,000	849,728	785,988	38,272	2,701,988
MINIMUM CONTAINER TRANSPORT PRICE (TEU): 803,360,527 €					

Source: Prepared by the author based on source material.

c6. *Optimisation of container transport time from PKT/A to PKT/E in 2012*

The optimization of container transport time from PKT/A to PKT/E in 2012 was also performed for a time of $T=15$ days based on previously obtained data using the North-West Corner method.

Table 38 - Optimal solution for transporting containers from maritime container terminals in the Eastern United States (PKT/A) to maritime container terminals in Western Europe (PKT/E) for the third optimization model

Maritime container terminals in Eastern US states	Maritime container terminals in Western European countries				Total TEU volume
	Rotterdam	Antwerp	Hamburg	Le Havre	
<i>Boston</i>					
Quantity TEU	57,595	-	-	-	57,595
<i>Transport time (days)</i>	<i>13</i>	<i>13</i>	<i>14</i>	<i>12</i>	
<i>New York</i>					
Quantity TEU	929,931	539,478	-	-	1,469,409
<i>Transport time (days)</i>	<i>15</i>	<i>11</i>	<i>13</i>	<i>12</i>	

Philadelphia					
Quantity TEU	40,474	-	-	-	40,474
Transport time (days)	14	14	15	13	
Baltimore					
Quantity TEU	-	195,602	-	-	195,602
Transport time (days)	14	13	15	13	
Norfolk					
Quantity TEU	-	52,079	785,988	-	838,067
Transport time (days)	17	13	13	10	
Savannah					
Quantity TEU	-	62,569	-	38,272	100,841
Transport time (days)	19	15	17	12	
Total quantity received (TEU)	1,028,000	849,728	785,988	38,272	2,701,988
TOTAL CONTAINER TRANSPORT TIME (TEU): 15 days					

Source: Prepared by the author based on source material.

c7. Optimization of container transport costs from PKT/A to PKT/E in 2012

The optimization of container transport prices from PKT/A to PKT/E in 2012 was carried out for a period of T=15 days based on previously obtained data using the North-West Corner method.

$$\begin{aligned}
 Z_{3C} = & 270 \times 57,595 + 268 \times 0 + 287 \times 0 + 252 \times 0 + 282 \times 929,931 + \\
 & 298 \times 539,478 + 301 \times 0 + 266 \times 0 + 294 \times 40,474 + 255 \times 0 + \\
 & 330 \times 0 + 285 \times 0 + 305 \times 0 + 306 \times 195,602 + 325 \times 0 + \\
 & 285 \times 0 + 295 \times 0 + 296 \times 52,079 + 315 \times 785,988 + 280 \times 0 + \\
 & 328 \times 0 + 328 \times 62,569 + 344 \times 0 + 312 \times 38,272
 \end{aligned}$$

Table 39 - Optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the third optimization model

Maritime container terminals in Eastern US states	Maritime container terminals in Western European countries				Total TEU volume
	Rotterdam	Antwerp	Hamburg	Le Havre	
<i>Boston</i>					
Quantity TEU	57,595	-	-	-	57,595
<i>Trans. cost (€/TEU)</i> ¹⁴⁰	<i>270</i>	<i>268</i>	<i>287</i>	<i>252</i>	
<i>New York</i>					
Quantity TEU	929,931	539,478	-	-	1,469,409
<i>Trans. cont. price (€/TEU)</i>	<i>282</i>	<i>298</i>	<i>301</i>	<i>266</i>	
<i>Philadelphia</i>					
Quantity TEU	40,474	-	-	-	40,474
<i>Trans. cost (€/TEU)</i>	<i>294</i>	<i>255</i>	<i>330</i>	<i>285</i>	
<i>Baltimore</i>					
Quantity TEU	-	195,602	-	-	195,602
<i>Trans. cost (€/TEU)</i>	<i>305</i>	<i>306</i>	<i>325</i>	<i>285</i>	
<i>Norfolk</i>					
Quantity TEU	-	52,079	785,988	-	838,067
<i>Trans. cont. price (€/TEU)</i>	<i>295</i>	<i>296</i>	<i>315</i>	<i>280</i>	
<i>Savannah</i>					
Quantity TEU	-	62,569	-	38,272	100,841
<i>Trans. cont. price (€/TEU)</i>	<i>328</i>	<i>328</i>	<i>344</i>	<i>312</i>	
Total quantity received TEU	1,028,000	849,728	785,988	38,272	2,701,988
MINIMUM CONTAINER TRANSPORT COST (TEU): 805,774,304 €					

Source: Prepared by the author based on source material.

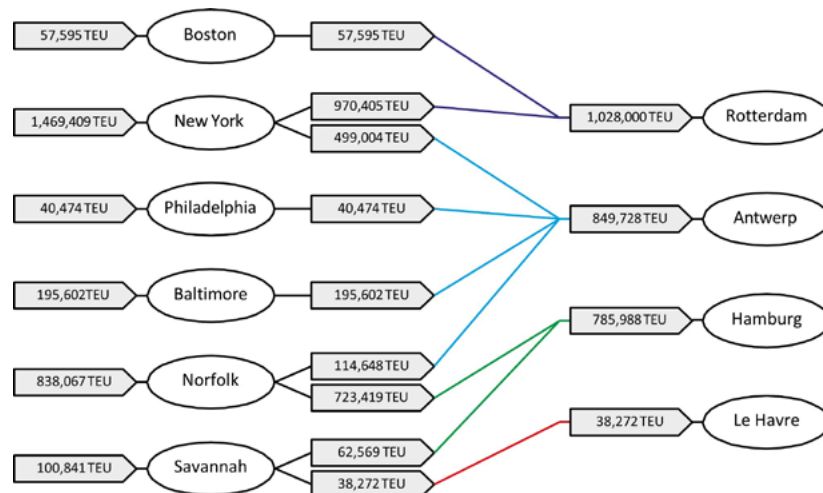
The optimal solution for transporting containers from maritime container terminals in the Eastern United States (PKT/A) to

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Internet, <http://www.kline.com/KAMSurcharges/Surcharges-TransAtlantic-Eastbound.asp>, (28 April 2014).
Transport cost calculated as €0.045/TEU * distance between maritime container terminals in km

maritime container terminals in Western Europe (PKT/E) for the third optimization model is shown in Diagram 4.

Diagram 4 - Optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the third optimization model



Source: Prepared by the author based on source material.

The profit matrix is defined as:

$$C = \begin{bmatrix} c_{ij} & \text{if } t_{ij} < 17 \\ 0 & \text{if } t_{ij} \geq 17 \end{bmatrix} \quad (116)$$

The optimal solution for transporting containers from maritime container terminals in the Eastern United States (PKT/A) to maritime container terminals in Western Europe (PKT/E) for the fourth optimization model is shown in Table 39. In accordance with Hammer's defined profit matrix, the price of transporting containers from seaport container terminals in the Eastern United States (PKT/A) to seaport container terminals in Western European countries (PKT/E) where the time is greater than or equal to 17 days is not taken into account. Therefore, the transport volume of 62,569

TEU and the cost of €21,523,736 on the Savannah–Hamburg route are not taken into account.

$$Z_{3C} = 270 \times 57,595 + 268 \times 0 + 287 \times 0 + 252 \times 0 + 282 \times 929,931 + 298 \times 539,478 + 301 \times 0 + 266 \times 0 + 294 \times 40,474 + 255 \times 0 + 330 \times 0 + 285 \times 0 + 305 \times 0 + 306 \times 195,602 + 325 \times 0 + 285 \times 0 + 295 \times 0 + 296 \times 52,079 + 315 \times 785,988 + 280 \times 0 + 328 \times 0 + 0 \times 62,569 + 344 \times 0 + 312 \times 38,272$$

Table 40 - Optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the fourth optimization model

Maritime container terminals in Eastern US states	Maritime container terminals in Western European countries				Total TEU volume
	Rotterdam	Antwerp	Hamburg	Le Havre	
<i>Boston</i>					
Quantity TEU	57,595	-	-	-	57,595
<i>Trans. cost (€/TEU)</i> ¹⁴¹	270	268	287	252	
<i>New York</i>					
Quantity TEU	970,405	499,004	-	-	1,469,409
<i>Trans. cost (€/TEU)</i>	282	298	301	266	
<i>Philadelphia</i>					
Quantity TEU	-	40,474	-	-	40,474
<i>Trans. cost (€/TEU)</i>	294	255	330	285	
<i>Baltimore</i>					
Quantity TEU	-	195,602	-	-	195,602
<i>Trans. cost (€/TEU)</i>	305	306	325	285	
<i>Norfolk</i>					
Quantity TEU	-	114,648	723,419	-	838,067
<i>Trans. cont. price (€/TEU)</i>	295	296	315	280	

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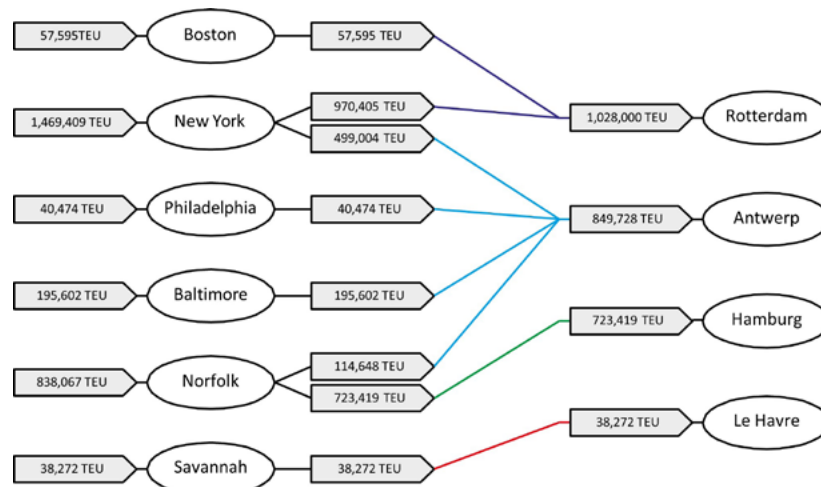
Internet, <http://www.kline.com/KAMSurcharges/Surcharges-TransAtlantic-Eastbound.asp>, (28 April 2014). Transport cost calculated as €0.045/TEU * distance between maritime container terminals in km

Savannah					
Quantity TEU	-	-	-	38,272	38,272
Trans. cost (€/TEU)	328	328	344	312	
Total quantity received TEU	1,028,000	849,728	723,419	38,272	2,639,419
MINIMUM CONTAINER TRANSPORT COST (TEU): 781,836,791 €					

Source: Prepared by the author based on source material.

The minimum total average price of container transport from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries Europe (PKT/E) in 2012 for the fourth optimization model is $Z_{3c} = 781,836,791$ €, which would save 20,899,620 € (3%) compared to the traditional method of container transport, where the total average cost of container transport by sea is 802,736,411 € (Table 7).

Diagram 5 - Optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the fourth optimization model



Source: Prepared by the author based on source material.

d. *Optimal solution for transporting containers from PKT/A to PKT/E in 2012 for the fifth and sixth optimization models*

The optimal solution for transporting containers from PKT/A to PKT/E in 2012 for the fifth and sixth optimization models is calculated using the North-West Corner method.

d1. *Optimization of container transport time from PKT/A to PKT/E in 2012*

The optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E), taking into account the level of development of maritime container terminals S_r in Western European countries for the fifth optimization model is the same as for the third optimization model (Table 35).

d2. *Optimization of the price of container transport from PKT/A to PKT/E in 2012*

The optimization of the price of container transport from PKT/A to PKT/E in 2012 is performed for a period of $T=17$ days based on previously obtained data using the North-West Corner method (North-West Corner method) and taking into account the level of development of maritime container terminals in Western European countries S_r .

$$Z_{4C} = 900 \times 0.3 \times 57.595 + 850 \times 0.3 \times 0 + 1,100 \times 0.3 \times 0 + 1,425 \times 0.2 \times 0 + 900 \times 0.3 \times 970.405 + 850 \times 0.3 \times 499.004 + 1,100 \times 0.3 \times 0 + 1,425 \times 0.2 \times 0 + 900 \times 0.3 \times 0 + 850 \times 0.3 \times 40,474 + 1,100 \times 0.3 \times 0 + 1,425 \times 0.2 \times 0 + 900 \times 0.3 \times 0 + 850 \times 0.3 \times 114,648 + 1,100 \times 0.3 \times 723,419 + 1,425 \times 0.2 \times 0 + 900 \times 0.3 \times 0 + 850 \times 0.3 \times 0 + 1,100 \times 0.3 \times 62,569 + 1,425 \times 0.2 \times 38,272$$

Table 41 - Optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the sixth optimization model

Maritime container terminals in Eastern US states	Maritime container terminals in Western European countries				Total TEU volume
	Rotterdam	Antwerp	Hamburg	Le Havre	
<i>Boston</i>					
Quantity TEU	57,595	-	-	-	57,595
<i>Trans. cost (€/TEU)</i> ¹⁴²	270	255	330	285	
<i>New York</i>					
Quantity TEU	970,405	499,004	-	-	1,469,409
<i>Trans. cont. price (€/TEU)</i>	270	255	330	285	
<i>Philadelphia</i>					
Quantity TEU	-	40,474	-	-	40,474
<i>Trans. cost (€/TEU)</i>	270	255	330	285	
<i>Baltimore</i>					
Volume TEU	-	195,602	-	-	195,602
<i>Trans. cont. price (€/TEU)</i>	270	255	330	285	
<i>Norfolk</i>					
Quantity TEU	-	114,648	723,419	-	838,067
<i>Trans. cont. price (€/TEU)</i>	270	255	330	285	
<i>Savannah</i>					
Quantity TEU	-	-	62,569	38,272	100,841
<i>Trans. cost (€/TEU)</i>	270	255	330	285	
Total quantity received TEU	1,028,000	849,728	785,988	38,272	2,701,988
MINIMUM CONTAINER TRANSPORT COST (TEU): 764,524,200 €					

Source: Prepared by the author based on source material.

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Internet, <http://www.kline.com/KAMSurcharges/Surcharges-TransAtlantic-Eastbound.asp>, (28 April 2014). Transport price calculated as €0.045/TEU * distance between maritime container terminals in km

In accordance with Hammer, I modify the profit matrix:

$$C_{ij} = \begin{bmatrix} u_j S_{rj} & \text{if } t_{ij} < 17 \\ 0 & \text{if } t_{ij} \geq 17 \end{bmatrix} \quad (117)$$

The optimal solution for transporting containers from maritime container terminals in the Eastern United States (PKT/A) to maritime container terminals in Western Europe (PKT/E) for the sixth optimization model is shown in Table 41. In accordance with Hammer's defined profit matrix, the price of transporting containers from maritime container terminals in the Eastern United States (PKT/A) to maritime container terminals in Western European countries (PKT/E), where the time is greater than or equal to 17 days, is not taken into account. Therefore, the transport volume of 62,569 TEU and the cost of 21,523,736 € on the Savannah-Hamburg route are not taken into account.

The optimal solution for container transport from PKT/A to PKT/E in 2012 for the sixth optimization model:

$$\begin{aligned} Z_{4C} = & 900 \times 0.3 \times 57,595 + 850 \times 0.3 \times 0 + 1,100 \times 0.3 \times 0 + 1,425 \times \\ & 0.2 \times 0 + 900 \times 0.3 \times 970.405 + 850 \times 0.3 \times 499.004 + 1,100 \times \\ & 0.3 \times 0 + 1,425 \times 0.2 \times 0 + 900 \times 0.3 \times 0 + 850 \times 0.3 \times \\ & 40,474 + 1,100 \times 0.3 \times 0 + 1,425 \times 0.2 \times 0 + 900 \times 0.3 \times 0 + 850 \times 0.3 \times \\ & 114,648 + 1,100 \times 0.3 \times 723,419 + 1,425 \times 0.2 \times 0 + 900 \times 0.3 \times \\ & 0 + 850 \times 0.3 \times 0 + 1,100 \times 0.3 \times 0 + 1,425 \times 0.2 \times 38,272 \end{aligned}$$

Table 42 - Optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the sixth optimization model

Maritime container terminals in Eastern US states	Maritime container terminals in Western European countries				Total TEU volume
	Rotterdam	Antwerp	Hamburg	Le Havre	
<i>Boston</i>					
Quantity TEU	57,595	-	-	-	57,595
<i>Trans. cont. price (€/TEU)</i> ¹⁴³	270	255	330	285	
<i>New York</i>					
Quantity TEU	970,405	499,004	-	-	1,469,409
<i>Trans. cont. price (€/TEU)</i>	270	255	330	285	
<i>Philadelphia</i>					
Quantity TEU	-	40,474	-	-	40,474
<i>Trans. cost (€/TEU)</i>	270	255	330	285	
<i>Baltimore</i>					
Volume TEU	-	195,602	-	-	195,602
<i>Trans. cont. price (€/TEU)</i>	270	255	330	285	
<i>Norfolk</i>					
Quantity TEU	-	114,648	723,419	-	838,067
<i>Trans. cont. price (€/TEU)</i>	270	255	330	285	
<i>Savannah</i>					
Quantity TEU	-	-	-	38,272	100,841
<i>Trans. cost (€/TEU)</i>	270	255	330	285	
Total quantity received TEU	1,028,000	849,728	723,419	38,272	2,693,419
MINIMUM CONTAINER TRANSPORT COST (TEU): 743,876,430 €					

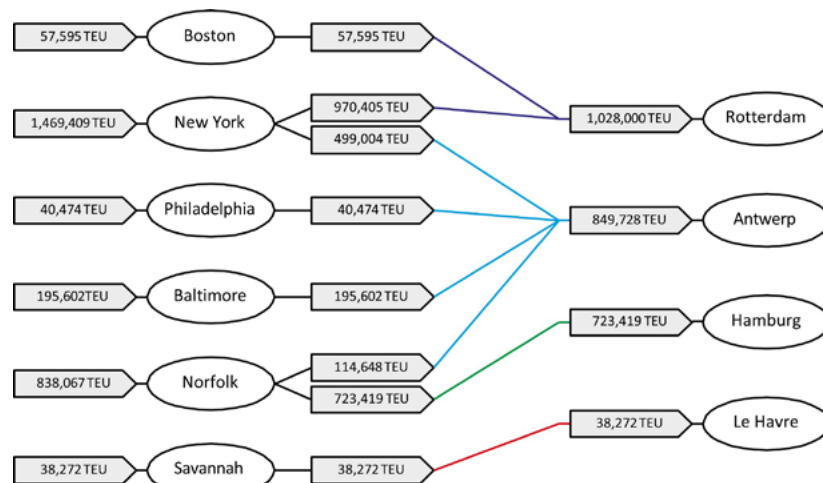
Source: Prepared by the author based on source material.

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Internet, <http://www.kline.com/KAMSurcharges/Surcharges-TransAtlantic-Eastbound.asp>, (28 April 2014). Transport cost data calculated as €0.045/TEU * distance between maritime container terminals in km

The optimal solution for transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the sixth optimization model is performed using the Northwest Corner method and taking into account the level of development of maritime container terminals S_r in Western European countries, as shown in Diagram 6.

Diagram 6 - Optimal solution for transporting containers from maritime container terminals in the Eastern United States (PKT/A) to maritime container terminals in Western European countries (PKT/E) for the sixth optimization model



Source: Prepared by the author based on source material.

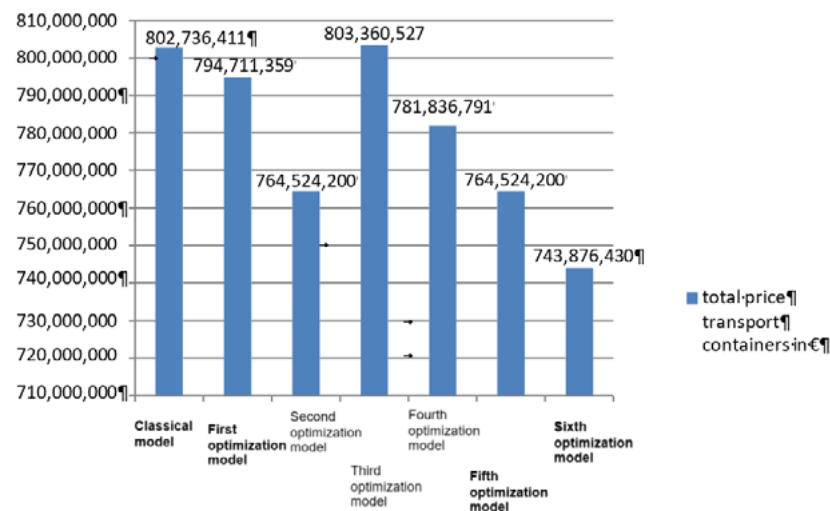
Minimum total average price of container transport from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) in 2012, using the northwest corner method and taking into account the level of development of maritime container terminals S_r in Western European countries, is $Z_{4C} = 743,876,430$ €, which would save 57,826,637 € (7%) compared to the conventional method of container

transport, where the total average cost of container transport by sea is 802,736,411 € (Table 7).

The total average cost of transporting containers from maritime container terminals in Eastern US states (PKT/A) to maritime container terminals in Western European countries (PKT/E) in 2012 for conventional container transport and for six implemented container transport optimisation models is shown in Graph 28.

Graph 28 shows that the optimal solution for transporting containers by sea from maritime container terminals in the Eastern United States (PKT/A) to maritime container terminals in Western European countries (PKT/E) with the sixth optimization model.

Graph 28 - Total average cost of transporting containers by sea from maritime container terminals in the Eastern United States (PKT/A) to maritime container terminals in Western European countries (PKT/E)



Source: Prepared by the author based on source material.

4.8 IMPACT OF THE OPTIMIZATION MODEL FOR CONTAINER TRANSPORT FROM EASTERN US STATES TO WESTERN EUROPEAN COUNTRIES ON SUSTAINABLE DEVELOPMENT

In the coming years, areas related to container transport, such as the market, interest groups, customers, and regulatory (mandatory) burdens, will have a significant impact on changes in the way international liner container shipping is conducted. Regulations designed to protect the environment are likely to become the most significant cost for carriers in the coming years, as governments and corporations have raised environmental levies on air emissions, ballast water discharge, and ship design and recycling. Likewise, legislative changes related to safety, business ethics, health, safety and labor standards will put additional pressure on international container shipping lines to achieve and increase sustainable development.¹⁴⁴ To all these micro-level changes, four broader societal megatrends are likely to be added: **high transparency, carbon and carbon source constraints, the rise of rights and local governance, and socio-economic change**. Research shows that these mega-trends will pose additional challenges for the transport industry (Figure 5).

Environmental protection and **commitment to sustainable development** are currently the biggest challenges for international shipping companies and the container industry. Most of the issues relate to emissions. The current focus is on greenhouse gases (GHGs). Emissions such as sulfur oxides (SOx), nitrogen oxides (NOx), particulate matter (PM), and especially black carbon will also need

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PRUZAN-JORGENSEN P.M., FARRAG, A.: **Sustainability Trends in the Container Shipping Industry, A Future Trends Research Summary**, BSR, September 2010, p. 3.

to be given greater attention in order to protect human health and reduce local environmental impacts in the future.¹⁴⁵ Fuel and energy consumption will also need to be given considerable attention.

Figure 5 - The impact of megatrends related to container transport on sustainable development



Source: *Ibidem*, p. 3.

Table 42 shows the amount of CO₂ emissions, fuel and energy consumption of maritime container ships in the conventional mode of container transport from maritime container terminals in the Eastern United States (PKT/A) to maritime container terminals in Western Europe (PKT/E) in 2012¹⁴⁶. Table 43 shows the amount of CO₂ emissions, fuel and energy consumption of maritime container ships with a capacity of 9,000 TEU in the sixth optimization model, which gives us the best results.

¹⁴⁵ *Ibid.*, p. 6.

¹⁴⁶ CO₂ multimodal emissions from Port Siad to main European destinations, Transport, Territory and Logistics, Research Unit of IUAV University of Venice, Venice, 2010, pp. 3-6.

Table 43 - Amount of CO₂ emissions into the environment, energy and fuel consumption in the conventional method of container transport

Maritime container terminals in Eastern US states	Maritime container terminals in Western European countries				Total TEU volume
	Rotterdam	Antwerp	Hamburg	Le Havre	
<i>Boston</i>					
Quantity TEU	22,174	33,500	1,921		57,595
<i>Distance (km)</i> ¹⁴⁷	<i>5,948</i>	<i>5,957</i>	<i>6,386</i>		
<i>CO₂ emissions (kg/kmTEU)</i> ¹⁴⁸	<i>2,110,255</i>	<i>3,192,952</i>	<i>196,280</i>		5,303,207
<i>Fuel consumption (kg/kmTEU)</i> ¹⁴⁹	<i>4,748,074</i>	<i>7,184,142</i>	<i>441,630</i>		12,373,846
<i>Energy consumption (kg/kmTEU)</i> ¹⁵⁰	<i>3,165,383</i>	<i>4,789,428</i>	<i>294,420</i>		8,249,231
<i>New York</i>					
Quantity TEU	462,967	386,682	599,289	20,471	1,469,409
<i>Distance (km)</i>	<i>6,259</i>	<i>6,628</i>	<i>6,697</i>	<i>5,913</i>	
<i>CO₂ emissions (kg/kmTEU)</i>	46,363,367	41,006,853	64,215,015	1,936,720	153,521,955
<i>Fuel consumption (kg/kmTEU)</i>	104,317,576	92,265,419	144,483,784	4,357,621	345,424,399
<i>Energy consumption (kg/kmTEU)</i>	69,545,051	61,510,279	96,322,522	2,905,081	230,282,933
<i>Philadelphia</i>					
Quantity TEU	23,859	15,000		1,615	40,474
<i>Distance (km)</i>	<i>6,527</i>	<i>6,536</i>		<i>6,181</i>	
<i>CO₂ emissions (kg/kmTEU)</i>	2,491,643	1,568,640		159,717	4,220,000
<i>Fuel consumption (kg/kmTEU)</i>	5,606,197	3,529,440		359,363	9,495,000
<i>Energy consumption (kg/kmTEU)</i>	3,737,465	2,352,960		239,576	6,330,000

147 Distances between maritime container terminals are calculated using the program on the Ibsite: <http://www.sea-distances.org/>, (May 2, 2014).

148 For a 9,000 TEU maritime container ship= 0.016 kg CO₂/kmTEU; CO₂ multimodal emissions from Port Siad to main European destinations, Transport, Territory and Logistics, Research Unit of the IUAV University of Venice, Venice, 2010, p. 6.

149 For a 9,000 TEU container ship = 0.036 kg/kmTEU; CO₂ multimodal emissions from Port Siad to main European destinations, Transport, Territory and Logistics, Research Unit of the IUAV University of Venice, Venice, 2010, p. 3.

150 For a 9,000 TEU container ship= 0.024 kg CO₂/kmTEU; CO₂ multimodal emissions from Port Siad to main European destinations, Transport, Territory and Logistics, Research Unit of the IUAV University of Venice, Venice, 2010, p. 3.

Baltimore					
TEU volume	56,000	63,000	74,539	2,063	195,602
Distance (km)	6,790	6,799	7,228	6,444	
CO ₂ emissions (kg/kmTEU)	6,083,840	6,853,392	8,620,286	212,704	21,770,222
Fuel consumption (kg/kmTEU)	13,688,640	15,420,132	19,395,644	478,583	48,982,999
Energy consumption (kg/kmTEU)	9,125,760	10,280,088	12,930,429	319,055	32,655,333
Norfolk					
Quantity TEU	411,000	321,618	95,239	10,210	838,067
Distance (km)	6,562	6,571	7,000	6,216	
CO ₂ emissions (kg/kmTEU)	43,151,712	33,813,630	10,666,768	1,015,446	88,647,556
Fuel consumption (kg/kmTEU)	97,091,352	76,080,668	24,000,228	2,284,753	199,457,001
Energy consumption (kg/kmTEU)	64,727,568	50,720,445	16,000,152	1,523,169	132,971,334
Savannah					
Quantity TEU	52,000	29,928	15,000	3,913	100,841
Distance (km)	7,283	7,293	7,635	6,938	
CO ₂ emissions (kg/kmTEU)	6,059,456	3,492,238	1,832,400	434,374	11,818,469
Fuel consumption (kg/kmTEU)	13,633,776	7,857,537	4,122,900	977,342	26,591,555
Energy consumption (kg/kmTEU)	9,089,184	5,238,358	2,748,600	651,561	17,727,703
Total quantity received TEU	1,028,000	849,728	785,988	38,272	2,701,988
CO₂ EMISSIONS = 285,477,689 kg/kmTEU					
FUEL CONSUMPTION = 642,234,800 kg/kmTEU					
ENERGY CONSUMPTION = 428,216,534 kg/kmTEU					

Source: Prepared by the author based on source material.

In 2012, using conventional methods to transport containers from maritime container terminals in the Eastern United States (PKT/A) to maritime container terminals in Western Europe (PKT/E), container ships with a capacity of 9,000 TEU would have emitted₂ emissions into the environment would amount to 285,477,689 kg/kmTEU, fuel consumption would amount to 642,234,800 kg/kmTEU, and energy consumption would amount to 428,216,534 kg/kmTEU.

Table 44 - Amount of CO₂ emissions into the environment, energy and fuel consumption for the calculated optimal container transport solution for the sixth optimization model

Maritime container terminals in Eastern US states	Maritime container terminals in Western European countries				Total TEU volume
	Rotterdam	Antwerp	Hamburg	Le Havre	
<i>Boston</i>					
Quantity TEU	57,595				57,595
<i>Distance (km)</i> ¹⁵¹	5,948				
<i>CO₂ emissions (kg/km TEU)</i>	5,481,201				5,481,201
<i>Fuel consumption (kg/km TEU)</i>	12,332,702				12,332,702
<i>Energy consumption (kg/km TEU)</i>	8,221,801				8,221,801
<i>New York</i>					
TEU volume	970,405	499,004			1,469,409
<i>Distance (km)</i>	6,259	6,628			
<i>CO₂ emissions (kg/km TEU)</i>	97,180,238	52,918,376			150,098,615
<i>Fuel consumption (kg/km TEU)</i>	218,655,536	119,066,346			337,721,883
<i>Energy consumption (kg/km TEU)</i>	145,770,357	79,377,564			225,147,922
<i>Philadelphia</i>					
TEU volume		40,474			40,474
<i>Distance (km)</i>		6,536			
<i>CO₂ emissions (kg/km TEU)</i>		4,232,609			4,232,609
<i>Fuel consumption (kg/km TEU)</i>		9,523,370			9,523,370
<i>Energy consumption (kg/km TEU)</i>		6,348,914			6,348,914
<i>Baltimore</i>					
TEU volume		195,602			195,602
<i>Distance (km)</i>		6,799			
<i>CO₂ emissions (kg/km TEU)</i>		21,278,368			21,038,327
<i>Fuel consumption (kg/km TEU)</i>		47,876,328			47,336,237
<i>Energy consumption (kg/km TEU)</i>		31,917,552			31,557,491

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Distances between maritime container terminals are calculated using the program on the lbsite:
<http://www.sea-distances.org/>, (May 2, 2014).

Norfolk					
TEU volume	114,648	723,419			838,067
Distance (km)	6,571	7,000			
CO ₂ emissions (kg/km TEU)	12,053,632	81,022,928			93,076,560
Fuel consumption (kg/km TEU)	27,120,672	182,301,588			209,422,260
Energy consumption (kg/km TEU)	18,080,448	121,534,392			139,614,840
Savannah					
Quantity TEU			38,272		38,272
Distance (km)			6,938		
CO ₂ emissions (kg/km TEU)			4,248,498		4,248,498
Fuel consumption (kg/km TEU)			9,559,121		9,559,121
Energy consumption (kg/km TEU)			6,372,747		6,372,747
Total TEU intake	1,028,000	849,728	723,419	38,272	2,639,419
CO₂ EMISSIONS = 278,415,851 kg/km TEU					
FUEL CONSUMPTION = 626,435,664 kg/km TEU					
ENERGY CONSUMPTION = 417,623,777 kg/km TEU					

Source: Prepared by the author based on source material.

With the calculated optimal solution for transporting containers from maritime container terminals in the Eastern United States (PKT/A) to maritime container terminals in Western European countries (PKT/E) using the sixth optimization model in 2012, container transport would be 2,639,419 TEU¹⁵² with maritime container ships with capacity 9,000 TEU, CO₂ emissions into the environment by 7,061,838 kg/kmTEU (1%), fuel consumption would be reduced by 10,592,757 kg/kmTEU (2%) and energy consumption would be reduced by 103,349,083 kg/kmTEU (1%).

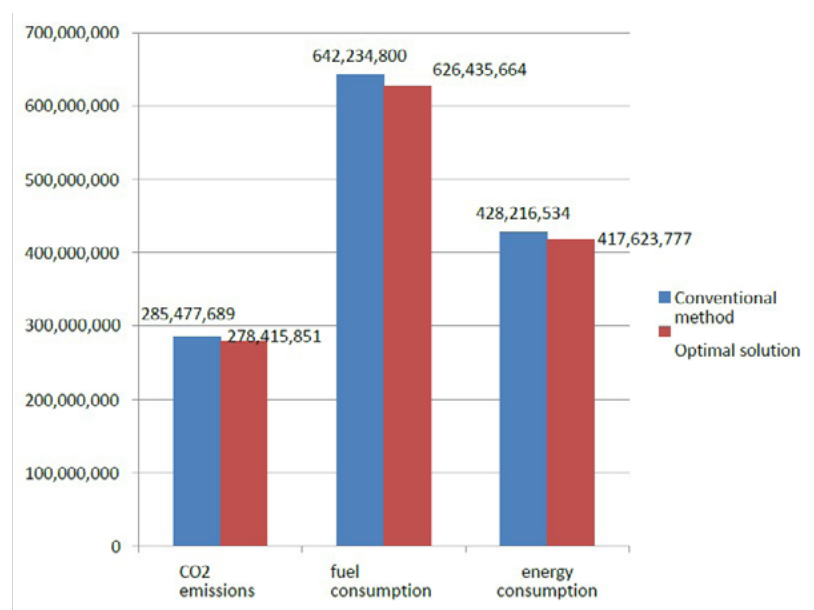
Comparison of CO₂ emissions, fuel consumption, and energy consumption of 9,000 TEU container ships 9,000 TEU capacity in the

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Due to the non-profitable Savannah-Hamburg maritime link, the total volume of containers transported by sea on this link is reduced by 62,569 TEU.

transport of containers by sea from maritime container terminals in the Eastern United States to maritime container terminals in Western European countries in 2012, compared to the conventional method of container transport and the calculated solution of the sixth optimization model, is shown in Graph 29.

Graph 29 - Comparison of CO₂ emissions into the environment, fuel consumption, and energy consumption energy



Source: Prepared by the author based on source material.



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CONCLUSION

The main objective of this book is to optimize transoceanic transport routes and reduce the time and cost of container transport between the Eastern United States and Western European countries as part of the logistics system in a transnational context, and to define and calculate the level of development of maritime container terminals in the Eastern United States and Western European countries.

The research reveals various directions. First, concrete estimates and calculations prove hypothesis 1, namely that optimizing freight container flows between maritime container terminals in Eastern US states and Western European countries reduces the total cost of container transport by 5%. With an optimal solution that includes the level of development of maritime container terminals S_r in Western European countries, I arrive at an even lower total average cost of container transport compared to the conventional mode of transport in 2012. Here, I reduce the total average price of container transport by 7%.

Secondly, hypothesis 2 has been proven, namely that the optimal solution for optimizing cargo flows on transatlantic container liner routes in 2012, which includes the level of development of maritime container terminals S_r in Western European countries, the total amount of CO₂ emissions into the environment is reduced by 1%, fuel consumption is reduced by 2% and energy consumption by 1% for container ships with a capacity of 9,000 TEU.

With the development and application of integer linear programming optimization models, it is possible to significantly reduce the cost and time of container transport between maritime container terminals in the Eastern United States and Western European countries. In designing the model, I took into account the following elements: 1) transport infrastructure and transport superstructure, 2) the impact of an intelligent information system, 3) gross domestic product, 4) transport ecology, 5) transport flows, 6) innovation, 7) safety and security, and 8) transport energy, the introduction

of which in practical terms represents a reduction in the cost and time for transporting containers between container terminals in the Eastern United States and Western Europe .

Six optimization models for container transport Were modeled in the study. The first optimization model (Z_1) for sea transport of containers from maritime container terminals in the Eastern United States (PKT/A) to Western European countries (PKT/E) was modeled for optimization using the integer linear programming method in the Lingo 14 software tool, where the optimization criterion was the cost of container transport. The second optimization model (Z_2) was modelled for optimisation using the integer linear programming method in the Lingo 14 software tool, taking into account the level of development of maritime container terminals in Western European countries S_r , where the optimisation criterion was also the price of container transport. Since containers often also transport perishable goods, priority is given to the transport time optimization criterion over the transport price criterion. In these cases, the objective function remains linear. The third optimization model (Z_{3T}) was modeled for integer linear programming of transport time. The fourth optimization model (Z_{3C}) was then modeled for transport cost optimization, taking into account the results of the previous time optimization (Z_{3T}). The fifth optimization model (Z_{4T}) was modeled for integer linear programming of transport time. The sixth optimization model (Z_{4C}) was then modeled to optimize transport costs, taking into account the level of development of maritime container terminals in Western European countries S_r , while considering the results of the previous optimization by container transport time (Z_{4T}).

First, I performed integer linear programming of container transport prices without and with consideration of the level of development of maritime container terminals in Western European countries S_r . Taking into account the level of development of maritime container terminals in Western European countries S_r , I obtained a 5% better result. I then performed sequential optimization of container

transport time and price, also using integer linear programming and the North-West Corner method. I optimized the price of container transport based on the previously obtained results of container transport time optimization. I also performed the aforementioned sequential optimization of container transport time and price, taking into account the level of development of maritime container terminals in Western European countries S_n , and obtained the best result. I reduced the price of container transport between maritime container terminals in the Eastern United States and Western European countries by an additional 2%.

The research conducted in the book could have a significant impact on the national economy and politics, as well as on the decisions made by port management and freight forwarders (e.g., manufacturing and trading industries), especially with regard to the planning of maritime (shipping) systems. The findings of the research in the book also have international significance, e.g., in multilateral negotiations in connection with GATS, in trade and business.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation	Page
A		
APL	American President Lines Ltd.	51
AIG	American International Group, Inc.	51
F		
FEU	„Forty foot Equivalent Unit“ (40-foot container), 1 FEU = 2 TEU	58
G		
GATS	General Agreement on Trade and Services	24
GDP	Gross domestic product	95
H		
HHLA	Hamburger Hafen und Logistik AG: Container	51
HPH	Hutchison Port Holdings	51
L		
LPI	Logistic Performance Index – index of logistics efficiency	83
M		
MAERSK	Maersk Line	60
N		
NVOOC	Non Vessel Owning Ocean Carrier - Organizer of sea transport who is not a maritime carrier	56
R		
ROCE	ROCE - return on capital employed calculated at EBIT (earnings before interest and taxes) divided by net working capital plus book value of plant and equipment - Profit excluding taxes, divided by the net working capital and the sum of the book values of tangible fixed assets	56
T		
TEU	Twenty-foot Equivalent Unit: Standard unit based on an ISO container, 20 feet in length.	14

Abbreviation	Explanation	Page
	U	
UNCTAD	United Nations Conference on Trade and Development	19
	W	
WTO	World Trade Organization	24
	Z	
ZIM	ZIM Integrated Shipping Services Ltd	60

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AN OPTIMAL CONTAINER TRANSPORTATION MODEL (TEU) BETWEEN THE EASTERN STATES OF THE UNITED STATES AND WESTERN EUROPEAN COUNTRIES

