Electronic Seals and their Influence on the Dynamics of Container Logistics

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Abstract

After events 9/11 the unpredictable changes have affected the global container flows in international affairs. In order to define and explore the trade-off between international security requirements and reasonably practicable measures for business, the analysis of one of the application of e-seal technology, promising to improve container transportation processes, have been evaluated in this doctoral research. The intent of this research is to investigate the impact of container detection intrusion technology on dynamics of container logistics processes at container terminals and on the complete network. In this study a model for container transhipment between two continents through several see ports consisting of several maritime terminals and customs gates is developed. In this scenario we compare transhipment processes for three different types of container seals. One type is when containers are equipped with conventional mechanical seals, the next one is an e-seal without decision making, and the last one is an e-seal with a possibility to make routing decisions. These three cases are compared and the difference in dynamics of the transport processes is investigated. First we apply the methods of queuing theory as a most suitable mathematical tool for the analysis of the dynamics. We show that this theory works effectively in case of small number of nodes. However it turns out that we arrive at its limitations when the number of nodes becomes large. For this reason we continue our investigations with help of simulation technique by means of MATLAB that has been applied to a generic container logistic network. Further we also have estimated the economical effectiveness of investments in new container secure devices. It is evaluated whether the electronic seals bring more security for container flows. As well we have investigated their influence on the business efficiency for private sector. The evaluation and analysis of modifications in dynamics of physical container flows have been accomplished through the global container supply network in the first part of the thesis. In the second main part of the doctoral research the cost-benefit analysis shows the possible costs and benefits through the implementation and use of secure container electronic seals in global container network.

In this work we have determined the most feasible advantages of application of e-seals technology and the framework of its application. The influence of different types of e-seals on the dynamics of container logistics flows has been investigated, simulated and modelled analytically in the global network; various scenarios have been developed and considered to include the most happened situations in the practical cases. An evaluation model based on the cost-benefit analysis has been proposed and approved by different business cases for adoption of different types of e-seals in container system. The returns on investment index have been calculated to compare the investments in security electronic devices under different initial conditions.

Zusammenfassung

Die bekannten Ereignisse 9/11 haben die internationalen Angelegenheiten im weltweiten Containerverkehr drastisch verändert. Um die Balance zwischen internationalen Sicherheitsanforderungen und für den Handel zumutbaren Maßnahmen zu bestimmen und zu erforschen, wird hier eine neue auf e-Seal basierte Technologie analysiert. E-Seal-Technologie kann die Prozesse im Containertransport verbessern. Deswegen wurden diese Prozesse in der Doktorarbeit betrachtet und ausgewertet mit dem Ziel, die Auswirkungen der Containererkennungstechnologie auf die Dynamik der Container-Logistik-Prozesse zu untersuchen. Als ein repräsentatives Szenario betrachten wir ein Transportnetzwerk zwischen zwei Kontinenten, was aus mehreren Häfen und Lagern besteht. Drei Typen der Containerversiegelung wurden in diesem Szenario implementiert: Einerseits ist es die konventionelle mechanische Versiegelung, andererseits betrachten wir elektronische Versiegelung mit / ohne der Möglichkeit, Entscheidungen unterwegs zu treffen. Der Einfluss solcher Versiegelungen auf die Dynamik der Containerflüsse wurde analysiert und miteinander verglichen. Zunächst haben wir die Warteschlangenmethode für diese Analyse verwendet. Wir haben gezeigt, dass die Methode für kleine Netzwerke sehr effektiv ist, allerdings ist sie für große dynamische Netzwerke kaum anwendbar. Deswegen haben wir ein Simulationsprogramm in MATLAB entwickelt, um die Containerflüsse im oben genannten Szenario zu simulieren. In der Dissertation wurde auch die wirtschaftliche Effizienz untersucht, um zu bestimmen, ob es sich lohnt, in die neue sichere Technologie für Container zu investieren. Im ersten Teil der Arbeit geht es um Auswertung und Analyse der Veränderungen in der Dynamik des physischen Containerumladens durch das globale Container-Netzwerk. Im zweiten Hauptteil der Doktorarbeit ist die Kosten-Nutzen-Analyse aufgezeigt. Die Analyse beurteilt die möglichen Kosten und Gewinne durch die Einführung und Nutzung von sicheren elektronischen Siegeln in das globale Container-Netzwerk.

In dieser Studie wurden die möglichen Vorteile der neuen Container-Sicherheits-Technologien (E-Seal) und die Rahmen ihrer Anwendung bestimmt. Der Einfluss verschiedener Arten von E-Seals auf die Dynamik des Container-Logistik-Verkehrs wurde simuliert und analytisch modelliert. Es wurden verschiedene Szenarien entwickelt und analysiert. Das vorgeschlagene Bewertungsmodell basiert auf der Kosten-Nutzen-Analyse und wurde benutzt um den Einsatz verschiedener E-Seal-Typen zu untersuchen. Der Return-on-Investment-Index wurde berechnet. Investitionen in verschiedene Typen von E-Seals wurden unter verschiedenen Anfangsbedingungen verglichen.

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1 Introduction

1.1 Background and motivation

> *“When the first container ship docked in Bremen on 6 May 1966, it caused, as does any novelty, a great deal of excitement. But back then, nobody could imagine the extent of the revolution that had been set in motion.”* (Gesamtverband der Deutschen Versicherungswirtschaft e. V., 2009)

Logistics is one of the most important functions in business today. For many companies, 10 percent to 35 percent of gross sales are logistics cost, depending on business, geography and weight/value ratio. Logistics is a comparatively new term, but not the operation. It has existed since the beginning of civilization. Raw material and finished products had always to be moved, though on a small scale. Things began changing with the advance in transportation. In 1930s last century Malcolm P. McLean, the "Father of Containerization", came to idea of rationalizing goods transport by avoiding the constant loading and unloading from ships. Since that the oversea transportation has acquired its new form – the business scene of container cargo trade has changed from local market towards global.

By enabling a greater degree of freight distribution velocity, global containerisation has made it possible to connect markets and sources through both export and import flows. Thereby, all around the globe, 24 hours per day, 7 days a week, during 52 weeks a year, that logistics is concerned with *getting the right products and services in the right quantity at the right time at the right point for the right price and in the right conditions to the right customer* (Bowersox, Closs & Cooper, 2007). By-turn, the globalization, the free market, and the competition contribute to the increasing the dynamics of efficient and low-cost movement of containers over the world. In view of growing complexity due to increasing dynamics, size, congestions and different disturbances the global container system is faced with a problem of optimization of all the operations involved in the container flow in order to achieve the maximal global productivity that is expressed in terms of turnaround time, throughput or hourly containers handled. One has to take into account that the expected economic benefits come with large external costs: traffic congestions, air pollution, noise, and other impacts on local quality of life. For example the port as the most overloaded transport node in the container system is faced with a problem of optimization of all the operations involved in the container flow in order to achieve the maximal global productivity that is expressed in terms of turn-around time, throughput or hourly containers handled. The congestion in mega-ports is the everyday occurrence that many ports cannot avoid. About 40% of all container transactions in the port terminals have been estimated with more than 2 hours waiting time (Giuliano & O'Brien, 2007); other research shows that the most working day time the truck drivers spend in the port area (Monaco & Grobar, 2004). Therefore, the shippers, port operators, logistics service providers, transportation companies (ship, truck, train) are focused now on the problem of finding a trade-off to achieve the greater efficiency level of container transport flows – without, at the same time overloading the international transport system with additional operational costs.

Contrariwise, as maritime containers are very popular transport units in the system of global trade, more and more international organizations, and shippers/container service providers/ports authorities/transport provider companies/customers are concerned about the safety and security of container flows. Events of September 11^{th} changed the view on the security of container transportation. Since 2001, a variety of different unilateral and multilateral security measures, regulations and legislative initiatives has been developed or are under consideration. Given that world trade is largely dependent on maritime transport, much of the focus has been directed at enhancing maritime transport security and at addressing the particular challenges posed by containerised transport (UNCTAD, 2004). Transport authorities identify several criminal and terrorist-related challenges in container transport system. These illegal activities include theft of goods and vehicles, fraud, illegal immigration, drug and contraband smuggling, potential targeting dangerous goods and terrorist activities. Changes in security have also created new opportunities to strengthen import/export control of any type of containers along the supply chain of the maritime transport sector. Import/export control is strengthened through negotiations in the new organizational field of maritime transport security.

Active RFID electronic seals or e-seals have the potential for improving logistics operations at maritime transhipment terminals. With the various types of e-seals combined with RFID it is possible to enhance container security as well as to improve container visibility and transportation efficiency throughout the whole supply chain. In the last years the benefits of the RFID technology in supply chains have been made apparent. However, there is still a lack of research about advantages from application of electronic seals on containers in logistics networks and their influence on container logistics. Application of RFID e-seals in container supply chains is now considered only for security purposes of customs authorities. However this new technology has a large potential for use in such areas as control of container flows and more efficient storing, processing and monitoring of containers. Potential profits of these advantages and their influence on the dynamics of container flows are investigated in this thesis.

Our investigations show that the implementation of e-seals is effective not only in security but can accelerate the container turnover in global transport chain up to 30-32 % annually, decrease the level of transport congestion and therefore reduce air pollution, influence positively the storage places in transport nodes and distribution centres, reduce cargo theft, make the global container system more sustainable and transparent.

1.2 Aims and research concept

> "*Container security is not just a national issue for a single country, but rather an international issue and it should be implemented on a global scale for all modes of transport in order to work satisfactorily*" (Dahlman, Mackby & Sitt, 2005).

The Security and Accountability for Every Port Act (SAFE) requires 100 percent of US-bound cargo containers to be scanned using nonintrusive imaging equipment and radiation detection equipment at foreign seaports "*as soon as feasible.* The Implementing Recommendations of the 9/11 Commission Act (9/11 Act) requires 100 percent scanning by 2012. However, the CBP (US Customs and Border Protection) Pilot Report concluded: "physically inspecting every single container … would be impractical and detrimental to our own economy… and the global economy" (Report to Congress on Integrated Scanning System Pilots, 2009).

Participation in the Customs-Trade Partnership against Terrorism (C-TPAT) program and 3-Tiers statuses will give companies an opportunity to avoid the additional expenses on containers waiting for customs formalities, to save costs of manual customs inspections itself and to accelerate the container turnover through the whole supply chain, namely, by implementing "GreenLane". In port security, such an approach has taken the form of cooperative arrangements between private operators and public regulators in developing, financing and implementation of various security programs and initiatives. One of the essential parts of this multi-layered international security system is container electronic seal that is able to protect against theft, smuggling and terrorism as well as to improve the container visibility and transportation efficiency in container networks.

The thesis aims to discover possible impacts of container securing technology on container logistics, especially on its dynamics. The research presents the impact of container detection intrusion technology, namely, electronic seals, on the dynamics of container logistics processes at container terminals, and the evaluation of changes in dynamics of physical container flows through the global container supply chain. In the thesis a model for container transhipment through a terminal considering new regulations for security and safety of container transport chains is described. Theoretical approach based on queuing theory and simulation technique by means of MATLAB tool has been applied to the designed container logistics network.

The aim of the dissertation is also to show the economic effectiveness to invest in new container secure devices; i.e. to evaluate whether the higher level of security in container flows will increase the business efficiency in private sector. The dissertation provides the cost-benefit analysis which is intended to estimate possible costs and benefits through the implementation and use of RFID container electronic seals in global secure container network. We include only direct benefits from e-seals in container systems. The cost-benefit analyses was applied to different business cases in order to evaluate an appropriate cost-benefit ratio values. The thesis approaches to develop a model for measurement of the effect of the container secure devices (active RFID e-seals) on the logistics container network.

As the first step in the dissertation we determine, what the direct and indirect impacts of container intrusion detection technology (e-seals) on container logistics in global transport networks are. Then we provide a model for a secure network and develop an economic model to measure the effectiveness of investments in new technology.

To this end we propose a transportation scenario typical for the oversee transshipment of containers. In particular we consider a network that consists of 10 ports and 10 distribution centres spread over two continents. Moreover each port consists of 5 terminals and two customs gates. As an analytic approach we apply the queuing theory to investigate the dynamics of the involved processes. We show that this theory works effectively in case of small number of nodes, however we demonstrate that this approach fails to handle large networks as for example the network in our scenario. For this reason we use simulations in our further analysis. A simulation program was written in MATLAB for the scenario mentioned above. All questions stated above were then investigated with help of simulations using this program. Since our scenario is close to a real network that can be considered as a representative part of the global container network, we expect that the obtained results are representative and hold true at least qualitatively for similar networks. Moreover our program can be easily expanded for larger and more complex networks to model and predict their behaviour.

1.3 Outline of the thesis

The first chapter gives a brief illustration of the real world container logistics issues. It describes the roots of the problem considered in this work, namely global containerization and security issue in container system. The statement of the problem and main goals are described as well as structure of the dissertation is introduced.

The second chapter gives an overview of major scientific contributions in the container logistics and security. E-seals is a relatively new technology which becomes increasingly implemented in container logistics. However not much research was devoted to explore its influence on the dynamics of container flows and to systematically analyse all the benefits it provides. Literature review of scientific and practical papers is divided in two parts: Information and security technology application in logistics and container logistics processes and state of the art of e-seal technology.

The third chapter concentrates on the detailed investigation of the existing processes in container logistics. The dynamics of global container trade demonstrated by the growth in the amount of containers shipped in the world during last years have been considered as a significant factor in future global trade development. This chapter explores the structure of container networks and complexity of container flows inside of them. As well the container logistics in port terminals has been analysed comprehensively. The initial connection between security issue in container transport system and transportation process itself is shown.

The fourth chapter approaches the exhaustive survey about international security initiatives and programs concerning container transportation system. Furthermore, the main container security strategies related to the prospect of electronic seals implementation in container processes have been discussed and analysed in this part. One of the sub-chapters describes different types of container seals - mechanical and electronic seals – and electronic seals' system structure. In this chapter we identify the major challenges and benefits of electronic seals in global container system. RFID is the most popular Hi-Tech for container security devices. It is an automated data-capture technology that can be used to electronically identify, track, and store information about groups of products, individual items, or product components. The efficiency and productivity of global container system can be achieved when electronic seals are part of a harmonized and standardized international transportation process. In this chapter we determine the main areas of logistics applications of e-seals such as automation of containers passes to the territory of distribution centres, control of access to the containers contents, minimization of container loss, tampering, theft or cargo pilferage etc. This was done by analysis of two scenarios for container shipping through the ports. The scenario without e-seals presents the current inspection costs for containers. For the scenario with e-seals we have analysed how effective investments in container "security" by means of e-seals can be. The direct impact of "secure" container trade comes from avoiding of customs inspections. As our calculations show, this advantage can bring monetary benefits for shippers in less than one year. The obtained results show the positive tendency of investment in security devices like e-seal on efficiency of container business.

The challenges of e-seals implementation in global container system such as undefined electronic seal's status on the world market and manipulations with international standards have been also discussed in chapter 3.

The fifth chapter elaborates on the modelling and simulation of container network. Firstly, an analytic approach based on queuing theory has been applied to a simple container network. Two types of queuing systems (with and without e-seals on containers) were analysed. However, this approach arrives very fast to its limitations in case the size of the network increases, i.e., the complexity of the network did not allow to provide a satisfied analysis of the whole container system analytically. Hence to handle larger networks the discrete-event simulation technique has been employed in this chapter.

In one of the sub-chapters the description of simulation scenarios and its goals is described. The initial data for simulation model have been taken from different online sources and based on author's estimations. The analysis of simulation results provides the comparison of container turnover in the designed network for containers equipped with different types of container seals. Moreover, the obtained results enable the evaluation of e-seals influence on container delivery time under the customs inspections.

Finally, the cost-benefit analysis which is intended to estimate possible costs and benefits through the implementation and use of RFID container electronic seals in global secure container network have been developed. It is based only on direct benefits from e-seals in container systems. The cost-benefit analysis has been effectively applied to eight different business cases and appropriate cost-benefit ratio values were calculated.

The sixth chapter presents the main results and authors contributions to the field of container security research. The author proposes further directions for research in the investigation of various influences of security concept on global container system.

The structure of the thesis and connections between its chapters is summarized and visualized on the following diagram:

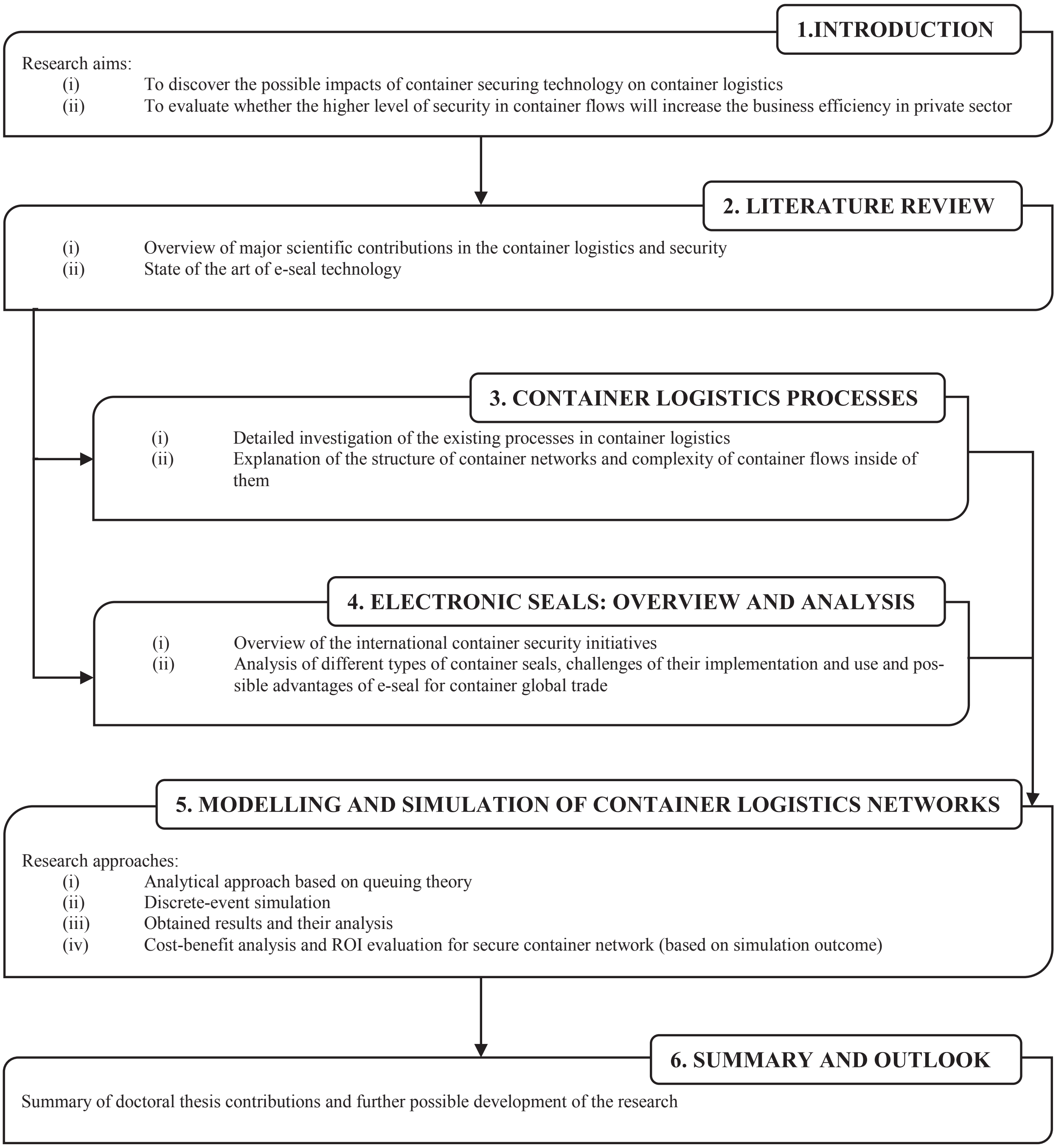

Fig. 1 Structure of the thesis

2 Literature review

E-seals is a relatively new technology which becomes increasingly implemented in container logistics. However not much research was devoted to explore its influence on the dynamics of container flows and to systematically analyse all the benefits it provides. In particular there are only a few research papers published in this area. For this reason the literature review is divided into following parts: information and security technology application in supply chains, security measures in container logistics processes and state of the art of e-seal technology.

2.1 Information and security technology application in supply chains

New informational and security technologies provide opportunities for increasing the overall security and safety of shipments by introduction of powerful security solutions. Concept development methods, risk management tools and technology expertise can be combined to a process that resulted in effective business solutions for enhancing supply chain security.

P. Barnes and R. Oloruntoba (Barnes & Oloruntoba, 2005) suggest that the complexity of interaction between ports, maritime operations and supply chains create vulnerabilities that require analysis that extends beyond the structured requirements of international security initiatives and creates significant management challenges. Also the paper highlights the need for enhanced crisis management capabilities within ports as part of a standard management repertoire and suggests a new classification scheme for mapping vulnerability within ports and across supply networks. It examines the goodness-of-fit of these security initiatives against business efficiency and competitiveness. It considers also the training needs for crisis management capabilities that will allow private and public sector groups involved in global trade to effectively mitigate the threat of maritime terrorism and loss of competitiveness.

K. Bichou (Bichou, 2004) discusses in his paper that the subject of port security must shift from the current agenda of port-facility security to the wider context of port supply chain security, with a view to ensuring superior security standards and practices in ports and across their supply chain networks. Based on the rationale of logistics integration and supply chain partnership, a conceptual framework to port security is proposed through integration and optimization in three initial models related, respectively, to channel design and process mapping, risk assessment and management, and cost control and performance monitoring.

The other author (Hellström, 2009) explores and describes in his paper the costs and process of implementation of radio frequency identification technology to manage and to control the rotation of returnable transport items. Owing to the novelty of using RFID in logistics and supply chain management, in-depth case studies were conducted at two global firms in the retail industry to investigate how and why organizations implement and assess RFID technology.

While the benefits of radio frequency identification in supply chains have had extensive press, published cases showing poor returns on investment and a relative lack of research into its adoption has left organisations feeling uncertain about the challenges to be managed when assessing RFID adoption. Four new factors not previously mentioned in research were identified: related initiatives; the integrated structure of the industry; organisational dominance with the supply chain and the supply chain culture. An argument for their validity within the RFID adoption framework is presented (Seymour, Lambert-Porter & Willuweit, 2008). The research reveals that cost, the absence of a universally-adopted standard and the supply chain culture are currently the major setbacks to RFID adoption in the South African port community.

2.2 Security measures in container logistics processes

The global container networks may be represented as a complex logistic/transport system where several components interact at different levels. These interactions have strategic impact on security and efficiency. In other words, container logistics network is a massive dynamic environment, where on the outer edges, millions of shippers depend on the services of thousands of intermediaries to organise and carry their goods to hundreds of ports where they are shipped overseas by maritime carriers. There are some scientific works that show that the application of information and secure technology results in more efficiency and a higher performance (Wan, Wah & Meng, 1992).

In the next case study the author discuss the development of a prototype system in a container depot that uses radio frequency identification (RFID) features (Ngai, Cheng & Au, 2007). Benefits and advantages as well as problems of the RFID-based approach are discussed. For example, the system supports tracking of the locations of stackers and containers. Furthermore, it improves the visibility of operations data as well as of control processes. In particular, mobile commerce activities in a container depot are supported by the system. Disadvantages of typical information systems regarding storage data, such as misplaced containers or inefficient search for containers, are avoided in processing order requests.

In the next other paper the author describes an approach for design and implementation of an RFID system for IT-based port logistics (Cho, Choi & Lee, 2006). The proposed solution is named Logistics Information Technology electronic Tag (LITeTag) and consists of three parts: a smart tag, a smart electronic container seal, and a Real-Time Locating System (RTLS). A performance evaluation of the system is also included in the paper.

Some authors describe the RFID systems in different ports that improve the security and efficiency of the processes surrounding cargo container shipments (Roberti, 2005); enable shipments' tracking (Swedberg, 2006); utilize RFID to track containers, thus, securing and speeding its business processes (Collins, 2005). (Collins, GE uses RFID to secure cargo, 2005) discuss some progress of General Electric (GE) on the new generation of containers; the great innovation of the GE method is that seals are affixed on the internal side of the containers to enhance security.

Another author presents the direct benefits of RFID in ports: accurate and complete data collection and better utilization of employees' time (Mullen, 2005). The paper also identifies the five major areas of potential RFID applications in a water ports mind-set: access control, container security, container identification and location, activity tracking and regulatory compliance.

The paper of T. C. Chen describes an RFID and sensor based Container Content Visibility and Seaport Security Monitoring System under development that can fulfil this need (Chen, 2005). The System integrates the latest technologies in the fields of RFID, sensor, door tamper-proof device, and Wi-Fi communications to allow container contents to be identified and inspected automatically without opening it.

Another study discusses risk management tools and the mobile enterprise factory innovation process as a motor for security enhancement using new technological solutions (Salmela, Toivonen & Scholliers, 2010). As practical results, this study presents a new risk assessment model, the supply chain security and technology management model, and a case study of a solution for integrity monitoring of shipments.

Container security can be enhanced by using RFID technology, especially electronic seals consider the authors of this paper (Meyer-Larsen, Lyridis, Müller & Zacharioudakis, 2012). CHINOS project puts a special focus on the integration of these new technologies into the terminals' business processes and the demonstration of its success at several European locations.

The following paper describes the pilot project of using e-seal in paperless system for e-customs in goods transportation process of e-free zone (Plangprasopchoke & Muttitanon, 2013). This pilot project used the new technology of RFID in customs process by using e-seal in the paperless system for control goods transportation. The results showed that the project was successful because government and the private sector were cooperating to design of the system together and all groups of workers were accepted in highest level for the three components of the system: the organization policy, the effectiveness of the system and the working skills of the stakeholders.

Automated container identification procedures are in the stage of research and development, conducted collaboratively by the shipping operators. At present, material handling systems are generally manually operated. The models developed in the paper (Kia, Shayan & Ghotb, 2000) deal only with the operational improvements to compare a terminal without any electronic devices and a model of the terminal equipped with electronic devices. They consider activities within the terminal, predominantly ship-to-shore operations, and the movement of containers from ship-to-stacking area. Their models do not cover activities beyond the terminal gates (e.g. land transport). The advancement of information technology provides a wide range of options for the container terminal operator to automate its information system. Electronic devices employed in container terminals reduced the manual effort and paper flow, facilitated timely information flow and enhanced control and quality of service and decision made.

2.3 State of the art of E-seal technology

One technology application that potentially addresses both security and processing concerns is the use of RFID (radio frequency identification device) electronic seals (E-seals) to secure the doors of the containers. (Zhang, 2007; Müller, 2005; Tsilingiris, 2007a; Tsilingiris, RFID-enabled innovative solutions promote container security, 2007b; Moskal, 2009)

Different E-seal designs have been developed over the last decade and include devices that communicate by using RFID, infrared, direct contact, long-range cellular, or satellite transmissions. Each seal has its own characteristics. RFID E-seals, selected for the State of Washington test, were a relatively mature product that showed promise for both increasing container security and reducing processing delays for cargo inspections (McCormack, Jensen & Hovde, 2010).

The RFID E-seal design involved relatively simple technology that potentially could be mass-produced at a reasonable cost. The RFID E-seal is the most common type in use today because of its reliability and ease of integration with current infrastructure (Le-Pong & Wu, 2004; Wolfe, 2002). In the paper of C. Le-Pong and C.-L. Wu the basic technical features of RFID systems are described and linked to the practical applications (Le-Pong & Wu, 2004). In this paper the authors determine how the technologies perform in the real-world operational environments and evaluate the various trade-offs that exist with e-seal design and the potential impact of those trade-offs on functionality, reliability, utility, and cost.

Another security system is a Security Event Management System which takes care of all security related events in the intermodal chain (Müller, 2008). The security system registers the schedule and transport information of a container and assigns a corridor for its transport. During the transport the system receives events which will be used for computing a security risk factor for each container, by considering restrictions like position with respect to the assigned corridor, duration of standstill and others.

The basic technical features of RFID systems are described and linked to the practical application in the paper of (Zhang, Liu, Yu & Zhang, 2008; Müller, 2005; Tsilingiris, Psaraftis & Lyrdis, 2007a; Moskal, 2009). This papers also determines how the technologies perform in the real-world operational environments and evaluates the various trade-offs that exist with e-seal design.

More attention needs to be given to the security of electronic seals, that was highlighted by the authors in (Min & Park, 2007). For sure, the commercial availability of these devices and their readers, at reasonable and competitive prices, could be a significant factor to businessmen in their decision whether to use manual or electronic seals as an indicator of transit tampering. From one side, it is important to recognize that low cost e-seals are not necessarily a solution to containerized cargo security concerns (Johnston, 2003). From another side, by implementing electronic seals and sensors as agents, standardized communication protocols can be applied for the interaction. In addition, aspects of trust and encryption must be considered as not every communication partner is trustworthy. In order to save resources multiple components of one container security system as well as multiple systems may join forces by cooperating (Werner, Schuldt & Daschkovska, 2007).

Next article explores the use of passive RFID electronic seal monitoring systems to supplement marine container transportation security (Huang, Lee & Gong, 2012). The authors describe the use of low-cost passive RFID e-seals devices to replace the manual escorts (which are used to identify, track, and monitor containers). The authors report that the system has also maintained normal operation 24 hours a day, year round. In addition to replacing escort operations, this system enhances customer clearance efficiency, ensures the safety of containers, and reduces costs. The authors conclude that this system has proven itself in the real world operations of large-scale logistics systems and can be introduced successfully in the container transport industry.

2.4 Summary

In this chapter we have reviewed the literature concerning research about electronic seals technology. We have divided the literature sources in three categories: information and security technology application in supply chains, security measures in container logistics processes and state of the art of e-seal technology.

An increasing number of theoretically and practically oriented papers indicates a growing interest of scientific community to the development and implementation of e-seal technology. As the papers show, this technology can be used to optimize logistics processes in transport and supply chains. From this literature we have seen that the majority of papers are devoted to single and local aspects as for example to the port logistics or conceptual ideas in the field of supply chains. Some practical projects investigate major areas of potential RFID applications for e-seals in the ports have been done or currently in processing. The results were obtained always for particular cases in logistics or single situations.

Consequently, this literature review makes it obvious, that there is no research activities that investigate how the e-seals technology can influence the global dynamics of container flows. As well there is only few research papers that analyse benefits of implementation of the e-seals technology. In these research papers and project reports only one or two benefits from the use of e-seals, like container monitoring, automation of container processing in the port or container tampering, have been analysed and investigated. No author proposes a complex and systematic analyses of the whole collection of benefits of the e-seals that can be achieved by implementation of these devises on all containers of global transport supply chain. As well from the literature review follows that there is the lack of investigations to understand the influence of the e-seals technology on the global dynamics of container flows. The published papers show as well a relative lack of research on returns on investment from the adoption of the e-seals technology in the global container supply chain.

Therefore, in the next chapter 3 we will analyse the global container networks as a basis for the e-seals implementation and show the initial connection between security issues in container transportation system. In the chapter 4 different areas of logistics applications of e-seals will be determined. In the same chapter the complex analysis of challenges and benefits of the e-seals in global container system will be provided.

3 Container logistics

In this chapter we will discover the structure of container transport chains and what kind of logistics process are in these chains involved. We will analyse the links inside intermodal container transport systems and determine the general structure of global container networks. Furthermore we will determine different layers of general container system. The security issue in the container logistics will be also concerned in this chapter.

3.1 Introduction to container logistics

In the last 50 years the vision of cargo transportation has been absolutely changed. One of the main driving factors in globalisation process became the adopting of the container technology. Containerisation, logistics integration and globalisation have reshaped the port and shipping industry. An accelerated competition across borders impels the pursuit of new and attractive markets as well as high-quality and low-cost sources. Marketing, production and sourcing fronts have indeed shaped material, information and value streams in more distant, dynamic and complex manners. The dynamics of global container trade is demonstrated by the growth in containers number shipped in the world last years. Approximately 90 per cent of all cargo is moved in containers. Different types of containers with various types of goods are transported between thousands of origins and destinations. The dynamics of one single container can be represented by complex transport chain where approximately 25 different actors are interacting, generating 30-40 documents, using 2-3 different modes and handling material at as many as 12-15 physical locations (Christ, Crass & Miyake, 2005) with high level of coordination to ensure the flows of millions of containers. Increasingly, the responsibility of ensuring the seamless, efficient and low-cost movement of containers is entrusted by cargo owners and transport providers to logistics operators, freight forwarders or third-party logistics providers, who are expected to optimize the chain for the benefit of their customers (Sciomachen, Acciaro & Liu, 2009).

Providing the reliable service to the interacting elements of transportation chain is the major objective of any container port. The complexity of the supply chain, with multiple participants, there is ample opportunity to increase efficiency and reduce costs by electronic commerce, which enables integration of the increasingly tighter links in the supply chain.

Automated container identification procedures are in the stage of research and development, conducted collaboratively by the shipping operators. At present, material handling systems are generally manually operated. The models developed in the paper (Kia, Shayan & Ghotb, 2000) deal only with the operational improvements to compare the terminal without any electronic devices and model of the terminal equipped with electronic devices. They cover activities within the terminal, predominantly ship-to-shore operations, and the movement of containers from ship-to-stacking area. The models do not cover activities beyond the terminal gates (e.g. land transport). The advancement of information technology provides a wide range of options for the container terminal operator to automate its information system. Electronic devices employed in container terminals reduced the manual effort and paper flow, facilitated timely information flow and enhanced control and quality of service and decision made. Nowadays, evolutions in supply chains and container logistics networks have forecast the function of ports and shipping lines in the logistics process as elements of value-driven supply chain networks (Robinson, 2002). The dynamic market forces demand that ports and container terminals – nodal points within global container networks – improve both their operational and management efficiency to enhance competitiveness of a system (Le-Griffin & Murphy, 2006). Different types of containers with various types of goods are transported between thousands of origins and destinations. Approximately 90 per cent of all cargo is moved in standard steel or aluminium boxes (van de Voort, O'Brien & Rahman, 2003). Naturally, the dynamics of global container trade can be also demonstrated by the current growth in containers shipped in the world. Since last years China's international trade became the major driving force for global trade as well as for container shipping (Fig. 2). In 2005, almost 65 per cent of container traffic was attributed to Asian ports, whereby the top 8 Chinese ports alone represented 26.5 per cent of total container traffic (Heideloff & Stockmann, 2006).

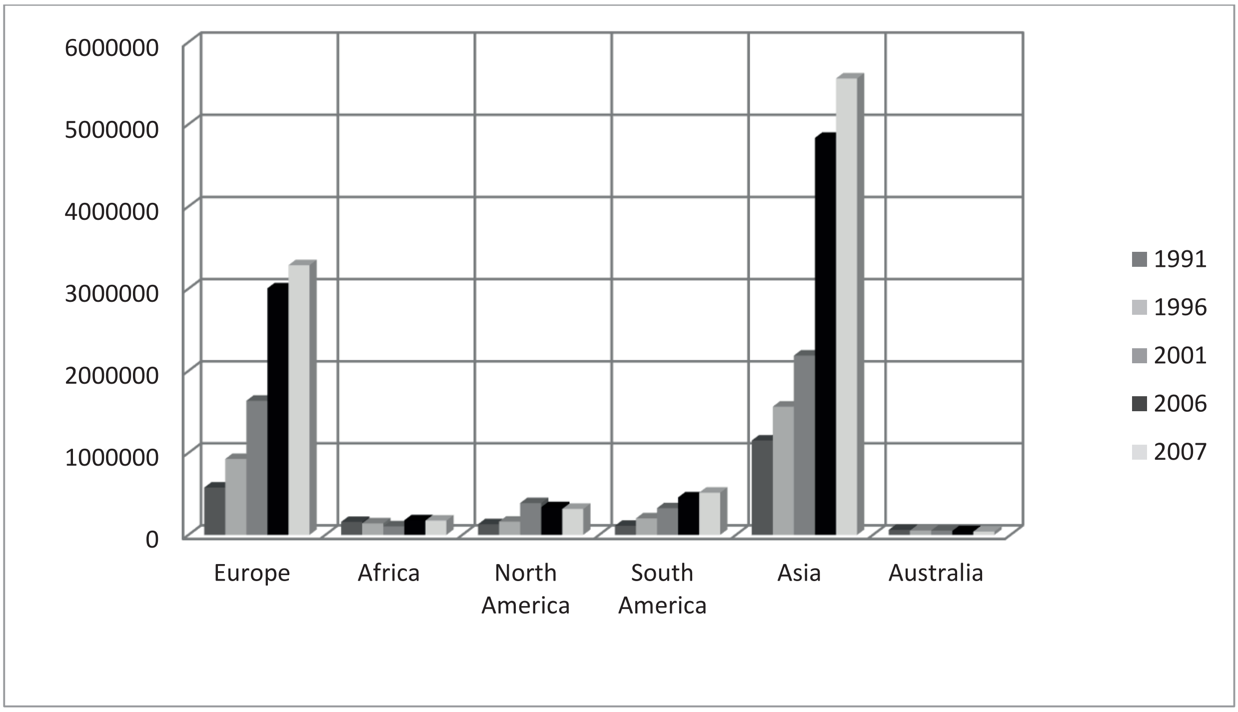

Fig. 2 Container turnover by continents, TEU (Christ, Crass & Miyake, 2005)

Massive flows of exporting/importing containers are the main physical connection behind today's soaring trade circulation. In 2002, the Bureau International des Containers (Christ, Crass & Miyake, 2005) estimated that approximately 15.000.000 containers were in global circulation. Containerisation Online (Christ, Crass & Miyake, 2005) indicate that over 264 million containers were moved through container ports in 2002. As an illustration, in 1980 total container throughput in world container ports did not exceed 40 million TEUs (Twenty-foot Equivalent Unit). In 1990, it reached 75 million TEUs (Fig. 3). Drewry Shipping Consultants (The Drewry Shipping Consultants, 2006) estimates that worldwide container handling is expected to increase further to 628 million TEUs in 2010, of which 57 per cent are port-to-port full containers, 14 per cent are port-to-port empty containers and 29 per cent are transhipment.

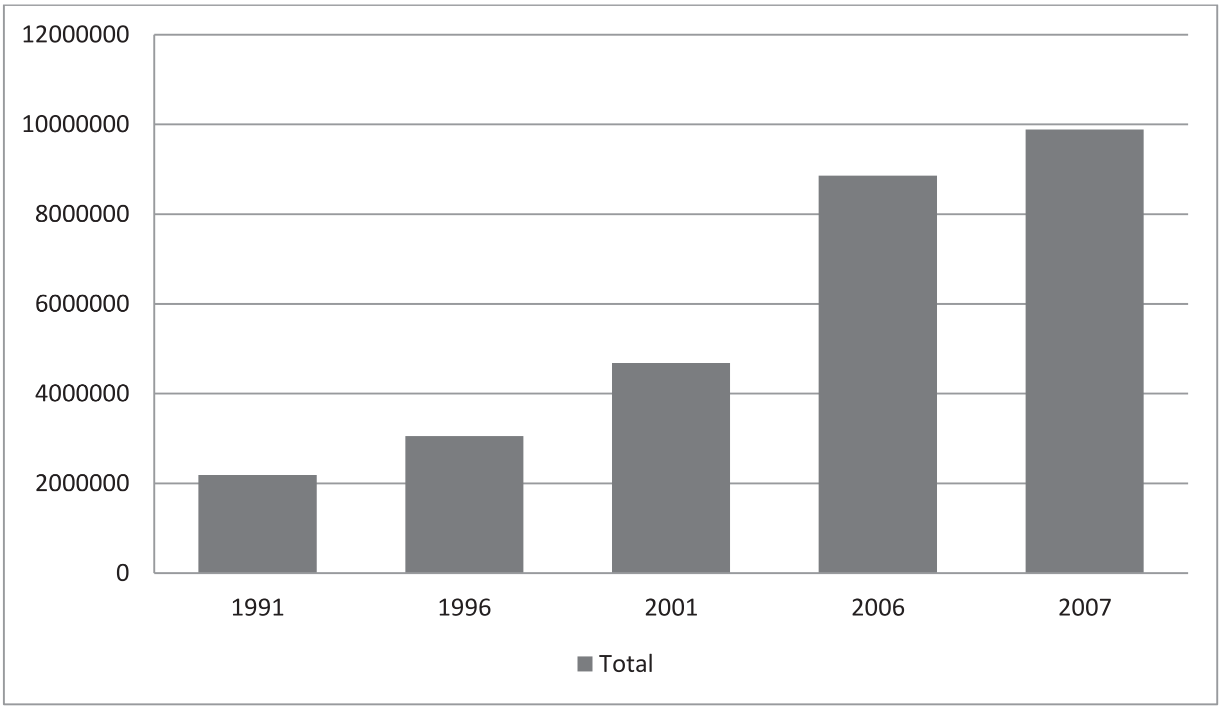

Fig. 3 Global container turnovers, 1991-2007 (Kia, Shayan & Ghotb, 2000)

Key factors for a container terminal are the efficiency of the stacking and the transport of this large number of containers to and from the ship's side. Shipping companies ask for reliability regarding adherence to delivery dates and promised handling times (Tongzon & Heng, 2005). Thus, container nodes are forced to provide efficient and cost-effective services. They have to invest heavily to meet the stringent demands for faster service and higher quality. The competition between container transhipment nodes has increased due to large growth rates on major seaborne container routes. Transhipment terminals are faced with more and more containers to be handled in short time at low cost. Therefore, they are forced to enlarge handling capacities and strive to achieve gains in productivity. Different concepts for meeting the current and future demand are utilized (Stahlbock & Voss, 2008).

3.2 The container transport chain

Container logistics as it called nowadays is the very important part of any transportation process. The complexity of container logistics system leads to the necessity of its optimization. Currently, *the container transport chain* does not begin or end at the maritime ports. An intermodal container transportation system links worldwide ports to consumer markets, manufacturing and distribution centres, and agricultural production and processing facilities via unique container box – Twenty-Feet-Unit (TEU). That global network – comprised of waterways, railroads, highways, distribution warehouses, container yards, and terminal facilities – is the *Container Transportation System*. The *logistics* concept is attributed intermodal, economic and organizational integration of transport modes and the evolving demands of end-customers to achieve logistics goals (Panayides, 2006). Maritime logistics term is largely applied to the containerized cargoes via liner shipping lines and the importance of containerization technology in the door-to-door concept of transportation and has an impact on the cost, efficiency, accessibility, service and reliability of logistics systems (Panayides, 2006). *Logistics* as a part of the supply chain process therefore deals with the planning and control of material flows and related information flows in order to satisfy customers' requirements in the public and private sectors (Panayides, 2006) (Ghiani, Laporte & Musmanno, 2004). It consists of number of facilities like manufacturing centres, warehouses, distribution centres, transhipment points, port terminals, etc. (Fig. 4).

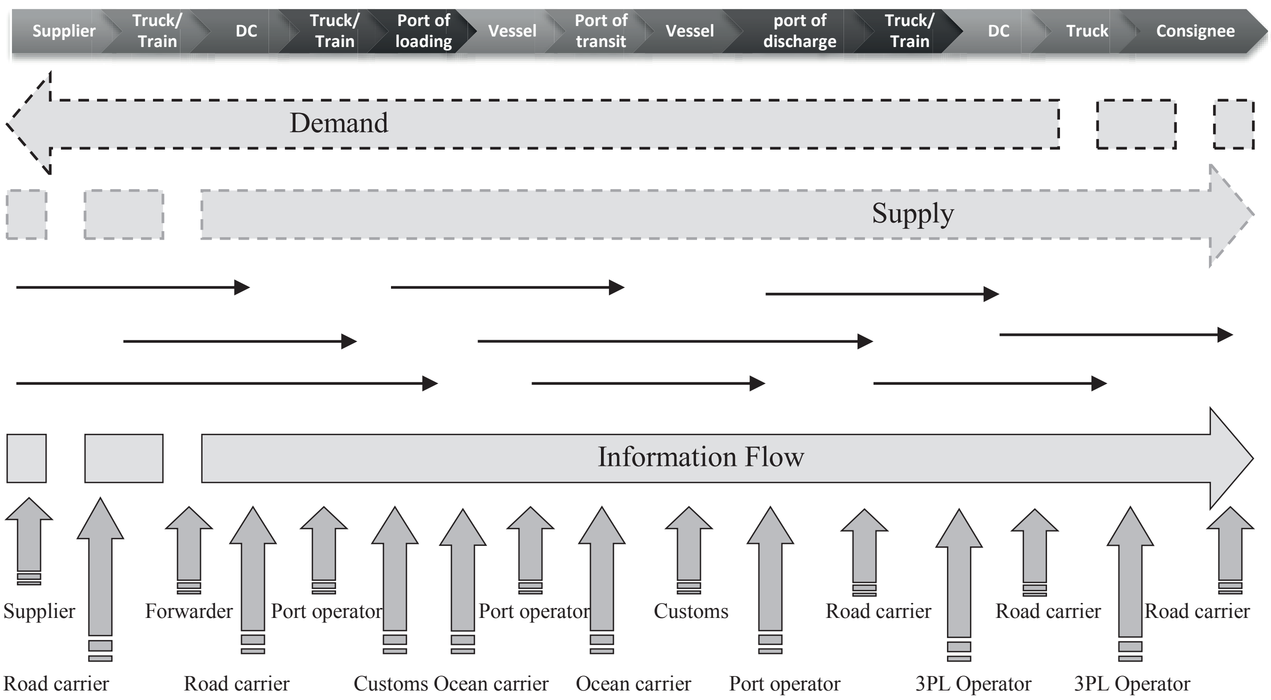

Fig. 4 Container logistics processes

The suitable transport (trucks, trains, ships) and equipment (pallets, containers) that move the materials between facilities are required. Thus, the container logistics system links together the facilities and transportation services. By enabling a greater degree of freight distribution velocity, global containerisation has made possible to connect markets and sources through both export and import flows. This velocity becomes more a function of time than speed as containerisation mostly improved the function of transhipment (Rodrigue, 1999). Communication and transportation evolution have allowed organisations to reach new markets, and locate production and material sources in different countries. The internationalisation of trade has intensified the dynamic and complex nature of global material and information flows.

3.2.1 Container logistics networks

Container logistics is one of the most important activities within global trade flows. Containers are uniform boxes whose contents do not have to be unpacked at each point of transfer. They have been designed for easy and fast handling of freight. The increasing number of container shipments causes higher demands on the seaport container terminals, container logistics, and management, as well as on technical equipment. An increased competition between seaports, especially between geographically close ones, is the result of this development (Steenken, Voß & Stahlbock, 2004). As the containers move from the point of origin to the point of destination as many as twenty different actors (e.g. transportation firms, logistic services firms, the shipping company, cargo-owners, the purchaser and banks) have to coordinate activities. Insensibly this process becomes more and more complex and risks (e.g. security risks) grow. Thus, global container networks may be represented as a complex logistic/transport system where several components interact in different levels. These interactions have strategic impact on security and efficiency.

The worldwide network of container flows on land and at sea is becoming increasingly meshed. Companies managing container terminals have the need of optimizing all the operations involved in the container flow in order to achieve the maximal global productivity that is expressed in terms of some opportune performance indices, such as turnaround time, throughput or hourly containers handled.

The globalization has impacted various segments of international shipping and logistics, the port industry has lagged behind other infrastructure and logistics sectors in embracing global changes. The combination of the institutionally rigid structures and spatially conventional arrangements meant that neither cross-industry integration nor cross-border expansion was possible. With the process of port privatization and deregulation being widely implemented, barriers to global port operations have started to be lifted gradually and new operating port structures have emerged. Global port operators can be defined as those actors who extend their activities to international port operations with a view of establishing globe-spanning network services (Bichou & Bell, Internationalisation and consolidation of the container port industry: Assesment of channel structure and relationships, 2007). Several transportation systems can be used to transport containers from one destination to another. Transport over sea is carried out by ships. On the other hand, trucks or trains can be used to transport containers over land. To tranship containers from one mode of transportation to another, ports and terminals can be used. For example, at a container terminal, a container can be taken off a train and be placed on a ship (Vis & de Koster, 2003). To ensure a fast transhipment process, at large terminals, control for efficiency a high degree of coordination is necessary. These can be obtained by using among others an information technology and an automated control technology.

Within container interfaces, as the ones represented by intermodal terminals or container transhipment nodes, the rational integration of material and information has a fundamental importance for planning and operating security, efficiency, effectivity and sustainable logistics. In such nodes, actors and stakeholders interact within a complex inter-organisational network.

3.2.1.1 Container logistics networks

Global container networks is a platform for global containerisation. It consists of the network of suppliers, manufacturing centres, warehouses, distribution centres, and retail outlets that transforms raw materials into finished products and delivers them to consumers (Simchi-Levi, Kaminsky & Simchi-Levi, 2007). Global container networks may be also represented as a complex transport (Christ, Crass & Miyake, 2005) (Fig.5).

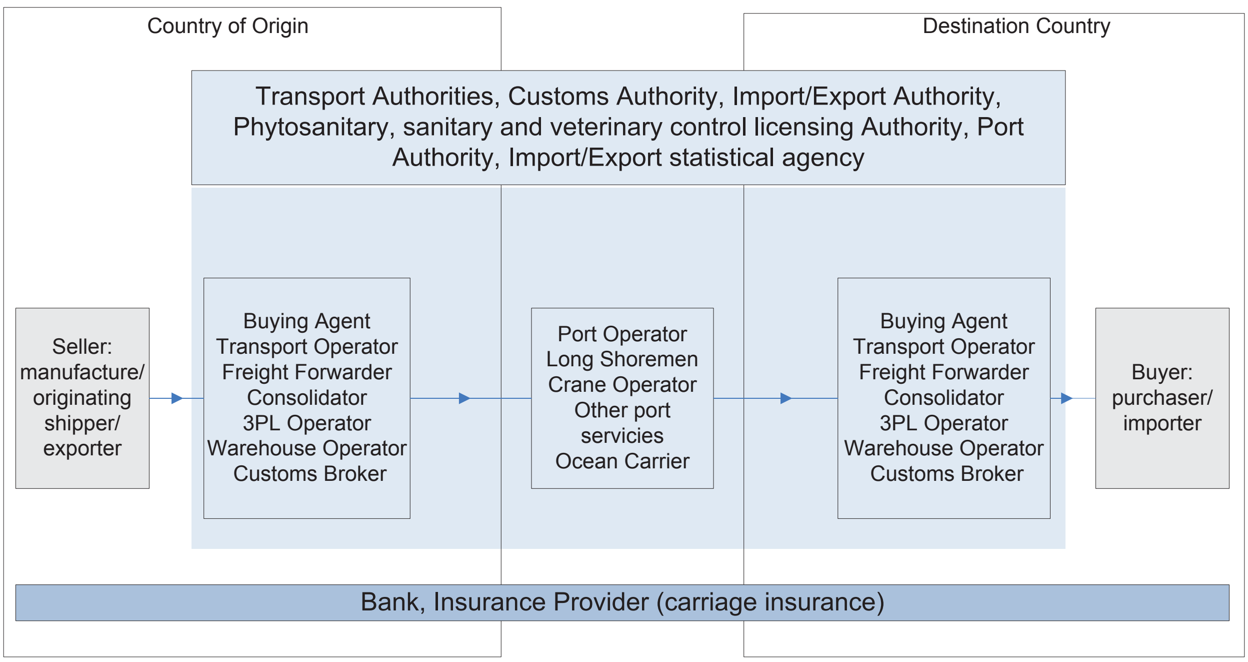

Fig. 5 Actors in the container logistics networks, adapted from (Christ, Crass & Miyake, 2005)

As a result, container networks link into global system a large number of production, distribution and consumption logistics networks, connecting hundreds of nations and each continent on the earth.

3.2.1.2 Flows in container logistics networks

The structure of general container system can be modelled (Fig. 6) in three layers: oversight, transactional and logistic. Consequently, the container network could be represent as three independent and interacting networks: a physical logistic system for transporting goods; a transaction system that is driven by information flows; and oversight system that regulates the subsystems through standards, fines and duties (Willis & Ortiz, 2004).

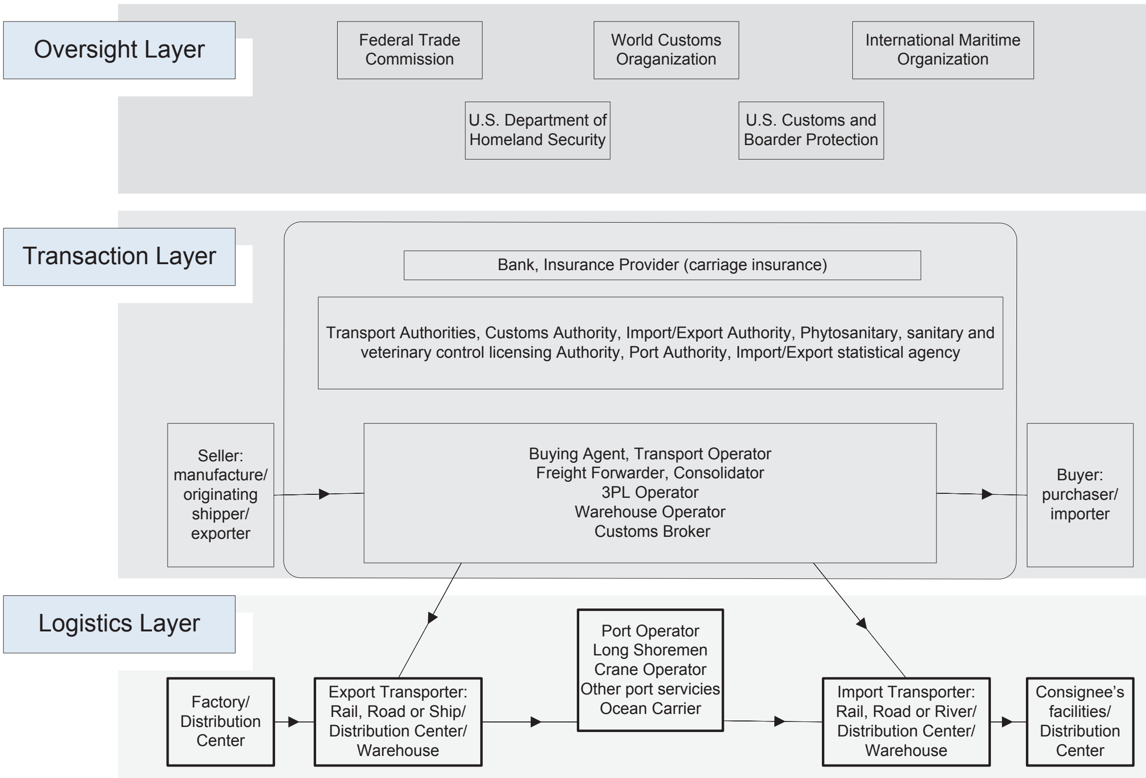

Fig. 6 The logistics, transaction, and oversight layers of the container supply chain, adapted from (Willis & Ortiz, 2004)

On the logistics layer the container network is represented as a physical system of moving containers, operated by trucking companies, rail freight firms, ocean carriers, freight forwarders and consolidators. All these actors add value and provide services to the producers and consumers of goods. The transaction-based layer connects participants (e.g. banks, non-vessel operating common carrier (NVOCC), retailers and suppliers) of each supply chain on informational, financial and physical levels. It can be represented as union of two interacting networks: informational and material networks.

Furthermore, each transaction or movement of goods is subject of some regime of international and domestic rules, regulations and enforcement mechanisms. These regimes regulate the structure and operations of the transaction and physical layers of the supply chain. The mechanisms and some institutions responsible for them are represented on the oversight layer, for instance: International Maritime Organisation (IMO), World Customs Organisation (WCO), Federal Trade Commission (FTC), US Coast Guard (USCG), International Standards Organisation (ISO), among others.

These institutions are responsible for establishing an international framework and setting out different security-related requirements and measures for container trade. In these international frameworks special attention has been designated to international security-related initiatives. Another relevant factor of global container logistics is the growing restrictions imposed by the rules of US Homeland Security.

The actors involved in the container transport chain can be broken down into five subgroups according to the roles they play (Christ, Crass & Miyake, 2005).

Most containerized moves start as a commercial interaction between a seller and a buyer. In many cases (but not at all) the seller is also the shipper. Both shipper and buyer have detailed knowledge of the transaction leading to the shipment of the container but, in most cases, the shipper is the only actor in the chain with detailed first-hand knowledge of the goods placed into a container. This fact is of fundamental importance to efforts seeking to secure the container transport chain.

Shippers are the most numerous actors in the container transport chain and are characterized by the presence of many small and medium enterprises (SMEs). From a security perspective, the large participation of SMEs in containerized trade has repercussions on efforts to secure the container transport chain. Indeed, efforts to extend supply chain security to the originating shipper must take into account these actors' relative lack of resources available, and/or motivation, to implement security measures.

A significant portion of international container movements concern intra-firm trade or trade between affiliates or otherwise linked firms. In many respects, intra-firm trade presents potentially fewer security risks as the parties to the transaction are known to each other and trusted – provided that these firms have in place sufficient security measures. Freight forwarders have tremendous visibility over the entire container transport chain. They have sometimes hybrid role (e.g., where they act as "carriers" to their clients and as "shippers" to their carriers) that can serve to concentrate a data regarding originating shippers that are hard to access. Forwarders are also characterised by a significant number of SMEs that may not be in a position to implement cumbersome or costly security measures. Just as with shippers, a significant number of transport operators in the container transport chain are SMEs. This is especially true in the road sector where most container voyages begin and end. Globally, the "first mile" and "last mile" are the most vulnerable as carriage is often undertaken by small entrepreneurs unable and/or unwilling to implement effective security measures.

The oversight role for containerized transport is split between transport authorities that are responsible for vehicles, drivers and operators (and their facilities) and customs authorities, responsible for the contents of the container. Responsibility for the container itself is indefinite as customs typically have responsibility for ensuring the integrity of the container once the containers and their contents are presented to a customs office, whereas transport authorities typically have a role to play in ensuring that the interface between the container and the mode of carriage is safe. A secondary issue related to the previous one is the wide disparity in land-side licensing systems. Even among harmonized systems security is rarely a criteria used to deliver operating permits (with the notable exception of hazardous materials carriage).

3.2.2 Container logistics in a port hub

The physical and information cargo flows within the container terminal is influenced by the sequence of processes, the relative capacity of each process, and the intervention of managers into the allocation of resources. Often analyses are conducted using a sequential control approach. Under a sequential control approach, the progress of cargo through the various component processes is based solely on the conclusion of one operation signalling the start of the next operation. Such an analysis, however, ignores the intervention of managers into the situation in response to disturbances and the plans generated from external inputs. These plans and interventions are influenced by information about the states in the yard, resources, and the ship, as well as external information flows.

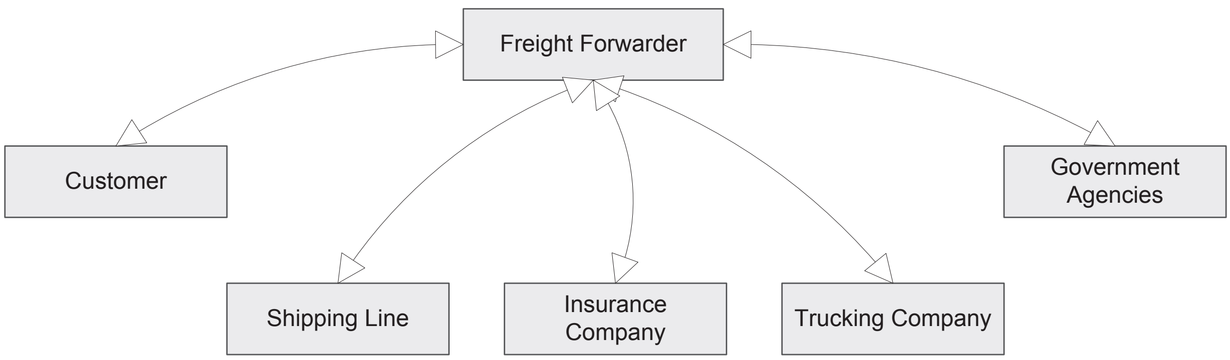

Fig. 7 Information flow in port hub (Higgins, Dessouky & Hall, 2000)

As with many industrial operations, there is no single controlling manager; rather, the processes are managed by the interactions of several parties. Each of these managers creates plans and directives based on incomplete knowledge of the state of the system and the full potential consequences of the action. For example, the ship rotation schedule is created without a complete understanding of the consequences this will impose upon the terminal yard, the over-the-road truckers, and the customers using the steamship line. Furthermore, this information would most likely be considered to be of little or no use since methods and procedures are not available to vary the ship schedule based on these facts.

In the port hub there are several interaction of operational plans, data obtained during the check-in process, and the physical flow of a container. Certain data from the yard plan and the container itself must be available to the gate clerks performing the check-in process so that they may determine the appropriate disposition of a container.

Delivering an empty container to a customer and then transporting the filled container back to the terminal is a multi-step process that requires entering the terminal twice: once to pick up the container and again to deliver the container for shipment. In each case the trucker must wait in a queue to check in at the gate.

Container ships are nowadays unloaded and loaded at large container terminals. Container technology has many advantages. They are easy to load and empty. The same container can be reused many times over many years to carry many different types of cargo. Perhaps most significantly, a container can be transferred between different modes of transportation - vessel, truck, rail, and barge - without intermediate reloading. Over the last 30 years, the "intermodal" capabilities of containers have altered many aspects of maritime shipping and inland freight movement. The expanded use of containers has influenced vessel design as well as the most fundamental concepts of port operations and terminal development.

Delays can occur for a variety of reasons, including lack of equipment, insufficient staffing, and missing, incomplete, or inaccurate information. For instance, if yard equipment is unavailable for rapid loading and unloading of the over-the-road trucks, congestion can appear within the terminal. This can, in turn, interfere with the bomb cart movements and other terminal activities.

This entire process could be examined for procedures that would decrease the number of entries and exits made by the over-the-road trucks using the concepts of re-engineering. Both the congestion outside the terminal gate and the congestion in the yard could most likely be reduced by restructuring this process.

Thereby, container terminals are very specific connecting nodes between other modes of container network: any bottlenecks in terminal operations may influence the outside-terminal traffic of containers. As a container port nodes consist of a number of different subsystems, the operating and business processes there need to be well harmonized as well as the resources to be efficiently allocated. Thus, information technology likely RFID become an essential part of the rapid and accurate transfer and processing of huge volumes of data processed in international transport companies and port organizations. The further increase in ship sizes and increasing security concern make a productivity, security, and efficiency of container handling operations more important in order to achieve competitive terminal fares and increase therefore the attractiveness for new customers.

3.3 Security issue in container logistics

Since 2001, a variety of different unilateral and multilateral security measures regulations and legislative initiatives have been developed or are under consideration. Given that world trade is largely dependent on maritime transport, much of the focus has been directed at enhancing maritime transport security and at addressing the particular challenges posed by containerised transport (UNCTAD secretariat, 2004). Transport authorities identify several criminal and terrorist-related challenges in container transport system. These illegal activities include theft of goods and vehicles, fraud, illegal immigration, drug and contraband smuggling, potential targeting dangerous goods and terrorist activities.

The container industry has proved to be a remarkably efficient commercial system, designed to move goods through the international supply chain in the fastest way. The main drivers of the system are speed and low cost. The huge volume of container traffic plus the normal controls over cargo packing and shipping provide opportunities to introduce weapons of mass destruction into a container at several stages of the supply chain. The amount of documentation, companies and institutions involved certainly overwhelmed any inspection process (Binnendijk, Caraher, Coffey & Wynfield, 2002).

Several International Organizations, such as the International Maritime Organization (IMO), the World Customs Organization (WCO), and the International Labour Organization (ILO) have been working on a wide range of measures to enhance maritime transport security. The International Maritime Organization (IMO) developed a new comprehensive security regime for international shipping, by adopting a number of amendments to the Safety of Life at Sea Convention (SOLAS) in 2002. The Government of the U.S. has also promoted the main initiatives relevant to maritime transport security, which are: the Customs Trade Partnership against Terrorism (C-TPAT), the Container Security Initiative (CSI), the "24-Hour Rule" and recent regulations under the U.S. Trade Act of 2002 which amend U.S. customs regulations for obtaining and monitoring information on cargo. The Proliferation Security Initiative implemented by the US Department of State falls under the new security measures of the maritime transport sector as well. The U.S. Customs and Border Protection Service (CBP) is now the relevant government agency in charge of the administration and enforcement of these programs and regulations.

After 9/11 container and shipping industry have something else in common: the international security perception that ships and containers could be used as weapons of mass destruction. Since 9/11, a new pattern of organizational field around the issue of security has emerged. The institutions related to the maritime transport sector have negotiated and implemented new regulations oriented to enforce security in the logistics supply chain. Changes in security have also created new opportunities to strengthen import/export control of any type of containers along the supply chain of the maritime transport sector. Import/export control is strengthened through negotiations in the new organizational field of maritime transport security. As this issue continues to evolve, new institutional changes are expected to emerge.

3.4 Summary

In this chapter we have exposed the structure of container transport chains and what kind of logistics process are in these chains involved. We have analysed the links inside intermodal container transport system and determined the general structure of global container networks. As a result, container networks link into the global system, a large number of production, distribution and consumption logistics networks, connecting hundreds of nations and each continent on the earth. Furthermore we have determined different layers of general container system: oversight, transactional and logistic.

Consequently, the container network could be represent as three independent and interacting networks: a physical logistic system for transporting goods; a transaction system that is driven by information flows; and oversight system that regulates the subsystems through standards, fines and duties. The complexity of container supply chains, with multiple participants, requires from logistics providers to look for opportunities to increase efficiency and reduce costs, and enable the integration of the increasing strong links in the supply chain. Different concepts for meeting the current and future demand are utilized on the theoretical level and in close interrelation with practices.

In order to understand and realize the weak points in container logistics, the detail analysis of container logistics processes and structure of container networks have been done in chapter 3. The security problems in the container logistics have been also discussed in this chapter. The institutions related to the transport sector have negotiated and implemented new security regulations oriented to enforce security in the logistics supply chain. Changes in security have also created new opportunities for implementing new technologies to enhance visibility, security and safety of containers along the supply chain. In the next chapter we will introduce one of the technology that can be effectively integrated and is used on different stages of container transportation process worldwide.

4 Electronic seals: overview and analysis

In the aftermath of September 11, 2001, there has been understandably increased attention paid to the issue of port security. Koch-Menard (Koch-Menard, 2009) reviews in his paper the development of detection programs since 9/11 and identifies three emerging trends in the security environment in North America in the years to come. The first of them is a movement away from evidence-based detection to rule-based discovery; the second tendency to secure the transport system is a move away from the observation of actual behaviour to the analysis of electronic records; and the last up to nowadays trend is a move away from national discovery systems to multinational structures. The existing tendency demonstrates the importance of development and implementation of new security detecting technology, like RFID seals in container transportation; to achieve international secure and efficient global trade. The implemented measures can significantly change, for instance, port operations, as well as significantly influence the shipping cost and time over the whole container supply chain. With the purpose to determine and explore the trade-offs between security and commerce sector, the analysis of one of the technologies – RFID e-seals – promising to improve container transportation processes, is prepared in this chapter.

4.1 International security initiatives

Before September 11th the security of supply chain was focused mostly on reducing the loss of cargo shipments through theft or misrouting. As maritime containers are extremely popular and ubiquitous in the world trade system, they are the most vulnerable to criminals' purposes. These daily problems have real influence on the container transport system's ability to ensure the efficient flow of cargo within the national and international marketplace. Thus, U.S. Customs and Border Protection (CBP) created the Container Security Initiative (CSI) and Customs Trade Partnership against Terrorism (C-TPAT) voluntary programs as a specific security measure to protect the global container trading system and trade lanes between CSI ports and the U.S. (Fig. 8). To implement CSI, U.S. Customs have been entering into bilateral agreements or partnerships with foreign governments (UNCTAD, 2005).

It is clear, protection against terrorist risks will cost money; and developing countries that view these additional costs as undermining their competitiveness in accessing the US market may be compelled to direct their trade elsewhere, if that is an option (UNCTAD, 2003). Simple maintains to legal requirements while may facilitate transport crossing at international boundaries, it does not go far enough to take advantage of the opportunity to refine inter-firm relationships and processes that can potentially produce efficiencies (Gould, 2008).

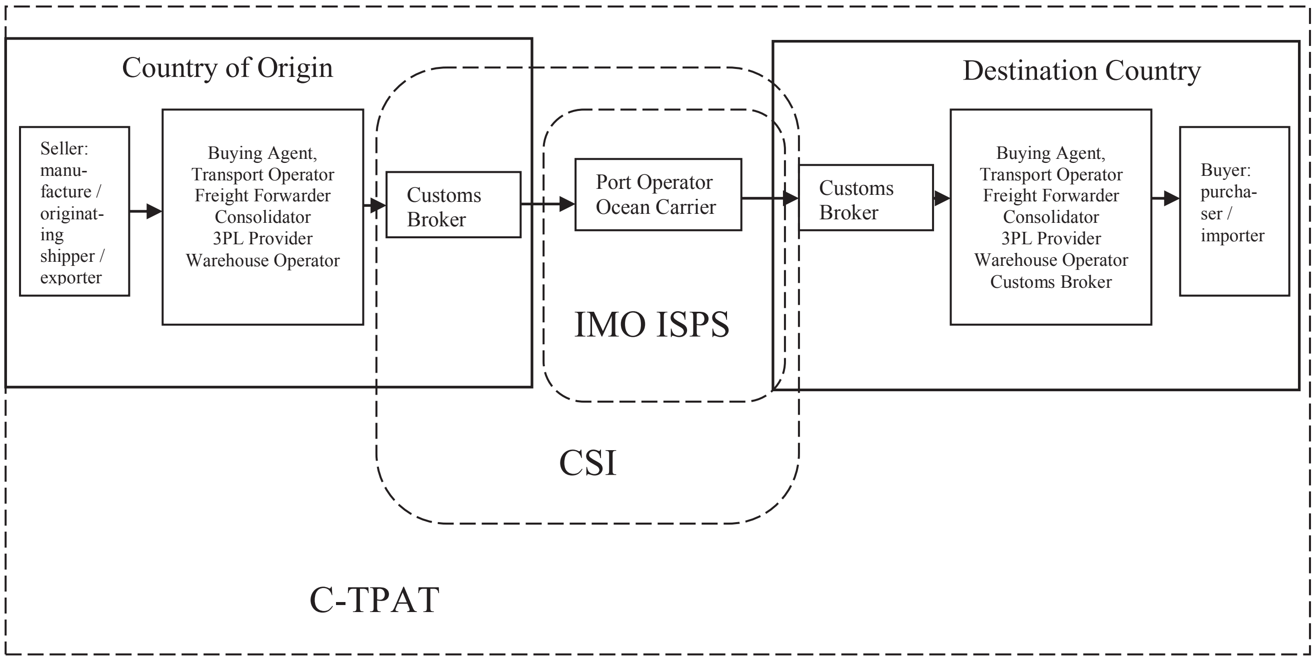

Fig. 8 International Container Logistics Chain: Scope of IMO and US Security Initiatives, adapted from (Crist, 2003)

4.1.1 The Container Security Initiative (CSI)

The *Container Security Initiative* (CSI) is the first USA security program concerning ocean going sea containers. It is based on the premise that the security of the world's maritime trading system needs to be enhanced and it will be more secure if high risk cargo containers are targeted and screened before they have been loaded. The initiative aims the detection of potential problems at their earliest possible opportunity and to prevent the smuggling of terrorists or terrorist weapons in ocean-going cargo containers.

The Container Security Initiative is a four-part program, which involves (Hoffmann, 2006):

1. Establishing security criteria to identify high-risk containers based on advance information;
2. Pre-screening those containers identified as high-risk before they arrive at U.S. ports;
3. Using technology to pre-screen high-risk containers, including radiation detectors and large-scale x-ray and gamma ray machines;
4. Developing secure and 'smart' containers.

To implement CSI, and in particular its second aspect, U.S. Customs have been entering into bilateral agreements or partnerships with foreign governments. The goal of CSI is to improve security without, however, slowing down the movement of container trade. Thus, if it is possible, container screenings are to be carried out during periods of down time, when containers sit on the docks waiting to be loaded on a vessel and screenings should not have to be carried out again in the United States. In the case a cargo container suspected for potential weapons of mass destruction is discovered, it will not be permitted to continue on its course to a U.S. port (U.S. Customs and Border Protection). The initial aim of U.S. authorities was to implement CSI at the (U.S. Customs and Border Protection, 2007) ports that send the largest volumes of cargo containers into the United States, in a way that facilitates detection of potential security concerns at the earliest possible opportunity.

As regards to the costs of implementation of CSI, it should be noted that while U.S. Customs are paying to deploy their officers and computers in the foreign ports, host seaports need to obtain screening and detection equipment, which is not provided by or paid for by the United States. As for the costs of screening individual containers, it is for the host country to determine which party (i.e. exporter, importer, or any other party) is to pay for the direct costs of screening and unloading containers. An important aspect of CSI, which still requires further clarification, is the question of effective identification of high-risk containers (Mikuriya, 2007).

German Seaport Operators argues that scanning 100 percent of US-bound container cargo would require tremendous financial outlays and time (Special Report: Container security: Congress debates the feasibility of scanning 100 percent of US-bound container cargo, 2008). The port of Hamburg ships 120,000 containers to the U.S. per year. The "Zentralverband der deutschen Seehafenbetriebe e. V." (ZDS) estimates the incremental per-container cost to transport containers from the port terminal area to a scanning facility at 300€.

Annually, that amounts to an extra 36 million €. Bremerhaven handles more than 1 million US-bound containers, ca. 12% of overall US-bound container traffic. Here the annual cost – just to move containers from terminal to scanner– would amount to 300 million €. ZDS reports that image viewing can take 15 minutes for accurate assessment, and that with current technology "false positive" rates can reach 5%. If Hamburg and Bremerhaven ship 1.2 million containers to the U.S. per annum, per-day container traffic is 3,287. If each port has 20 scanners processing images every 15 minutes, non-stop 3,840 containers could "scan-reviewed". Consider a false positive rate of 5%. If physical inspections would be required for every false positive, at a per-day rate of 3,287 containers, 165 would require laborious manual inspection.

4.1.2 Customs-Trade Partnership against Terrorism (C-TPAT)

Customs-Trade Partnership against Terrorism (C-TPAT) is the second major security program. It poses to enhance security throughout the supply chain and ensure that its participants implement the policies, plans and procedures to ensure the integrity of their supply chains. The C-TPAT means for the trade community to collaborate with the CBP to ameliorate the security of international supply chains that flow through the United States. The C-TPAT is a certification that is awarded to companies which enables customs clearance more quickly and at a lower total cost. These are benefits that only the CBP can provide. The C-TPAT is a major federal initiative designed to make international shipping efficient and secure.

The following are the benefits the CBP provides though C-TPAT certification (U.S. Customs and Border Protection, 2004):

1. A reduced number of inspections and reduced border wait times.
2. A C-TPAT supply chain specialist to serve as the CBP liaison for validations, security issues, procedural updates, communication and training.
3. Access to the C-TPAT members through the Status Verification Interface.
4. Self-policing and self-monitoring of security activities.
5. In the Automated Commercial System, C-TPAT certified importers receive reduced selection rate for Compliance Measurement Examinations and exclusion from certain trade-related local and national criteria.
6. C-TPAT certified importers receive targeting benefits by receiving a "credit" via the CBP targeting system.
7. Certified C-TPAT importers are eligible for access to the FAST (Fast and Secure Trade) lanes on the Canadian and Mexican borders.
8. Certified C-TPAT importers are eligible for the Office of Strategic Trade's (OST) Importer Self-Assessment Program (ISA) and have been given priority access to participate in the Automated Commercial Environment (ACE).
9. C-TPAT certified highway carriers, on the Canadian and Mexican borders, benefit from their access to the expedited cargo processing at designated FAST lanes. These carriers are eligible to receive more favourable mitigation relief from monetary penalties.
10. C-TPAT certified Mexican manufacturers benefit from their access to the expedited cargo processing at the designated FAST lanes.
11. All certified C-TPAT companies are eligible to attend CBP sponsored C-TPAT supply chain security training seminars.

The C-TPAT certifications are industry specific. There are different certifications for importers, air carriers, foreign manufacturers, and air freight consolidators. Initially, the program gives companies a competitive edge by granting quicker, hassle-free movement of goods across the border as well as formal security training and other advantages. However, as a greater number of companies are awarded the certification, the C-TPAT will in all probability become an industry standard, and companies that do not apply, or are denying the C-TPAT, will be at a competitive disadvantage.

One of the greatest benefits of the C-TPAT is that with a faster and more reliable flow of goods through the border, companies can better forecast inventory needs and lower safety stock levels. If the program functions properly, one of the potential benefits of the C-TPAT is that companies will have a higher percentage of on-time deliveries.

This will allow them to lower safety stock, and should help companies get closer to just-in-time levels of inventory.

A major problem companies are facing regarding C-TPAT certification is the cost. The largest costs are not in terms of filling forms or paying for inspections, they are the internal costs and investments in security and consulting. Firms often have to change legacy information technology systems in order to be capable of collecting additional information, change processes, train employees on new processes, and hire consultants to actually define and design the processes.

As the C-TPAT rules evolve, many of the initial all-voluntary guidelines have become regulation. This demonstrates a shift in strategy. Obviously, as the C-TPAT voluntary rules increasingly become regulation, the C-TPAT essentially becomes mandatory. Either way, voluntary or not, companies will have to subscribe to the C- TPAT rules in order to be competitive or follow regulation - thus, it is in a company's best interest to become C-TPAT compliant and apply for certification as quickly as possible. Some of the major complaints industry has put forth are that shipments are not moving any quicker through the border, nor are they receiving the variety of training that was promised. The information regarding shipment has also been incomplete or missing.

The C-TPAT program, once the U.S. CBP pulls out of this early stage of development, in essence, should be a beneficial for the import industry players and the U.S. CBP. However, notwithstanding the fact that the program is in its early stages of implementation, the U.S. CBP must still work out some of the aforementioned issues if it is to win the support it requires for the program to be considered successful.

Whereas the C-TPAT and CSI are partnership-oriented programs, other security initiatives focus on the collection of information, in particular cargo-related information. A requirement for CSI and C-TPAT programs is the “24-Hour Rule” which means manifest information must be provided 24 hours prior to the container being loaded onto the vessel in the foreign port. It provides CBP with more time to identify high-risk containers. It is on the basis of the information provided in the manifest pursuant to this new rule that U.S. customs officers posted in CSI host are to identify high risk containers prior to loading. Prior to December 2, 2002, the relevant customs regulations simply required the master of every vessel arriving in the U.S. to have the manifest on board the vessel. Comprised in the vessel manifest had to be a cargo declaration listing all the inward foreign cargo on board the vessel regardless of the intended U.S. port of discharge of the cargo.

4.1.3 The 24-Hour Rule

Following the events of September 11th, new regulations have been adopted with the aim of enabling U.S. Customs to evaluate the terrorist risk of cargo containers. The '24-Hour Rule,' require ocean carriers to transmit cargo manifests for cargo being shipped on a container vessel to the United States 24 hours in advance of loading at foreign ports. For each container, the manifest must provide a large number of data elements (Prokop, 2004):

1. Detailed and precise description of the cargo or the 10 digit Harmonized Tariff Schedule of the United States;
2. Numbers and quantities of the lowest external packaging unit as per bill of lading;
3. Container number and seal number;
4. Accurate weight of the cargo;
5. The foreign port where the cargo is loaded, the last foreign port before the vessel departs for the U.S. and the first foreign port where the carrier takes possession of the cargo;
6. The full names and complete, accurate and valid addresses of the consignee and the shipper of the cargo; alternatively, a unique "identification number" for shipper and consignee to be "assigned by CBP upon completion of the Automated Commercial Environment".

It must be emphasized that *"Customs, having analyzed the cargo information, do not send "permission to load" messages to carriers to authorize them to proceed with loading. Therefore, in order to avoid risking a penalty, carriers need to delay loading operations for 24 hours after the submission of the manifest to U.S. Customs to be sure that there is no problem with any particular container"* (UNCTAD secretariat, 2004). Of course, this is, unless a "do not load" message has been sent by U.S. Customs. Upon arrival of a vessel at a U.S. port, in cases where complete advance manifests in accordance with the new requirements have not been received in relation to part of the cargo, U.S. Customs may delay issuance of a permit to unload that cargo; alternatively, unloading of the entire vessel may be delayed, until all required information is received. The application and enforcement of the new 24-Hour Rule requires the quick and efficient handling and analysis of very significant amounts of information on the part of U.S. Customs. In the longer term, the sustained ability of U.S. Customs to carry out its functions efficiently will be crucial to ensuring that costly delays and congestions will not arise and legitimate trade will not be unnecessarily slowed down. It is clear that security measures add to the transport and logistics costs of exports, which, in many developing nations are already disproportionately high.

4.1.4 “10+2" Rule

The new rule on “Importer Security Filing and Additional Carrier Requirements”, was published on 2 January 2008, and this is commonly referred to as the ‘10+2 rule’ (Bureau of Customs and Border Protection, 2008). Essentially, the 10+2 rule is an extension of the 24 hour rule, requiring importers to declare ten additional data fields, and carriers an additional two data fields (Bergami, 2009).

Mandatory is the filing of a container status messages (CSM) such as confirmation of a booking, container terminal gate inspection, loading or unloading of a container, gate-in or gate-out movements, container stuffing or unstuffy, and intra-terminal movements. Given the majority of these events are routine with containerized traffic, as the consignment travels form origin to destination, it is no surprise that carriers/logistics providers are concerned with the “over-reporting” required by the CBP, as this increases operating costs.

The data required by US Customs and Border Protection from importers are:

1. Manufacturer (or supplier) name and address,
2. Seller (or owner) name and address,
3. Buyer (or owner) name and address,
4. Ship-to name and address,
5. Container stuffing location,
6. Consolidator (stuffer) name and address,
7. Importer of record number/foreign trade zone applicant identification number,
8. Consignee number(s),
9. Country of origin,
10. Commodity harmonized tariff schedule number.

As “10+2" is an extension of Custom’s strategy to use data in advance to identify high-risk shipments before they reach the United States” (Bergami, 2009).

The “2” data files that the ocean carrier will transmit to CBP are:

1. Vessel Stow Plan to indicate the location of each container on the ocean vessel.
2. CSM, which detail information on the movement and status changes of a container as it travels through certain parts of the supply chain (U.S. Department of Homeland Security, 2008).

4.1.5 "GreenLane" Program

Participation in the C-TAT program and 3-Tiers status will give companies an opportunity to avoid the additional expenses on containers waiting for inspection, to save costs of manual customs inspections itself and to accelerate the container turnover through the whole supply chain, namely, implementing “Green Lane”. In port security, such an approach has taken the form of cooperative arrangements between private operators and public regulators in developing, financing and implementing the various security programs and initiatives. Such mechanisms do not, however, exist at the international maritime level and for developing countries in particular (UNCTAD, 2005).

There are different levels of C-TPAT members’ validations in order to achieve supply chain security best practices or to get “GreenLane benefit” (U.S. Government Accountability Office, 2008).

First tier certified C-TPAT importers, who meet C-TPAT minimal security criteria, will receive the reduced the Automated Targeting System (ATS) scoring. It will result in fewer security inspections and fewer compliance inspections. But a second and third tier C-TPAT partners are validated as C-TPAT importers using Priority for cargo inspection. The “Tier Three” level reserved for members who exceed the agency’s published minimum security standards. Approximately 22% were awarded with Tier Three status (UNCTAD, 2005). At some U.S. ports, CBP has recently begun to allow C-TPAT members to reduce their handling costs by removing to their own location all containers not selected for inspection before CBP has completed its inspection of the entire shipment. Cargo of C-TPAT members arriving from Canada or Mexico by truck are eligible for quicker transit through Free and Secure Trade (“FAST”) lanes set up at border check points. In other words, the is a more secure supply chain that includes point of origin security, security at point of stuffing, ensured by C-TPAT validated partners who control their supply chain and assure point of origin security, who use a smart container, or see that their foreign vendors do, and who ship their goods through a CSI port to the United States. That shipment should get the green lane on arrival. A third tier status of C-TPAT offers additional benefits to validated C-TPAT participants that demonstrate a sustained commitment beyond the minimum requirements for participation in C-TPAT.

The basic requirements for GreenLane participants should ensure that (S. 2459--109th Congress: GreenLane Maritime Cargo Security, 2006):

1. entry data is submitted on shipments before loading;
2. cargo is loaded at a port designated under CSI for transit to the United States;
3. cargo is loaded on a vessel with a vessel security plan approved or accepted under United States Code;

4. cargo is made available for screening and examination before loading using technologies, processes or techniques;
5. the supply chain visibility procedures are utilized;
6. container security devices meeting the standards and procedures security regulations are utilized;
7. cargo complies with additional security criteria beyond the minimum requirements for C-TPAT participation, particularly in the area of access controls;
8. cargo complies with any other requirements determined by the Secretary of Homeland Security.

As a result more than 58 biggest ports take part in CSI program, and approximately 8400 partners have applied to join C-TPAT, accounting for 85 percent of container traffic bound for the United States (U.S. Department of Homeland Security, 2006):

In the Americas:

1. Montreal, Vancouver, and Halifax, Canada
2. Santos, Brazil
3. Buenos Aires, Argentina
4. Puerto Cortes, Honduras
5. Caucedo, Dominican Republic
6. Kingston, Jamaica
7. Freeport, The Bahamas
8. Balboa, Colon, and Manzanillo, Panama
9. Cartagena, Colombia

In Europe:

1. Rotterdam, The Netherlands
2. Bremerhaven and Hamburg, Germany
3. Antwerp and Zeebrugge, Belgium
4. Le Havre and Marseille, France
5. Gothenburg, Sweden
6. La Spezia, Genoa, Naples, GioiaTauro, and Livorno, Italy
7. Felixstowe, Liverpool, Thamesport, Tilbury, and Southampton, United Kingdom (U.K.)
8. Piraeus, Greece
9. Algeciras, Barcelona, and Valencia, Spain
10. Lisbon, Portugal

In Asia and the Middle East:

1. Singapore*
2. Yokohama, Tokyo, Nagoya, and Kobe, Japan
3. Hong Kong
4. Busan (Pusan), South Korea
5. Port Klang and TanjungPelepas, Malaysia
6. LaemChabang, Thailand
7. Dubai, United Arab Emirates (UAE)
8. Shenzhen and Shanghai
9. Kaohsiung and Chi-Lung
10. Colombo, Sri Lanka
11. Port Salalah, Oman
12. Port Qasim, Pakistan
13. Ashdod, Israel
14. Haifa, Israel

In Africa:

1. Alexandria, Egypt
2. Durban, South Africa

Within the European Union (EU) the Revised Customs Code has been developed. It is done in line with the C-TPAT program and the Framework for Standards of the World Customs Organization (WCO). The Revised Customs Code is expected to be fully in force in 2009. Although currently lobbying of the latest European Commission proposal for transition arrangements for the industry, as all security criteria have already been met until 31 December 2009 is still not acceptable to trade (European Express Association, 2009). The EU introduced the principle of Authorized Economic Operator (AEO): an AEO will be subject to reduced customs inspections when he complies with the administrative rules and the supply chain security requirements as defined by the code; it is promoted to be the international concept, therefore resulting in international agreements between the EU and various countries. The AEO concept means (DNV Consulting, 2005), that cargo passing through ports or crossing the outside EU borders will be subject to inspections for illegal goods. Simultaneously logistics operators with AEO status will get a "Green Lane" advantage through customs, implying reduced inspections and delays.

A majority of the US security initiatives do not have legal status (Only the 24 hour rule in the US has a legal base (DNV Consulting, 2005)). They are completely voluntary programs and only contain recommended measures which industries are free to implement. The US initiatives, implemented under the Department of Homeland Security, are however often criticized for their limited effectiveness because of their non-binding status. It is believed that only through stringent binding policies effective implementation of measures can be assured (DNV Consulting, 2005).

4.1.6 The Smart and Secure Tradelanes Initiative

Another program designed to harmonize C-TPAT and CSI initiatives is the Smart and Secure Tradelanes (SST). The Smart and Secure Tradelanes initiative was established by the container shipping industry to ensure the security of cargo containers. The purpose is to identify the tampering of containers while in transit using automated tracking, detection, and security technologies (Hudson, 2009):

1. Tight physical and information flows in supply chain in real time through automated data collection;
2. Be compatible with business and political systems;
3. Be appropriate to existing processes and technology solutions.

SST's objective is to "rapidly deploy a baseline infrastructure that provides real-time visibility, physical security through non-intrusive, automated inspection and detection alerts, as well as a complete audit trail of a container's journey from origin to final destination". To achieve this objective, SST is using the Total Assets Visibility (TAV) network which was developed by the U.S Department of Defence. This network allows the integration of data collection devices such as RFID and GPS with the Universal Data Appliance Protocol (UDAP). Using these transhipment port, and to final delivery. Ports involved in the initiative install RFID reader technology that can communicate with the network, enabling monitoring of containers with smart electronic seals (Hudson, 2009).

4.1.7 Summary

According to discuss above, the current security initiatives are a good start for improving security arrangements in container transport chains. Nevertheless it is not address the end-to-end security problem (Dahlman, Mackby & Sitt, 2005). The government initiatives should provide security accountability of standards for all elements of container operations. Such an approach could lead to a harmonization of security requirements that can be applied to the container transportation operations from beginning to end: importers/exporters, port authorities, and shipping industry.

Some security initiatives require the enhancing the traditional level of cargo security thought integrating of new secure technology for containers. One kind of such a technology is container electronic seal. In the next sub-chapter we will consider different types of container seals.

4.2 Types of seals

As noted by the World Customs Organization, "*High security manual or mechanical seals can play a significant role in a comprehensive container security program. But it is important to recognize that container security starts with the stuffing of the container and that seals do not evidence or guarantee the legitimacy of the container load*" (Administrative Committee for the Customs Convention on Containers, 2004). Currently used container seals are not difficult to remove from the container door; they can be reproduced or simply forged. Conventional seals can be overreached by lifting off container doors or entering the container through holes that are cut out and welded back together afterwards. Stakeholders have had little motivation until recently to implement additional security measures in the highly competitive container transport market.

4.2.1 Mechanical seals and locks

To use mechanical cargo seals are part of conventional container transportation practice. There are two major categories, indicative and barrier seals, both of which detect tampering or entry (Fig. 9).

Indicative seals, regarding to (Wolfe, 2002) are "usually made of plastic, wire, or a combination of both, marked with a unique serial number or identifier. The purpose is simply to be a sign of whether or not the sealed entrance has been compromised. If the seal is unbroken, one presumes the cargo has not been tampered with. If the seal is compromised, one presupposes the integrity of the cargo has been compromised as well (Wolfe, 2002).

Fig. 9 Mechanical Seals (Transportation Information Service, 2009)

Barrier seals add physical protection to tamper detection and are more difficult to overcome (Wolfe, 2002). It usually takes bolt cutters or special tools to remove a barrier seal, not simple wire cutters, or a sharp knife. The most protective barrier seals are bolt seals, which can be similar to heavy-duty bolts with specialized single-use locking nuts and unique identifiers (Wolfe, 2002).

While neither is highly secure, both have high levels of usage in industry for two primary reasons: when the unit costs are extremely low, typically pennies a piece;

when and for everyday low-vulnerability operations they have provided adequate protection.

However, manual seals offer no precise information as to where, when, under what circumstances, or by whom the seal was broken. The best information, assuming the chain of custody and seal inspections has been maintained, is a time frame when and range of possible locations where the breach may have occurred – that is, since the last signature noting that the seal was intact. However, manual seals offer no precise information as to where, when, under what circumstances, or by whom the seal was broken. Such a situation can be modify by potential improvements from electronic cargo seals

4.2.2 Electronic seals

As it was introduced in "GreenLane Maritime Cargo Security Act" (GovTrack.U.S., 2005) the new security programs will require the use of 'smart containers', ones that are equipped with RFID sensing technology, that can detect tampering. One of the applications of this technology for container industry is electronic seal.

Electronic cargo seals are a subset of sensor technology receiving serious attention from U.S. Department of Transportation, Customs, and others. Pre-September 11, many developers and potential users of electronic seals put priority on low cost and simple devices aimed at theft prevention. After September 11, attention shifted to more robust seals with greater security capabilities. These tools may help reduce congestion at border inspection areas at the same time they increase confidence about security.

The general purpose of seals is to secure the content of containers. Conventional seals generally comprise a bolt that mechanically prevents the container from being opened (Field, 2005). At the destination it has to be validated that the seal is still intact and that it is still the same (Tirschwell, 2005). Conventional seals are comparatively cheap and not reusable: if a container is legitimately opened a new seal has to be affixed (Hadow, 2005) and its unique number (Field, 2005) has to be recorded. Compared to their low purchase price the handling costs are quite high since the inspection has to be conducted manually and is therefore time consuming (Tirschwell, 2005). Although mechanical seals increase the effort for tampering with a container their benefits are still limited. As an example, criminals can remove the doors of the container completely without damaging the seal, cut a hole into another wall, or create a new seal after having finished. Furthermore, containers are not monitored in real-time (Hadow, 2005).

Since October 15, 2008 U.S. Government requires sealing all maritime containers with a seal that meets the International Organization for Standardization, Publicly Available Specification 17712 (ISO/PAS 17712) (Fig.10), Freight Containers-

Mechanical Seals (Winkowski, 2008). This mandate is the result of several 2007 amendments to the Security and Accountability For every port (SAFE Port) Act of 2006. The provisions of Section 1701 of the Implementing Recommendations of the 911 Commission Act of 2007, codified at 6 U.S.C. § 944, impose a self-executing legal requirement.

Fig. 10 .Samples of mechanical seals that meet the ISO/PAS 17712 standard (Gate Way Logistics Group, Inc., 2009)

The statutory requirement applies to loaded containers, including freight remaining on board, arriving by vessel at U.S. ports of entry (SAFE Port). There are some exceptions, that includes tanks, non-standard containers (such as open top containers), and those incapable of being affixed with such a seal. U.S. Customs and Border Protection will ensure compliance with this new requirement as part of normal seaport container inspection activities and does not envision new activities aimed simply at seal verification.

Electronic seals are intended to overcome some of the limitations of conventional seals. Apart from mechanically locking the container they also exhibit computation and communication abilities. Therefore, it is possible to verify them by an RFID scan (Tirschwell, 2005). This feature does not only massively decrease the handling effort, but also enables an almost continuous monitoring as the scanning can be performed easily and often. Thus, the seal can also act as a surrogate for the container number since RFID technology enables a recognition rate of over 99% while optical character recognition systems achieve only about 80% under real-world conditions (Hadow, 2005). Despite of their higher purchase price electronic seals might therefore be the better choice regarding their total cost of ownership (Tirschwell, 2005).

4.2.2.1 Technical aspects of e-seals

E-seal is an electronic device to check the legitimacy and integrity of freight containers (Fig. 11 (http://www.gaports.com/)). This security device transmits information about container status when it passes through the reading infrastructure and creates alerts in the case if the seal was broken or container is tampered with.

Fig. 11 Electronic Container Seal

- **Communication protocol of e-seals**

The communications between an e-seal and a reader device process using a command-respond protocol, i.e. the reader always initiate the session using a command, and then the e-seal responds to it appropriate container/seal status data (Park, Lee & Kim, 2005; ISO, 2005). The e-seals employed various different communication protocols to transmit data to reader.

There were three basic methods that were used by different vendors:

1. Timed transmission from seal to reader (e-Logicity);
2. Queried transmission from a reader (AllSet and Hi-G-Tek);
3. Unique query type system that employs a “signpost” to query seals and separate reader to receive the transmitted seal signal (Savi).

- **Communication frequencies of e-seals**

Electronic seals have also the different communication frequencies. It is not only technical considerations but also international availability of frequencies and economic considerations. Only the 2.44 GHz frequency band is available worldwide and in that case the allowable power levels vary by country (Domdouzis, Kumar & Anumba, 2007).

Frequency	**Countries**
125 – 134 kHz	USA, Canada, Japan, Europe
13.56 MHz	USA, Canada, Japan, Europe
433.05 – 434.79 MHz	In most of USA and Europe and under consideration in Japan
865 – 868 MHz	Europe
866 – 869 and 923–925 MHz	South Korea
902 – 928 MHz	USA
952 – 954 MHz	Japan (for passive tags after 2005)
2400 – 2500 and 5.725 – 5.875 GHz	USA, Canada, Japan, Europe

Table 1 Frequencies of use RFID systems in different countries (Domdouzis, Kumar & Anumba, 2007)

- ***E-seal Reader infrastructure***

Reader infrastructure is also a major design trade-off between the e-seals produced by various manufacturers.
E-seals have additionally various different seal locations and attachment methods:

1. One of the ways to place the seal to secure container is to mount seals near the centre of the container doors close to the locking bars. The seals are affixed to the container and seal the doors either with a bolt through the hasp on the door handle or with a cable around the two vertical keeper bars. Tampering is detected if the bolt is removed or the cable is cut.
2. The other possibility is to mount it on the upper right of the container door between the frame of the container and the door itself. The seal is either permanently or affixed or help in place by a magnet. Tampering is detected using a pressure sensor on the door that is able to detect when the door is opened or closed.

These variations of seals allocations also initiate potential logistical problems, because the door of the container must be open to install the seal; and in these cases where seals might be installed in-transit, security could be compromised by having to open the doors.

Typically a security-enabled e-seal is operated in following steps (ISO, 2005):

1. The manufacturer sells the e-seal to the shipper and provides him with a set of cryptographic keys for each of e-seal. This process should be done in a secure way. The e-seal status is “Open and un-sealed”.
2. The shipper programs the e-seal with the required information such as the manifest for shipment or the policy on the environment inside a container. This “write” operation should be controlled using cryptographic mechanisms to prevent an attacker’s unauthorized write attempts.
3. After checking if required goods are loaded completely and safely, the shipper seals the e-seal and its status becomes “Closed and sealed”.
4. During the transportation, the e-seal information can be read several times by carriers and at check points, or even by some attackers. While accesses to public information of an e-seal, e.g., seal ID, are always permitted, accesses to confidential information should be controlled by cryptographic mechanisms.
5. After the container arrives at the destination point, the consignee checks the integrity of cargo container by checking the status of the e-seal attached to the container. At this point, the e-seal should be authenticated with the master key, since it could have been spoofed or cloned while transported.
6. If there is no problem, then the e-seal will be open by the receiver, and it becomes “Opened” status.
7. Optionally the e-seal can be recycled after deleting the information on the next shipment.

Electronic seals tend to combine physical seals and specific electronic components. The result is a hybrid electronic seal that provides tamper evidence, physical security, and data management. They indicate electronically whether a conveyance has been opened or tampered with. Electronic seals use RF (Radio Frequency), IF (Infrared) and/or fibre optics. Combined with these technologies, an electronic seal can also be compatible with GPS (Global Positioning System) and mobile phone protocols for particular applications. Most of the electronic seals include passive or active technologies.

- **Types of electronic cargo seals**

There are typically four types of electronic cargo seals:

1. RFID seals: passive and active
2. Infrared Seals (IR)
3. Contact Seals
4. Remote Reporting Seals.

The distinction between these four is found in the technical and functional means used by the seal and the reader to communicate with each other.

RFID is the most popular Hi-tech for container security devices. It is an automated data-capture technology that can be used to electronically identify, track, and store information about groups of products, individual items, or product components. The technology consists of three key pieces: RFID tags; RFID readers; and a data collection, distribution, and management system. RFID tags are small or miniaturized computer chips programmed with information about a product or with a number that corresponds to information that is stored in a database. The tags can be located inside or on the surface of the product, item, or packing material. RFID readers are querying systems that interrogate or send signals to the tags and receive the responses. These responses can be stored within the reader for later transfer to a data collection system or instantaneously transferred to the data collection system. Lastly, data collection systems consist of computers running data processing software, which typically are networked with a larger information management system (Sabbaghi & Vaidyanathan, 2008).

Passive RFID seals are short range, low cost, and disposable. They have no inherent electric power, such as a battery. The interrogator provides energy when it illuminates or scans the seal. The passive seal uses the absorbed energy to reflect its information back to the reader. The lack of on-board power limits the functionality. For example, since passive seals cannot provide continuous power to measure the condition of the seal cable, they cannot detect and record tampering at the time of the event – they simply report whether they are intact or not when interrogated by a reader (Wolfe, 2002). Pure passive RFID tags are relatively simple in design, inexpensive, and often disposable. When an energy source is added to a passive RFID tag, the range in which the seal can be read has the potential to increase to over 30 meters. From a security and productivity standpoint, there are industry issues relating to the limited capabilities and effectiveness of the purely passive seals, however (Donath, Murray & Short, 2005).

Active RFID seals are more sophisticated, have higher initial costs. Active seals carry batteries and the power permits longer range and greater functionality. They can detect tampering when it occurs and add it to a time log of events. If equipped or interfaced with GPS, an active seal can also log the location. Further, some seals can provide live "mayday" tampering reports as the events happen, mostly within specially equipped terminals (Wolfe, 2002).The term 'active RFID' generally implies the use of an on-board power source, which in many cases gives the e-seal the following capabilities (Donath, Murray & Short, 2005):

- Continuous monitoring of seal integrity within certain proximities;
- Capturing and logging time data when the seal recognizes an event or break in integrity;
- Omni-directional communications;
- Longer communication ranges than found in passive RFID e-seals;
- Real-time tampering reports.

Infrared seal is a less common media choice than RFID. Infrared seals essentially require line-of-sight communications capabilities (i.e. communications are blocked by any physical barrier between the seal and the reader.) Thus the effectiveness of infrared seals is limited to situations when readers and seals are within close range of each other (Donath, Murray & Short, 2005).There do not appear to be any standards issues about IR, but there are unresolved disagreements about its technical merits (Wolfe, 2002).

Contact and near-contact technologies include contact memory buttons, PDA and electronic key plug-ins, low frequency RFID, and short range IR. Proponents of contact and near-contact solutions argue that it is important to have a human being visually observe the seal, and their solutions provide that added benefit (Wolfe, 2002).These types of devices are generally not reusable (Donath, Murray & Short, 2005).

Remote reporting uses satellite or cellular communications. The great advantage is the ability to maintain visibility en-route and to obtain near real-time event reports. It is a high-end capability, usually at high-cost (Wolfe, 2002).

Because of their low unit cost and operational simplicity, passive seals were generally the preferred solution for “pre-9/11” security requirements aimed against theft. The greater functionality of active seals enhances their application for “post-9/11” security against terrorist tampering. For instance, for supply chain applications where there is a need to store an electronic manifest within the tag, such as customs inspection, only active RFID e-seal is an appropriate option. Passive RFID does not provide sufficient data storage or data search capabilities (Savi Technologies, 2002; Horowitz, 2005; Hickey, 2004). Another distinguishing feature of active RFID tags they are re-writeable tags, where information on the tag can be erased, rewritten, or modified, also allow the updating of data, and therefore have high utility in security and identification applications. The progress of technology development is still not finished, and several hurdles stand in the way of wide use of electronic seals (Wolfe, 2002):

- The International Standards Organization’s (ISO) Technical Committee 104 is still developing the multi-protocol standard for passive and active electronic seals.
- Today there are no global frequencies and technical specifications (for power levels and duty cycles) for electronic seals or other RFID logistics applications.
- Operating practices for reusable seals still pose a challenge for shippers and carriers. It may be differ for a significant segment of repetitive commercial containers that is more suited to recycling seals; and if empty container movements were sealed for security reasons, it should simplify the recycling process.

- Field experience on the market of electronic seals is relatively low and they are in limited use. This situation requires more pilot and demonstration program to accelerate the processes of accumulating field experience, fine-tuning products, and developing customer confidence – all important to support regulatory requirements for e-seals.

Thus, currently RFID technology is slightly too expensive for widespread security operations. There are high initial fixed costs – purchasing equipment, training employees, and upgrading information systems. RFID does have a few vulnerabilities. Tags or seals can be counterfeited, containers that contain cargo with and without tags are difficult to identify, containers still need to be shipped through facilities and terminals that may not be secure and RFID does not prevent dangerous cargo from being loaded into containers in the first place (Hickey, 2004). Even though the technology is still undergoing development, there are many potential uses and applications:

- Secure "Greenlanes" where E-tags are used in combination with U.S. Customs and Border Protection initiatives and partnerships such as CSI and C-TPAT
- Secure transport and product tampering protection
- Automatic seal verification
- Security and tampering investigations
- Logistics data provided in real time via Internet or file transfer technology
- Early warning of problems, intrusion

Electronic seals are part of a multi-layered approach to security; it is more crucial to precede the sealing process with business practices and tools that assure the integrity of the container loading and sealing process. The efficiency and productivity of global container system can be achieved when electronic seals are part of a harmonized and standard international transportation process. From a productivity perspective, electronic seals should be viewed as part of a management visibility and control system, not simply as a security tool (Wolfe, 2002).

4.3 Electronic seals system

Containers and their security systems are applied all over the world. The environment of each container changes dynamically on the way from its origin to its destination. The demand for flexible interaction with other entities often arises during transport. For instance, consider customs personnel wirelessly requesting security information with hand-held devices. As another example multiple containers from one company might cooperate in their security efforts in order to save their bounded resources. Although a great many vendors of container security solutions exists, their interoperability currently remains an open issue due to a lack of standards (Horowitz, 2005).

Apart from the seal, container security systems can be enhanced by embedded sensors which monitor tampering, theft, and placement of unintentional freight. Examples are door light sensors, gamma ray detectors, as well as chemical sensors (Schwartz, 2004). As the applied sensors depend on the concrete purpose, the participating entities must be equipped with the ability to establish ad hoc networks. In this context it has to be ensured that access to the network is restricted to trustworthy entities, e. g., by certification. Otherwise, thieves or terrorists could corrupt the system by injecting manipulated data.

The security systems interface to the outside world is another vulnerable point. As an example, stevedores and truckers are legitimate recipients of some security-related data. Due to restricted resources it might also be an option to join forces with security systems of neighbouring containers. These forms of communication have also to be restricted to trustworthy partners. As an example, from the perspective of safety it might be desirable for a container to inform the environment about hazardous content. By contrast, this is not the case from a security point of view. It is not advisable to broadcast a container's attractiveness for terrorist attacks to everyone including the terrorists themselves (Hadow, 2005).

To recapitulate, electronic security systems can significantly improve container security. Since they demand flexible cooperation, their interaction with the outside world has to be secured itself. This can be achieved by limiting communication to trustworthy partners. For instance, Savi Networks company has already deployed data capture infrastructure (Witt, 2008) for active RFID e-seals in facilities at the U.S. ports of Los Angeles/Long Beach, Oakland, Savannah and Norfolk; the Chinese ports of Hong Kong, Yantian, Shekou, Shatian, Chiwan and Mawan; the Korean ports of Busan and Kwangyang; the European ports of Rotterdam (Netherlands), and Felixstowe (United Kingdom); and, the ports in Kaohsiung, Taiwan; Laem Chabang, Thailand. Savi Networks LLC provides SaviTrak, an information service that is used to manage in-transit inventory in real-time, which extends to facilities at ports handling 20 percent of world trade. SaviTrak provides automated information and analytics derived from wirelessly captured data on the physical location, security status, and environmental condition of inventory. The data is captured in real-time as inventory moves through a global wireless network operated by Savi Networks.

Container security systems play an important role in securing container logistics. Nevertheless, a lack of standards currently prevents interoperability of components from different vendors. By implementing electronic seals and sensors as agents, standardized communication protocols can be applied for the interaction. In addition, aspects of trust and encryption must be considered as not every communication partner is trustworthy. In order to save resources multiple components of one container security system as well as multiple systems may join forces by cooperating (Werner, Schuldt & Daschkovska, 2007).

4.3.1 Challenges of e-seals implementation in global container networks

An RFID-enabled seal or electronic seal allows importers, shipping companies, port officials and customs inspectors to determine, without a physical inspection, whether the seal has been tampered with and the security of the container compromised. Currently, a number of companies produce e-seals. Nonetheless, it's unlikely the world's ports and ocean carriers, or U.S. importers, will invest in RFID seal and reader infrastructure until the International Standardization Organization (ISO) issues an e-seal standard (Barlas, 2009).

Many solutions based on smart locks and seals have been examined and extensively tested since 9/11. Most of the current proposed solutions focus on the electronic lock, seal, and sensor on the container door. They do not address the problem of intrusion through other surfaces of the containers not touching the lock and seal or gasket or the contents stuffed inside the containers. There is a list of the basic challenges for standardized e-seals (Chung, 2005):

- Impossible to inspect all of the containers or even 10%.
- No way to know if tampering occurs during transit and too late to prevent loss upon arrival at unloading port.
- Cannot be sure whether any contents may contain weapons of mass destruction (WMD)

4.3.1.1 Standardisation issue

Regarding (Sabbaghi & Vaidyanathan, 2008) it is still remains technical challenges despite the increasing attention to RFID applications. The use of radio waves obviates the needs for a clear line-of-sight placement of a container door with RFID seal, because metal sides of the container reflect electromagnetic energy. This often results in decreased identification rates of seals. Electromagnetic interference from other nearby transmissions in a port area can also affect the tag performance and tag to reader communications. Physical effects such as reflection and diffraction may also affect tag performance. Inconsistent interoperability across various RFID systems, companies, and countries also presents a challenge to the wide-scale development and deployment of RFID technologies. Technical standards, frequency and power levels are critical issues for successful global interoperability of RFID systems. There are several efforts in progress to develop and refine technical standards for tags and readers, and common standards remain a goal. Likewise, differences in operational frequency ranges, allowable transmission standards, and allowable power limits in countries continue to serve as operational constraints.

The current research and development of future RFID capabilities moves towards the processors fabricated with new conductive materials or use of organic microprocessors for RFID tags and other applications. For example, the National Institute of Standards and Technology is looking at the technical feasibility of replacing silicon or inorganic materials in RFID devices with mostly or wholly organic materials such as plastics. This and other ongoing research in materials and tag and chip design, fabrication, and production will result in more robust and functional tags over time (Sabbaghi & Vaidyanathan, 2008).

Container transport is an open system with a broad variety of often unknown actors who contribute to the services in the transport chain. The owners' code register of Bureau International des Containers in Paris notes more than 1600 owners and operators of containers using their world-wide unique code to establish identity for their containers. Standardization is a vital condition of the current efficiency of the container transport system. Standardization is needed for security actions as well. The Customs Convention on Containers (Geneva 1972) defines that a seal for container transport under customs seal must be approved by the national Customs Administration concerned. This regulation has, in the end, produced several 1000s of different seal designs. Under such condition, it would be most difficult to ascertain whether a seal has been attached by an authorized party or been replaced somewhere under way (Seidelmann, 2005).

The existing standards for electronic seals are developing by the International Organization for Standardization (ISO). ISO is a network of the national standards institutes of 148 countries, on the basis of one member per country, with a Central Secretariat in Geneva, Switzerland, that coordinates the system. Regarding ISO/IEC 19762, Parts 1 and 3, ISO 17712 electronic seal is "read-only, non-reusable freight container seal conforming to the high security seal defined in ISO 17712 and conforming to ISO 18185 or revision thereof that electronically evidences tampering or intrusion through the container doors" (ISO, 2006).

The original ISO PAS 17712, published in 2003, was developed by a working group of users and manufacturers assembled by ISO Technical Committee (TC) 104, Freight Containers. It describes three types of mechanical seals:

- High security seal
- Security seal
- Indicative seal

The strength of a seal is measured with tests based on impact, shear, bend and tensile strength. The values, the measures of strength, reflected numbers in use by major customs authorities. As a series of programs, such as the US Customs-Trade Partnership against Terrorism and the World Customs Organization's Framework of standards, endorsed and "encouraged" the use of ISO compliant seals, the quality of seals used in international trade improved. Following ISO procedures, the working group produced a Normative Annex for security-related management practices; the annex requires certification after inspection by a qualified and independent reviewer. TC 104 approved the revision and ISO published it as ISO PAS 17712, 2006.

Seals must show a mark to indicate their grade – “H” for high security, “S” for security and “I” for indicative. Only manufacturers certified as compliant with the normative annex may put grade marks on seals ergo ISO compliant seals can only come from ISO compliant sources.

The ISO 18185 e-seal standard is close to complete and in a little while being available as a useful tool for solution developers and end users. ISO 18185 is an application standard for electronic container seals developed by Technical Committee ISO/TC 104, Freight containers, Subcommittee SC 4, Identification, and communication. Since the year 1999, a specific workforce in ISO/TC 104 discussed various approaches to an electronic seal. The working package of e-seals standards now is known as ISO 18185, “Freight containers – Electronic container seals”. Some basic principles have been agreed on meanwhile: The standard electronic seal will be an attachment device fixed to (or integrated into) the mechanical seal that secures the door of the container. The seal is programmed with a standardized set of data with the following coded information (Seidelmann, 2005):

- Seal ID number
- Manufacturer ID number for the seal
- An indication of the time when the seal had been closed and when it had been opened
- A bit that indicates an eventual tampering of the seal.

Currently ISO18185 consists of the following parts, under the general title Freight containers— Electronic seals (ISO, 2006):

- ISO 18185-1, Freight containers – Electronic seals –Part 1: Communication protocol
- ISO 18185-2, Freight containers – Electronic seals –Part 2: Application requirements
- ISO 18185-3, Freight containers – Electronic seals –Part 3: Environmental characteristics
- ISO 18185-4, Freight containers – Electronic seals –Part 4: Data protection
- ISO 18185-6, Freight containers – Electronic seals –Part 6: Messages sets for transfer between seal reader and host computer
- ISO 18185-7, Freight containers – Electronic seals –Part 7: Physical layer

The 18185 system consists of the three distinct components: e-seal, LF transmitter, and reader. The main feature of the system is their dual frequency operations.

There are two kinds of political issues. The first is international and national spectrum regulation, which includes spectrum allocation and power and duty cycle regulation; this is an issue in part because there is no global frequency set aside for RFID logistics applications. The second political issue is about commercial interests, as different companies aim for market advantage (Wolfe, 2002). There several frequencies of use RFID systems in different countries (Domdouzis, Kumar & Anumba, 2007).

Therefore, undefined electronic seal's status on the world market and manipulations with international standards for such devices involve many discussions about when, how and what type of seal will be most effective and secure for container logistics purposes. The debates took a long time and there still no solution or trade-off between customs authorities and business sector, between manufactures of e-seals and standardization institutions regarding technical capabilities of security devices and logistics applications of it.

4.3.1.2 Costs for e-seals implementation

Increased container and port security will not come without costs, and it does not refer only to the money that the government must invest to increase security. It is essential to balance port and container security with economic efficiency of cargo flows. While port security is the crucial part of the competitive maritime transportation system, too much security can damper trade and leads to a loss of a sense of freedom and to feelings of insecurity (Firestone & Corbett, 2003).

Maritime transportation and logistics activities traditionally have been among the largest costs in international trade. But in contrast to that, the most significant advances in modern logistics have not been in cost reduction, but in improved processes to move goods and materials between nations in a timely and seamless manner. The implementation of CSI and other security initiatives have also placed an increased trouble in terms of processes and costs for all the players in global supply chains. This means that for CSI to be fully sustainable as a process in global supply chains, the financing of CSI must also be equitable or fair (Banomyong, 2005). There are two possible sources for financing CSI:

- Payment by users

A tax or a fee can be charged by the relevant authorities. This specific fee can be collected to finance the extra process, equipment and technology used for CSI. The use of appropriate INCOTERMS will become critical in deciding whether the exporter or the importer should pay this specific fee.

- Public sources

Financing can be national where each government is responsible for all security initiatives within its borders, but this type of financing is biased as most developed countries would already have the majority of equipment in place while the developing countries would have to invest a significant amount in order to achieve acceptable levels of security. Financing can be also international where the importing countries, such as the US, provide a grant to the implementation of CSI around the world. Public financing runs the risk of not achieving the desired level of security in global supply chains. Bilateral financing may help in the implementation of security initiatives but the financial sustainability of the initiatives must be demonstrated. The collection of funds from whatever source is necessary in order to finance security initiative but it is an insufficient condition for the guaranteeing of full global supply chain security. However, the present trend is for exporters to fund these security initiatives thus increasing their financial burden (Banomyong, 2005).

DNV (Det Norske Veritas) Consulting international company has done the study for European Commission regarding estimating the general economic impact of international and European programs towards improving and especially investing in transport security in EU (DNV Consulting, 2005). The DNV have analysed the effect from implementing high security seals, compliant to ISO/PAS 17712, for containers export to outside the EU if seal has a cost of below 0.75 Euro a piece. It is assumed that 80% of intra cargo (2 billion tons per year) is subject to the seal programme and an average cargo unit weighs 20 tons the number of seals needed to implement an EU seal program will be 80 million investment. It is assumed that it takes 2 minutes to mount and dismount such a high security bolt. The additional expenses for industry would be in the order of 150 million Euros.

Understanding the finances of current intermodal container tracking first requires an understanding of incentives, investment values and returns. In practical terms, this means the cost of the equipment and the detention charges applied to keeping equipment longer than the specified free period. Once these elements of the system are well understood, the value of better tracking systems can be evaluated.

The designs of reading infrastructure of e-seals have a principal impact on the range that the system can be effective and on the ability of the devices to communicate in complex environments such as container yard / terminal gate area. These differences in effective reader range have a key impact on the infrastructure required to cover a large reading area. This is an important trade-off that will determine the total infrastructure cost of an installation. Less complex systems will have a lower potential cost per reader; however multiple readers will likely be required. More sophisticated devices could have greater potential investment per reader but only a single reader might be required (Le-Pong & Wu, 2004).

The equipment costs can be broken down into the cost of the container, the seal, the RFID tag, and the smart box. The investment for new shipping containers is between \$7,000 and \$40,000, depending on the size and its function (dry goods or refrigerated goods) (Balog, Lim & Nettleton, 2005). High-security mechanical seals cost between \$0.50 and \$2 per seal depending on the material employed (Tirschwell, 2005).

Electronic seals developed by Savi Technology, used by the Department of Defence and tested in a pilot program with the Asia Pacific Economic Cooperation (APEC) Secure Trade in the APEC Region (STAR), have a value between \$300 and \$400 (Balog, Lim, & Nettleton, 2005), Industry estimates RFID tags hover around \$0.25 and \$0.55 cents. However, Alien Technology, a leading RFID manufacturer, predicts that in quantities of 1 billion, RFID tags will approach \$0.10 each, and in lots of 10 billion, \$0.05 per tag (Balog, Lim & Nettleton, 2005).

Finally, industry analysts estimate smart box technology costs approximately \$50 per container with an operational increase of \$10 per container to account for the infrastructure. Savi Technology, a specialist in RFID components, currently supplies the government side of the supply chain. Savi complies with the Department of Defence RFID policy, mandating that all DOD containers have the electronic manifests. These manifests are contained on an electronic seal that is approximately \$300-\$400 per seal.

However, it does not contain a multi-sensor feature capable of detecting invasion into the container. In 2003, the Port of Seattle joined the Asia Pacific Economic Cooperation's (APEC) program Secure Trade in the APEC Region (STAR) as the North American partner. Together with Bangkok/Laem Chabang, this project aims to demonstrate end-to-end supply chain security between Thailand and the U.S. Savi electronic seals were used on inbound containers. While the trial produced encouraging results, the seals were cost prohibitive and Savi Technology was not willing to comply with port technology demands. These requirements included using commercial off the shelf technology in an open architecture environment, one where competitors are free to bid to the port price competitive technologies (Balog, Lim & Nettleton, 2005).

15 October 2008, a mandate issued by the United States Customs Border Protection became effective requiring all US inbound maritime containers to be secured with an International Organization for Standardization ISO/PAS 17712 bolt seal. However, many shippers and container carriers have been using these bolts for years with no appreciable effect (Carroll, 2009). These seals are easily counterfeited, and their main advantage seems to be that they are inexpensive.

The technology is available now to develop a single-use, disposable, inexpensive, versatile and reliable e-seal. Part of the argument put forward by the DHS for not using e-seals is the concern by both government and industry about the costs of the e-seals, the costs of an extensive and expensive RFID infrastructure, the logistics of returning reusable e-seals and responding to ‘false positive’ alarms caused by defective and unreliable e-seals.

Recent surveys show that many executives from the supply chain and logistics industry consider cargo theft as the main challenge to supply chain security, while safeguarding against a terrorist attack is slightly less important. This reflects an attitude that, despite a growing number of government regulations that suggest terrorism is still a relevant threat; shippers are mainly worried about theft of their cargo. The Federal Bureau of Investigation has estimated that the cost of cargo theft to the US is between $15 billion and $30 billion a year (Carroll, 2009). As the economies of the US and the EU in terms of GDP are equal it is not unrealistic to estimate that the cost of cargo theft in the EU is in the same order of magnitude.

SaviTrak customers in Asia and South America are discovering that the real-time data the system captures from shipments tagged with active Radio Frequency Identification e-Seals enhances security visibility, speeds clearance by their countries' Customs authorities, and reduces in-transit inventory costs. For example, Emprevi Ltda., a logistics and security firm, said the Savi Networks system has cut security costs in Colombia by $300 per container trip for its customers, which include Johnson & Johnson, Pfizer and Cadbury Adams. Western Digital, a leader in information storage products, says that per-trip costs have been reduced by $40 for point-to-point shipments from its manufacturing facilities to Royal Thai Customs authorities in Bangkok because the automated security devices speed collaboration and government clearances (Witt, 2008).

Therefore we can recognize, that any technological advancement to enhance security must also stimulate trade by reducing the cost or increasing the efficiency of operations. Therefore, integrating a modular tracking, seal and sensor system utilizing RFID and GPS into the container structure will both increase container security and optimize trade. Its success depends on business/government partnerships and international implementation. It must be partnered with stringent initiatives that enhance information exchange and security of the physical and personal components of the supply chain.

4.3.2 Business benefits of e-seals for global container chain

As RFID is the most prominent technology for enhancing efficiency and security of global container systems, it is necessary to define the realistic benefits from its application in container security devices. Several companies are already experiencing great savings and increased efficiencies using this technology in their supply chains. Moreover, the use of Global Positioning System (GPS) technology, coupled with use of RFID tags, has significantly improved the movement of containers through ports. For example, the Trans Pacific Container Service used to move 7,000 containers a week through its 175-acre Los Angeles Terminal. Today, it moves 12,000 containers a week in the same amount of space as a result of implementation of a combination RFID and GPS tracking system. Links between gate, yard and vessel operations through the terminal’s computer system automatically trace a container's movement through the terminal (Sabbaghi & Vaidyanathan, 2008).

In the last years the benefits from RFID technology in supply chains have been made clear. However, there is still a lack of research about advantages from application of electronic seals on containers in logistics networks. The general benefit from RFID e-seals in container supply chains are seemed to be only for securing purposes of customs authorities. However, the container transportation process is characterized by complex interactions of numerous operating companies and organizations. While a container moves from point of origin to destination point, as many as 20 different companies have to coordinate the operations of more than 25 documents with approximately 200 data elements for only one international shipment in the global container network (Downey, 2010). The companies include trucking firms, terminal operators, and the shipping company, the manufacturer of the shipped goods, the purchaser, banks, and others.

Currently, based on different types of container security devices, a sophisticated platform, that is capable to provide high-end security tasks and elaborated logistics management applications, can be developed (Notteboom, 2004). Actually, the biggest container ports in the world, namely Singapore, Kaohsiung in Taiwan, Rotterdam in the Netherlands, Pusan in South Korea and the ports of Los Angeles and Long Beach, have already adopted RFID projects, in particular, testing e-seals abilities for cargo tracking (Seymour, Lambert-Porter & Willuweit, 2007).

The projects were focused on various advantages from RFID system implementation in container port environment, like greater efficiency by shortening the time for container checking and management through the port by using active RFID e-seals (Collins, Korean seaports test RFID tracking, 2005c), the issues of congestion and security in the ports (Nguyen, 2006) or improving the security of containers destined for the USA, with more stringent security requirements (Clendenin, 2005). Their results show that smart RFID e-seal with its multifunctional ability can be effective for logistics purposes and applications in container supply chains/container ports.

4.3.2.1 Commercial and non-commercial benefits

IT and technological solutions supporting security improvements will potentially benefit not only security but also some quality factors. With investments in technological solutions such as electronic seals and Radio-frequency identification (RFID) control and supporting IT infrastructure, the control of shipment visibility during transit and container transhipment points can be facilitated and therefore the shipment tracing capability of shipping lines, container operators and freight forwarders/NVOCCs can also be enhanced (Thai, 2007).

We describe below the main areas of additional logistics applications of smart e-seals in global container logistics:

- Competitive advantages to connect container transhipment nodes into a global info-network

Key factors for a container terminal are the efficiency of the stacking and transportation of this large number of containers to and from the ship's side. Shipping companies ask for reliability regarding adherence to delivery dates and promised handling times (Tongzon & Heng, 2005). Thus, container terminals are forced to provide efficient and cost-effective services. They have to invest heavily to meet the stringent demands for faster service and higher quality. The competition between container terminals has increased due to large growth rates on major seaborne container routes. Terminals are faced with more and more containers to be handled in short time at low cost. Therefore, they are forced to enlarge handling capacities and strive to achieve gains in productivity. To secure the cargo containers more innovative companies use the smart e-seals, instead of simple mechanical seals.

How does it influence the container operator? Terminal operators in order to keep their positions on the market need to adapt to the new security requirements for container system. Investments in RFID reading infrastructure will bring the benefits by providing new kind of service for own innovative customers, who using e-seals. Such a service as RFID reading infrastructure will open the port gates for new companies looking for the partners that can provide higher level of security and visibility for their cargo flows. Investments in e-seal is a situation when no player can benefit by being the only one who changes his strategy. No player can better his position by opting out the impact of RFID seals in container system. No player can improve his position by adopting smart seals alone. The only way to move from the one equilibrium to another is to organize an agreement or consortium between the players to get some of them to adopt (Hadow, 2005).

- Automation of containers passes through the gates

E-seals can contain data about goods in container, ID number of container, shippers contact information, point of cargo destination etc. By passing port gates the RFID seal transmits container information to the local port network through the reading device fixed on the gate. In this case truck driver should not make any manual formalities to get access to the terminal. This procedure takes much less time, has higher degree of accuracy, and eliminates technical mistakes (human factor).

- Security and safety of containers along container transport chain

Security aspect is the strongest side of e-seals. Container terminals usually are not open territories. Nevertheless, the security of the most ports territory provides by the simplest methods of accident prevention. For a long time containers can stay without any supervision at a terminals that increase vulnerability of the container in total. E-seal can prevent un-authorized access or theft of the container contents and inform about such accident by alarm function. On the other hand, container door with any type of seal can be removed or container can be cut and open from the top, bottom and sides. It makes a huge loss for owners of high value cargo and for insurance companies as well. To avoid container intrusion, pilferage and thefts of containers or goods, it is necessary to combine electronic seal with different sensors (temperature, light, etc.).

- Control of access to the containers contents

E-seals possess a useful function to record the time of authorized access to the container contents or unauthorized access at the moment of e-seal breaking. Furthermore, the broken e-seal cannot be fabricated or changed on another one without any damages of electronic part of the seal. Hence, uniqueness of the e-seal ID number and alarm function of this device provides reliable security of goods and the real time control of access to the containers contents.

- Identification of containers and their locations in the logistic chain

Each ISO container has a unique ID number. Nonetheless, several identification numbers on the same container are the real case for many intermodal containers. In these cases terminal operators should identify which of the ID numbers is correct. Such type of information can be coded to the e-seal memory. Each time a container changes the hands or documents regarding the container are transferred, the potential for miscommunication and human mistakes exists. For instance, a trucker might bring a container to a port but do not communicate to the shipping company that he has arrived. It causes a container not to be loaded onto a ship. These kinds of problems cost money to the company awaiting the shipment. Electronic information, transmitted from e-seal to the local network of the terminal, can provide companies with authorized access with required data in real time about individual container location.

- Monitoring of containers movements

E-seals together with Real-Time Locating Systems (RTLS) allows not only control the container location, but also to monitor every moving of the container on the port territory. RTLS is indispensable to container operators because container yards and van pools are so vast and store so many containers that without the support of locating systems, workers cannot find a particular container in required time limit. This informative function of e-seal can be useful to the forwarding or agent companies to inform whether the container loaded or unloaded from the ship.

- Improving the congested situation in the container transhipment nodes

The combination of dramatic increases in freight traffic and transportation systems operating at or near capacity limit has only recently resulted in growing visibility of freight and its role in urban congestion and environmental problems as a symptom of greater supply chain congestion (Regan & Golob, 2000). The waiting time and variability of waiting time at ports can be significant. Delays are encountered entering the ports as well as inside the gates. Almost 44% of operators serving ports reported that their operations were often affected by congestion at the ports (Regan & Golob, 2000). By creating the Greenlane RFID e-seals can play an important role in paperless information exchange. Time savings in container processing through the container terminal will influence the improvement of situations with truck congestions at the port gates; that also will have a "green" impact on reducing of port-related truck emissions because of accelerating of truck-turn-over time at the terminals.

Another series of potential benefits belong to the logistics applications of e-seals for all businesses (Importers, Carriers, Manufacturers, and Service Providers). Regarding C-TPAT Survey 2007 (Diop, Hartman, & Rexrode, 2007) more than three-quarters (76.5%) of survey participants reported that it is extremely important to "reduce the time and cost of getting cargo released by U.S. Customs and Border Protection (CBP)". Next on the list of most important motivations for joining security programs are "to reduce the time in CBP secondary cargo inspection lines" and to "improve the predictability in moving goods and services across borders".

- Benefits for private sector from security enhancement – GreenLane

Membership in "GreenLane" Programm for U.S. firms operating in the supply chain is becoming the norm rather than the exception (Silverman & Seely, 2007), especially among service providers who have found it to be a relatively low cost and effective marketing tool. C-TPAT membership has certain benefits: several time less likely to be targeted for physical inspections, resulting in considerable savings in time and money as CBP increases the number of exams overall; priority for cargo inspection; reduce the handling costs by removing to their own location all containers not selected for inspection before CBP has completed its inspection of the entire shipment (Silverman & Seely, 2007). At present, the customs service physically inspects only 2 percent to 4 percent of containers arriving at U.S. seaports (Jackson, 2003). The smart-seal program can boost the number of the right inspected containers. Simultaneously, by using smart e-seals or smart boxes the shippers will get the most attractive benefit – the "GreenLane" advantage – to accelerate their cargo clearance and expedite processing through the port. More than half of C-TPAT Survey participants in 2007 indicated that benefits from enhanced security outweighed the costs (32.6%) or the benefits and the costs were is about the same (24.2) (Diop, Hartman & Rexrode, 2007).

- Smooth border crossing and gate processing

The enhanced security system could influence as well in another manner the container flows going through the port gates or borders of the countries: a U.S. Department of Transportation program "TransCore" shows that electronic seals could help secure containers and reduce border congestion (RFID Journal, 2002). At the Port of Seattle a reader at the port's gate indicates that the truck has entered/left the port. The truck is tracked at six weight stations and processing centres along a 300-mile stretch of Interstate 5. When the truck arrives at the Blaine border crossing, the e-seal is read with a handheld reader or a roadside reader. Information on the carrier, vehicle, cargo, location and time of detection, drivers, and security status is uploaded to a secure Web site. The shipper and carrier, as well as U.S. Customs Service agents and the U.S. Department of Agriculture agents can view the information on a secure Web site. The system requirements to be the most effective is existence of special lanes for trucks with sealed containers; otherwise, it do not help to reduce congestion at the port terminals or smooth the border crossing (RFID Journal, 2002).

- Improve process flows in global container networks

The improvement of process flows in container networks means that the flow of materials and the flow of information are synchronized when the information system continually displays the current status and stream of goods. The information system is thereby not just more accurate but is also up to date. E-Seals, which are unaffected by weather, can improve the process flow for containers at the gates (improvement of the operations at port gates by e.g. remote readability of a container number) as well as refine on the matching of the container to the manifest; or avoid typically errors made during issuing and receiving of goods, such as incorrectly logged quantities.

- Protect the brand name and the reputation

Looking for rewards from security programs, the huge companies like Procter & Gamble, Boeing, Starbucks, and Kmart with high-value products emphasize that they need to secure the cargo in order to “protect the brand” (Downey, 2010). Electronic seals with their track-and-trace ability not only ensure the container supply chain, but also gain supply chain efficiency from automatically tracking containers. Damage to intangible assets and the contingent losses which could arise in cases where e-seals are not used are even greater, e.g. damage to reputation (contaminated goods or non-delivery of goods). In some case the pilferage from the container or theft may lead to the loss of sensitive information or intellectual properties, therefore the container flows have to be under protection of secure environment attached to the particular container in the form of smart devices.

- Anti-temper system for container flows

One of the main applications of RFID technologies in the context of shipping containers is their use as e-seals. In the most cases they are active tags which provide efficient and instant notification of container security breaches. An identification number of an e-seal is protected by electronic encryption and authentication. Electronic seals have to work in harsh environments often under severe conditions. Active tags contain batteries, have more processing and operating power and hence appear be the most promising in container logistics. Such devices provide a 100% check to ensure the e-seals are not tampered with/replaced and could detect when/where container tampering occurred (this information can be useful for insurers, the police as well as for bankers). Smart seals integrate in itself useful information other than the seal number e.g. container number, destination and consignee. The shippers get automate monitoring and tracking of containers as well as higher processing level for their shipments through the customs via eliminating of human errors in reading or visual inspection or recording the seals on the containers and more effective customs work.

- Minimizing of container loss, tampering/theft or cargo pilferage

The risk of theft, especially if the goods have a black market value, is very real. Worldwide, the direct cost of cargo theft is estimated at about US$50 billion per year, with indirect costs many times higher, and US$15 billion of merchandize losses in the United States alone. Cargo theft occurs in freight-forwarding yards, warehouses and during transportation in trucks and on ships. Cargo is particularly vulnerable while in the process of being loaded or unloaded from trucks, or through documentary fraud (Mayhew, 2001). To ensure the process of container operations on its different stages the cargo owner or their service providers, either the carrier and port operators should provide the reliable protection of each container during its transportation. The e-seal is a right key to solve this problem. It combines mechanical mechanism to lock the container with specific electronic components. Therefore, it can provide tamper evidence, physical security and data management as well as indicate electronically whether a conveyance has been opened or tampered with.

- Loss of insurance claims

Theft or pilferage of goods from container leads to insurance claims. If the seal is checked at multiple points as the container moves through the supply chain, it will help the carrier, the shipper and the insurer to determine the weak link in the chain. But if the container seal have not been checked at different stages as the container moves through the supply chain, they will not be able to pin down the location where the pilferage is occurred, and law-enforcement agencies will not be able to deploy their resources effectively (Armbruster, 2006). Identifying the location of the breakdown by using of smart e-seals will help determine which party is responsible for the loss and thus to settle insurance claims to them.
Thereby, the range of presented e-seals advantages for container logistics describe the most attractive and useful functions for largest container logistics providers such as port operators, shipping companies, forwarders etc. Nevertheless, there are still some challenges in worldwide adoption of e-seals system. The first discussion point is what kind of technology should be used as a worldwide standard of e-seals. This discussion has a substantial importance for the next issues: what kind of infrastructure need to be installed and what kind of functionality one could obtain from the device (World Shipping Council, 2006). The infrastructure for e-seals does not

presently exist and need to be installed on thousands of different properties. Another actual issue for e-seals global implementation is international ISO standards for the devices. It is still an open question what the product needs to do; what specific events must be captured and recorded; is capturing entry through the doors enough or must it detect entry into the container through the walls, ceiling or floor; does the device have to detect conditions other than entry intrusion? Thus, the governments and industry have to achieve equilibrium from security requirements and all businesses benefits, before to set all these specifications for e-seals or container security devices.

4.3.2.2 Security improvements through supply chain

The main purpose of security control and management is to drive out the variability of pick-up, transit and delivery time, therefore increasing the reliability of service (Wolfe, 2002). Security improvements can also help maritime transport service providers in having better shipment loss and damage control; in other words, shipment safety and security. The impact between security improvements and shipment safety and security is the most direct and comprehensible. The importance of security improvements in this respect has been long acknowledged as a contributing factor to increase profits for organizations. In maritime transport, in addition, cargo loss and damage records have always been considered an indicator of service quality (Thai, 2007).

For example, at Kaohsiung Harbour, one of the 10 largest ports in the world, more than 1 million transit containers are imported and exported annually. To prevent smuggling, Taiwan Customs officers are required to escort some 50,000 unloaded containers each year from the carrier yard, through downtown, to one of the port's five container terminals (Friedlos, 2009). The escorts result in increased expenses for Customs, due to the need for additional employees, and for carrier companies, which must pay an escort fee. In addition, the long inspection times can cause an inconvenience. In 2004, the Taiwanese Government sought to replace manual escorts with an automated system to improve security and efficiency, as well as cut costs by reducing manned escorts. Some 40 Speedway readers were then installed at checkpoints along 20 lanes used for transporting containers. Customs has also purchased 40,000 e-seals, as well as handheld interrogators. When a transit container is chosen for e-sealing, a notification is sent to the carrier, and an e-seal is used to lock the container at the carrier's yard. A handheld reader is utilized to interrogate the RFID chip's ID number, which is transferred to a secure database, and the information is synchronized with the driver's ID, as well as those of the container and truck, which are printed on the vehicle and container. The system has an accuracy rate of 97.42 percent at a distance of more than 7 meters. It should result in an annual reduction of 6,000 man-hours for escorts, through the elimination of 10,000 escorts by Customs officers.

4.3.2.3 Economic effects from investing in e-seals

Heightened container security requirements, especially for import operations, influence the container custom inspection process in ports. Extensive inspections become a bottleneck for container supply chains that slow down and decrease operational performance. Tightened security control traditionally means increasing the inspection rate for container content rather than enhancing the effectiveness of it (Lee & Wolfe, 2003). The effect of increased random sampling checks of containers leads to extended dwell time of containers in a port through the increasing number of containers waiting for inspection and additional logistic costs.

The greatest part of world container volume is repetitive: the same shippers make the same shipments for the same consignees with a large number of containers. These routine container flows are quite easy to “secure” and can be placed under less precise customs scrutiny (Christ, Crass & Miyake, 2005). Participation in the C-TPAT program and third-tier status will give companies an opportunity to avoid the additional expenses on containers waiting for inspection, to save costs of manual customs inspections itself and to accelerate the container turnover through the whole supply chain. Electronic seals, as a necessary part of “green lane” advantage, lead to additional investments in “secure” container logistic processes.

We present the evaluation of cost-benefit influence of three different e-seals on efficiency of container supply chain by using the “green lane” opportunity. Cost-Benefit Analysis (CBA) allows us to weigh the expected investments against the expected benefits of one or more alternatives to choose the best or most profitable option.

To estimate additional logistic expenses caused by investments in electronic seals we compare three types of electronic seals:

1. <u>“Container Security Device” (CSD)</u>, containing seal ID number, container ID number, additional sensors to indicate environmental status of container content, alarm function to inform in real-time and satellite communication via GPS/INMARSAT systems. With the ability to provide real-time global visibility for container supply chain, CSD has the highest level of costs for its use. We assume that one CSD costs 4,000 € (Wolfe, 2002) and the possible rent price is equal to 10% from the original amount, i.e. 400 € per container per trip. We assume additional operating costs for container sealing (2.5 € per trip) and costs for information transaction (3 € per trip), when the minimum number of transactions is equal to 6 transactions per trip.
2. <u>Reusable or permanent active RFID e-seal</u> also includes a seal ID number, a container ID number; can initiate alarm calls and record time/date of container tampering. The current problem of RFID seals is that, for its implementation, they need worldwide RFID reading infrastructure. The question of who will invest to build a global RFID net is still under discussion among

many parties involved in container logistics. We assume that one permanent e-seal costs 500 € and the possible rent price is equal to 10% from the original price, i.e. 50 € per trip. We assume both additional operation costs for container sealing (1 € per trip) and costs for information transaction (3 € per trip). The minimum number of transactions is equal to 6 transactions per trip.

3. Read-only, non-reusable e-seal defined in ISO 18185. This type of electronic seals contains only a seal ID number and is attractively priced in comparison to the two previous e-seals. The most common technology for such e-seal is passive RFID, which requires an appropriate reading device and software. We assume that one-used e-seal costs 5 € per trip. We assume as well that operating costs for container sealing is 5 € per trip and costs for information transaction is 3 € per trip, the minimum number of transactions is equal to 6 transactions per trip.

We assume that necessary global reading infrastructure already exists for RFID transponders or will be a part of investments from the government. The RFID reading infrastructure is the most extensive share of all investments in e-seals and the issue of its responsibility is still open. The annual repair costs for e-seals are assumed as 5% from the original price of e-seals.

We assume that 1,000 containers move through the ports and each container makes 10 trips per year.

We consider two scenarios for containers shipping through the ports (Daschkovska & Scholz-Reiter, 2007):

1. **Scenario without e-seals.** When containers enter the port of loading A, as it shown in Fig. 12, two alternatives of physical container flows exist: the container goes directly to the waiting area to be loaded on the ship, or it is moved to the customs checking territory to be manually inspected by customs. The latter alternative brings additional operating cost for container logistics as well as extends container dwell time at the port, which in turn creates additional expenses. We assume that the volume of such expenses is equal to 1% of lost sales. We assume inspection costs to be 200 € per container. The realistic rate of customs inspections is 2% of total number of containers. We assume as well that inspections cause additional storage costs for a container at a port. It is assumed that storage costs 10 € per day. The number of storage days due to inspection control is 7 days in the port of loading and in the port of discharge. Following inspection a container at port A will be loaded on a ship and directed to a port of discharge B. We consider 3 possible variants of physical inspections: first, a container is checked once at the port of loading; second, a container is inspected once at the port of discharge, and; third, a container is checked once at the port of loading and once at the port of discharge. Customs

inspections are random checks, so no shipper can be fully confident that his containers will not be opened to scrutiny.

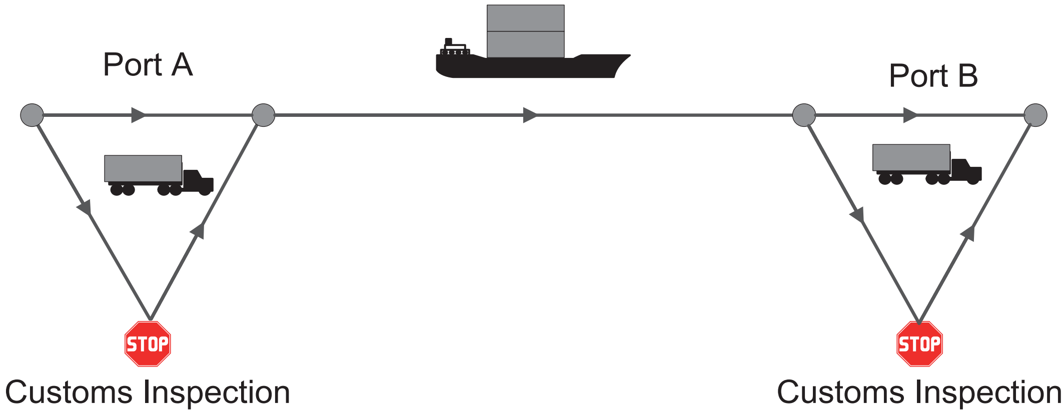

Fig. 12 1st Scenario for container processing through the ports under customs inspections

2. **Scenario with e-seals.** The second scenario describes the perspective of using "green lane" advantage for "secure" containers equipped with e-seals. A container moves from port A to port B without any stops for physical inspection, (Fig. 13). We assume that it brings one benefit for shippers like the possibility to increase container turnover at least by 1%.We consider that customs checks randomly 2% of total number of shipped containers in the first year following implementation of e-seals and in the second year is only 0.5% of all containers; since third year the "greenlane" advantage is fully available to use for "secure" containers.

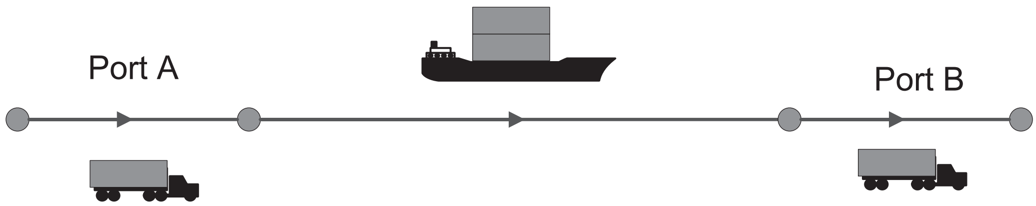

Fig. 13 2nd Scenario for container processing through the ports without customs inspections

The authors look only at the change in logistic expenses from the point of view of customs inspections and investments in electronic seals. Thus the assumption is that all other logistics overheads for container transportation through the ports do not change. Consequently, we can first calculate the customs costs in the cases when the inspection takes place at one or at two ports for the same container and storage expenses for inspected container. To calculate investments in e-seals we distinguish two variants of e-seal use: renting or buying them. The project time period is 5 years. We assume an increase in container turnover by 1% after the implementation of e-seals in container logistic process as one of others possible benefits. Its monetary effect is assumed as 1% annual growing in sales of carrying by container merchandise (estimated value of 1 container is equal 5,000 € per container). Our investigation distinguishes investment projects when CSD or reusable e-seal are rented by shipper for each container trip each year (I and II projects) and considers the situation where e-seals are purchased once (III-V projects) for whole project period:

I. "Rent CSD"
II. "Rent reusable e-seal"
III. "Buy CSD"
IV. "Buy disposable e-seal"
V. "Buy reusable e-seal"

Table 2 presents the initial data for the investment projects.

Initial Data	Abbr.	Container Security Device (CSD)	Disposable E-seal	Reusable E-Seal
E-seal Investment, €/unit	Sb	4 000,00 €	5,00 €	500,00 €
Rent E-seal Investment, €/unit	Sr	400,00 €	- €	50,00 €
Infrastructure Investment	Si	- €	- €	- €
Number of Ports	n	2	2	2
Sealing costs per container closing/opening, €/trip/cont.	Ss	2,50 €	3,00 €	1,00 €
Transaction Costs, €/transaction	Str	3,00 €	3,00 €	3,00 €
Min Number of Transactions per trip	ntr	6	6	6
Number of Containers	Ncont	1000	1000	1000
Number of Trips of 1 container per year	Ntrip	10	10	10
Inspection Costs, €/cont.	Sinsp	200,00 €	200,00 €	200,00 €
Percent of inspected containers per year	p	2	2	2
Percent of inspected containers per year after implementation e-seals	p'	0,5	0,5	0,5
Number of Containers Inspected with 2%, cont.	Ncont-insp	200	200	200
Number of Containers Inspected with 0.5%, cont.	Ncont-insp'	50	50	50
Storage Costs at a Port, €/day	Sstor	10,00 €	10,00 €	10,00 €
Number of Storage Days via Inspection in Loading port	Nd-i	7	7	7
Value of 1 Container, €/cont	Vcont	5 000,00 €	5 000,00 €	5 000,00 €
Project Time Period, years	t	5	5	5
Percent of Salvage Value, %	a	50	-	50
Repair Costs, %/ €/unit	krep	1	1	1
Interest Rate, %	r	10	10	10
Value of increased sales after 1 year, %	Vs	1	1	1

Table 2 Initial Data (authors estimations and personal communications)

Preliminary evaluation of the projects costs require to evaluate the investments volumes (IC) and further expenses (such as Transaction costs R_1, Sealing costs R_2, Repair costs R_3, Customs costs R_4, Storage costs R_5,) that follow the projects through the evaluation period.

The investment has been evaluated for two cases: if e-seals have been rent for the whole project period (IC_{rent}) and if they have been bought (IC_{buy}) at once.

$$IC_{rent} = S_r * N_{cont.} * N_{trip} * t \quad (1)$$

$$IC_{buy} = S_{b.} * N_{cont.} \quad (2)$$

The operation expenses we evaluate by the following way:

$$R_1 = S_{tr.} * N_{cont.} * N_{trip} * n_{tr.} \quad (3)$$

$$R_2 = S_{s.} * N_{cont.} * N_{trip} \quad (4)$$

$$R_3 = \frac{(S_{b.} * N_{cont.} * k)}{100} \quad (5)$$

$$R_4 = S_{insp.} * N_{cont.-insp.} \quad (6)$$

$$R_5 = S_{stor.} * N_{d.-i.} * N_{cont.-insp.} \quad (7)$$

$$R_4{}' = S_{insp.} * N_{cont.-insp.}{}' \quad (8)$$

$$R_5{}' = S_{stor.} * N_{d.-i.} * N_{cont.-insp.}{}' \quad (9)$$

The salvage value is used in conjunction with the purchase price and accounting method to determine the amount by which an asset depreciates each period. We estimate a salvage value of electronic equipment for containers within a useful life of five years (equation 10) and then the depreciation with a straight-line basis (equation 11).

$$SV = S_{b.} * a \quad (10)$$

$$D = \frac{(S_{b.} - SV) * N_{cont.}}{t} \quad (11)$$

$$I = \frac{V_{s.} * V_{cont.} * N_{cont.} * N_{trip}}{100} - D \tag{12}$$

The investment benefit for each project might be found from the equation 12.

To obtain the Cash Flows (CF) value for each project we have used following equations for the first year (13), for the second year (14) and for the following years (15):

$$CF_1 = I - R_1 - R_2 - R_3 - R_4 - R_5 \tag{13}$$

$$CF_2 = I - R_1 - R_2 - R_3 - R_4{}' - R_5{}' \tag{14}$$

$$CF_3 = CF_4 = CF_5 = I - R_1 - R_2 - R_3 \tag{15}$$

The Table 3 demonstrates the obtained cash flow values for the evaluated projects in 5 year period.

Projects	Cash Flows, CF (10^6 €)					IC
	1 Year	2 Year	3 Year	4 Year	5 Year	
I "Rent CSD"	-0.139 €	-0.114 €	-0.105 €	-0.105 €	-0.105 €	20 €
II "Rent reusable e-seals"	0.226 €	0.252 €	0.260 €	0.260 €	0.260 €	2.5 €
III "Buy CSD"	-0.179 €	-0.154 €	-0.145 €	-0.145 €	-0.145 €	4 €
IV "Buy disposable e-seals"	0.256 €	0.281 €	0.290 €	0.290 €	0.290 €	0.25 €
V "Buy reusable e-seals"	0.221 €	0.247 €	0.255 €	0.255 €	0.255 €	0.5 €

Table 3 Cash Flows

The cost-benefit calculations of e-seals investments involve, at first, using time value formulas for Present Value (PV) and Net Present Value (NPV) calculations as well as Profitability Index (PI); and secondly, formulas based on record appraisals like Payback Period (PP). It is required to analyse every potential investment project to consider the rent prices on e-seals, costs to buy each type of e-seal and additional operational expenses that occur within their use. We computed the values of PV, NPV, PI and PP for each project of potential investment by using Excel.

The analysis of the obtained results (Table 4) noted that variants IV and V are acceptable for realization over a reasonable 5-year project period. Project IV is the most profitable. It has the greatest NPV value and the highest ARR percent. The payback period is also the lowest for project IV. At the same time, reusable e-seals have a lower NPV and PP than project IV for the variant when a shipper buys the seals (Project V). It shows that this project is also acceptable for the future investment. Furthermore, considering that the NPV of single-use seals is not much larger than that of reusable e-seals, these two variants of investment should be analysed as alternative projects taking into account investments in reading infrastructure, development of device prices in the future, and the benefits for potential e-seal users.

Projects	IC, (10^6 €)	PV, (10^6 €)	NPV	PP, years	PI	ARR, %
I "Rent CSD"	20 €	-0.44 €	-20.44 €	-176,2	-0,022	0,91%
II "Rent reusable e-seals"	2.5 €	0.95 €	-1.55 €	9,9	0,093	32,73%
III "Buy CSD"	4 €	-0.59 €	-4.59 €	-26,1	-0,192	3,33%
IV "Buy disposable e-seals"	0.25 €	1.06 €	0.81 €	0,9	5,629	400,00%
V "Buy reusable e-seals"	0.5 €	0.93 €	0.43 €	2,0	2,465	120,00%

Table 4 Results of the investment values for different types of e-seals

Projects I and III have all negative parameters as seen from the Table 4. So we can conclude that, with current prices of CSD, to buy and exploit them the shipper has to get more monetary benefits. These benefits should be included in the investment analysis to get more realistic results.

Thus, it was analysed two scenarios for container shipping through the ports. The scenario without e-seals presents the current inspection costs for containers. For the scenario with e-seals we have analysed how effective investments in container “security” by means of e-seals will be. The direct impact of “secure” container trade comes from avoiding customs inspections. Already this advantage can bring monetary benefits for shippers in less than one year. Considering the obtained results the paper shows the positive tendency in influence of investing in security devices on efficiency of container business.

4.4 Summary

Firstly we discussed the background and motivation for intensive development of electronic seals since last 20 years. We have discussed the security initiatives post 9/11 that stimulate the appearance of different types of electronic container device on the market.

Then we have considered different types of container seals. The traditional mechanical seals contain only information about unique container number, however they do not provide any data as where, when, under what conditions or by whom the seal was broken. Electronic seal is an electronic device to check the legitimacy and integrity of freight containers.

In this chapter we also have analysed four different technologies that are used for electronic seals. As showed the analyses RFID e-seals can extremely improve the processes of container transportation. The most promising e-seals for logistics applications are active RFID seals. Such electronic seals can electronically provide a user with the data about seal ID number, security status of device, information about users, alarms, seal & container location, date & time, battery status, container ID number about and different environment conditions inside container. E-seals operate various communication protocols to transmit data to reader. Reader infrastructure for particular e-seals is major component in order to obtain and transmit the data from e-seal. During the communication process e-seals from different producers use diverse communication frequencies. We have explained how and what kind of different logistic information about goods in container, ID number of container, shippers contact information, point of cargo destination, electronic cargo manifest, can be stored on the electronic chip in e-seal. The data can be approached by authorized users by means of reading devices for e-seal.

Therefore, the usage of the electronic cargo information in container e-seal can improve the container logistics processes by speed up the container passes thought the container transhipment nodes (port terminals), prevention and control of unauthorized access or theft of the container contains, provide the information for the companies and authorities about container location as well as getting automate monitoring and tracking of the containers, avoid typically errors during issuing or receiving of goods. Some of this data we will apply in the model to investigate dynamical properties of a container transportation system, when containers are equipped with electronic container seals.

We have completed simple cost benefit analyses to calculate the investments in different types of e-seals under only one condition, that container equipped with e-seal can avoid customs controls. The obtained results show that the shippers will obtain less than in one year the first advantages. Nevertheless, this result is possible just for the case, when smart e-seal will be used for container transported expensive goods.

5 Modelling and simulation of container logistics networks

In this chapter we analyse a container transportation network from two perspectives: theoretic-analytical and by means of simulation. We begin with the application of the queuing theory as a suitable mathematical tool to describe the dynamics in a network with stochastic events. It will be seen that this approach works efficiently for networks of small size only. As the complexity grows, an analytic solution is hardly possible, i.e., this approach is not effective in case of networks with large number of nodes. Therefore, discrete-event simulation in MATLAB has been chosen to investigate the dynamics of container flows in a larger realistic network.

5.1 Modelling and simulation of complex systems

Most complex, real-world systems with stochastic elements cannot be accurately described by a mathematical model which can be evaluated analytically. A possible way how to study complex systems was described by Law and Kelton (Averill & Kelton, 1999) (Fig.19).

Thus, in many cases a simulation is the only possible approach to investigate dynamics and relevant logistics characteristics in large scale networks. Simulation can be used to check the validity of assumptions or to predict certain properties in a particular model. We would like to mention that analytic and simulation approach are complementary to each other, each of them possesses its own advantages and drawbacks. In both cases the notion of system (Graybeal & Pooch, 1980) is central in modelling and investigation of the desired properties. A system can be defined more broadly than a collection of physical objects and their interactions.

In our case, we consider two systems with different sizes: a container port terminal is considered to be a smaller system consisting of operations and interactions as the collection of objects. The second one is a system with large number of nodes, which models a global transhipment network. We begin with a brief introduction to queuing theory.

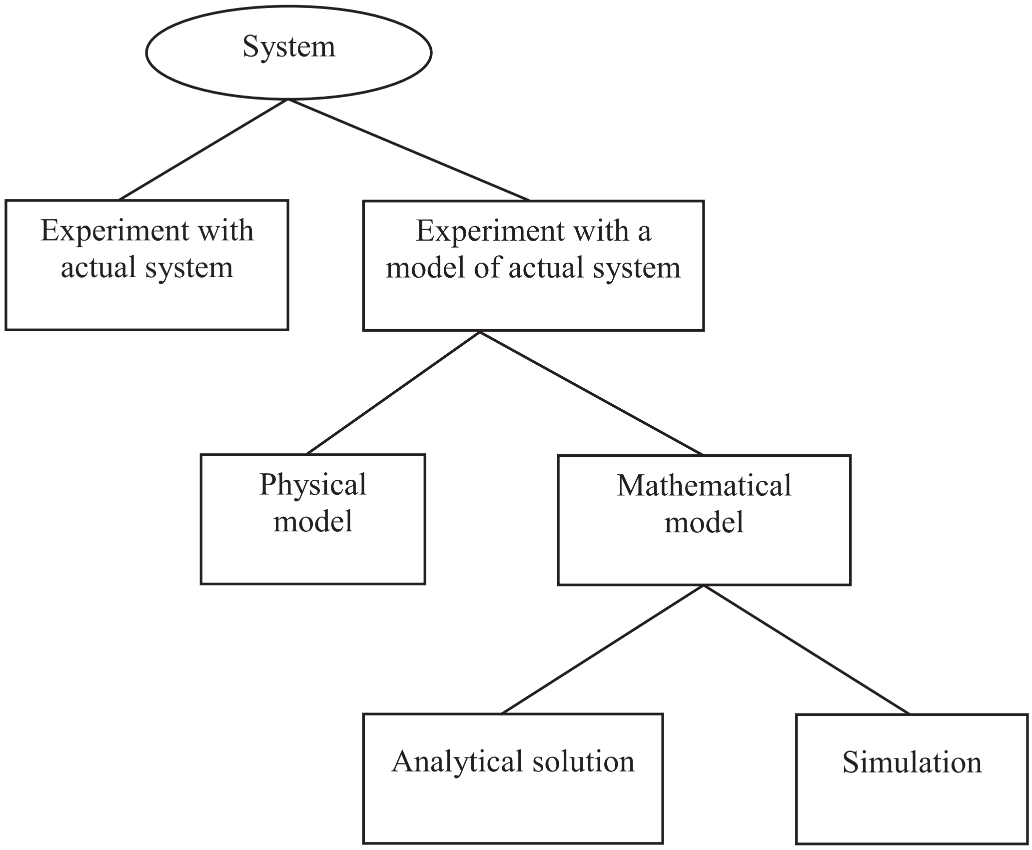

Fig. 14 Ways to study a complex system (Averill & Kelton, 1999)

5.2 Analytical approach based on Queuing theory

Queuing theory is concerned with the phenomenon of queues and its dynamics independently on its origin. A queue can be, e.g., the waiting line of ships at the sea ports or of container trucks to the gates entering a port. Other examples are queues of information messages inside a computer system; queues of industrial machines waiting for being repaired or queues of parts waiting to be processes at a machine. The objects waiting for a service are called customers. A queuing system is a system designed to serve customers demands arriving at random moments of time. It can be represented as a dynamic system or "system of flows" (Kleinrock, 1975). A facility that serves the customers' demands is called server (channel). A flow system is one in which some commodity flows, moves, or is transferred through one or more finite-capacity channels in order to go from one point to another. The moments of time at which customers arrive in a queuing system and the lengths of time that these customers occupy the servers are modelled by stochastic processes with given distributions. The purpose of the queuing theory is to describe the stochastic behaviour of the lengths of the queues and to provide tools to control and / or optimize the length the queues.

Historically, the specific probabilistic problems that led to the development of queueing theory emerged in connection with the operation of telephone systems.

The pioneers of queuing theory are the Danish mathematician Erlang (1917) and the Swedish mathematician Palm (1943) (Willie, 2004). Later on, it was discovered that similar problems arise in trade, in product equipment management, in scheduling of events and processes, in calculation of the traffic capacities of highways, bridges, tolls, canal locks, berths at seaports, etc.

Queuing theory is a branch of applied probability theory that is known as well as traffic theory, the theory of mass service, theory of stochastic service systems, and congestion theory.

5.2.1 Basic Notions and Notation

Most queuing systems can be defined in terms of the following characteristics:

- input process
- service mechanism
- queue discipline
- topology of the service network

The input process is a process of arrivals of customers, i.e., it is a sequence of times at which demands for service occur. These are random time instants that can be described in terms of distribution functions of the lengths of time between consecutive customer arrival instants.

The service mechanism includes characteristics such as the number of servers and the lengths of time that the customers occupy the servers. These are service times that are random with given distribution functions. In case of several types of customers and different types of servers, each kind of customer possesses its own random service time at each type of servers.

In case different kinds of customers are waiting in a queue at one server, certain rules can be prescribed for the order of serving these customers. These rules are called disciplines. A queue discipline manages the order of servers' occupation by the customers belonging to different types at the moment of their arrival or at the moment of service completion of a customer arrived before. For example, it can be assumed that arriving customer leaves the system immediately, if all servers are busy, or waits for a service in a queue and is served from the queue in his arrival order FIFO (First In First Out).

The topology of a queuing system determines the rule of customer's transition from one node of queuing network to another after being processed. Every node is a queuing system with its own service mechanism and queue discipline. The real prototype of such a queuing network is the data communication or container transportation nets.

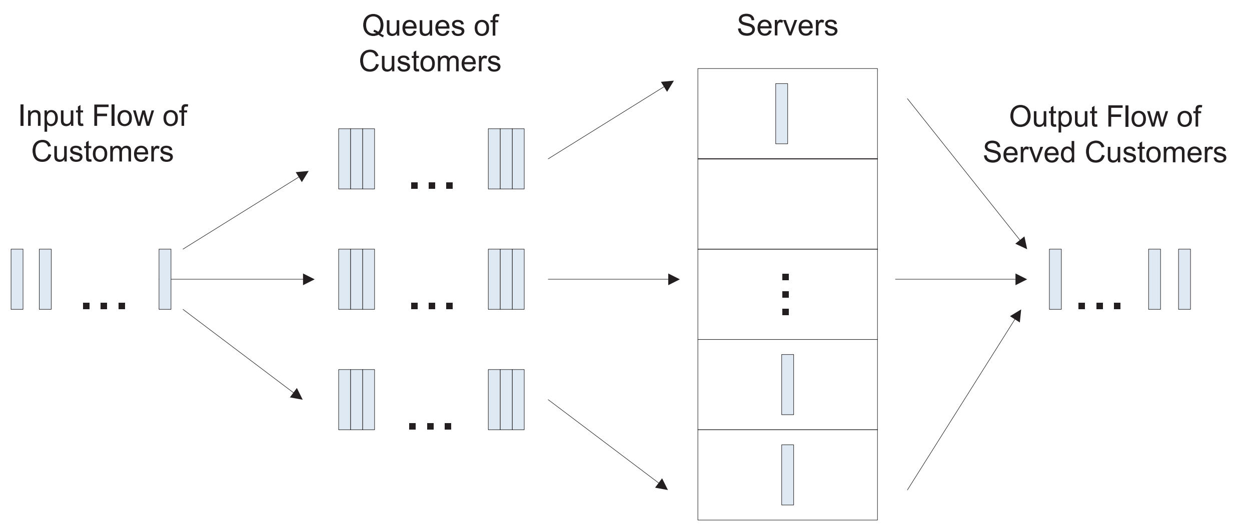

Fig. 15 Structural scheme of a queuing system

The aim and the scope of the queuing theory is to establish relationships between the random flow of customers, the capacity of the given channel, the number of channels, the service disciplines, and the efficiency of service performance.

All queuing systems can be divided in two large subsets: single-server (one channel) and multi-server (multi-channel) systems. There is a difference between congestion system (system with refusal) and delay queuing systems. A customer arriving at a congestion system, when all servers are busy, is refused service and departs without taking part in any further proceedings. In a delay queuing system, a customer arriving when all servers are busy does not leave the system but waits for free server. The number of places in the queue can be limited or unlimited. If the number of places is zero, a delay system turns into a congestion system. A queue may be bounded both in terms of the number of customers in it (the size of queue length or volume of waiting room) and in terms of the queuing time ("system with impatient customers"). Delay systems are also subdivided in terms of queue discipline, i.e. customers may be served either in order of arrivals in a random fashion, or some customers may be able to get the service before others (a priority discipline). A priority service may have several ranks of pronto (e.g. service without waiting).

The problems queuing theory deals with include calculation of probabilities of various states, i.e., queue lengths of the queuing system and establishing relationships between the parameters (the number of servers, the intensity of the input flow of customers, the distribution of the service time, etc.) and indices of service performance. The most important are the following indices:

- mean queue length
- mean waiting time
- mean time-in-system
- mean number of idle time of servers
- probability of refusal, i.e. the probability that an arriving customer will not be served
- intensity of served customers' flow

All mentioned indices are time dependent. However, in many practically important cases it can be assumed that the real queuing system operates under the same conditions for a long period of time and, therefore, its operation can be considered to be in steady-state (stationary), which is simpler to analyse. By means of the information about these indices one can formulate and solve several optimization problems concerning finding the optimal values of processing rates of servers, optimal number of servers, optimal configuration of system, optimal priorities, etc.

Modern probability theory of queues owes a great deal to the two fundamental papers by Kendall (Kendall, 1953; Kendall, 1951). In these works Kendall introduced the notation *GI/G/n* for the *n*-channel system, where *GI* (general input) indicates that the inter-arrival times have an arbitrary distribution, *G* that the service times have an arbitrary (general) distribution, and *n* indicates that the system has *n* servers. The simple queue is denoted by *M/M/n,* where *M* denotes the Markov (absence of memory) property of the arrival process and of the service times. Such queuing systems are called elementary queuing systems.

If all the flows of events are stationary Poisson flows, then the process in a queuing system is called Markov random process with discrete states and continuous time. In this case, the analysis of a queuing system can be carried out in a rather simple way.

Currently, the stationary distribution of waiting time and queue length is found in the closed analytical form only for the systems *M/G/1, GI/M/n* and some of their generalizations. The exact solutions in relatively simple or observable form for *M/G/n* and *GI/G/n* queues are known.

Nowadays, queuing theory includes a large number of different types of mathematical models and theoretical tools for their analytic, asymptotic, and numerical investigation. Queuing theory has a number of applications in modelling of logistics systems; in particular it is very convenient and flexible to describe the material and/or information flows in transportation systems.

Along this line, in the next sub-chapter we consider a model based on queuing theory for a small size transportation system with container flows through the port terminal. We consider 3 cases of container processing through the port gates; in this approach we consider as well the differences in dynamics of flows for containers equipped with electronic seals and the container flow without smart devices.

5.2.2 Two-phase queuing system without e-seals

In the first case, we have one gate with a flow of trucks with containers which are sealed with mechanical seals (Fig. 16).

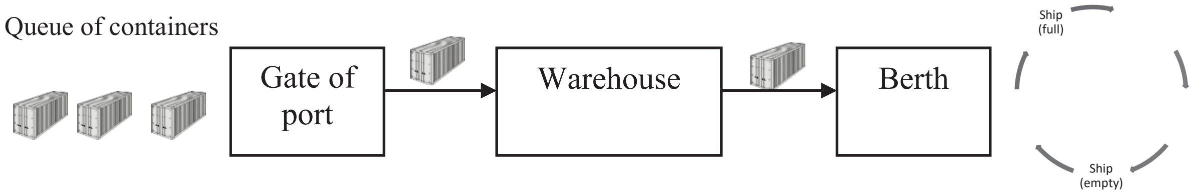

Fig. 16 Structure of 2-phase queuing system in a port "gate-warehouse-ship" for containers without e-seals

In this model we assume that:

- The flow of containers entering a port gate and then going to customs clearance warehouse is a Poisson distribution process with parameter λ;
- The cargo quantity in each container is random quantity with a distribution function $G(x)$, where capacity of all container are mutually independent random numbers with the same distribution function $G(x)$;
- The time for gate processing is a random quantity with the distribution function $1 - e^{-\alpha t}$, where time for gate processing of all containers are mutually independent and identically distributed random numbers;
- After check-up process at the gate, a container proceeds to a warehouse and then will be loaded on a ship (we consider that warehouse capacity is sufficiently large, in other words we neglect a container ability to wait for free place in a warehouse);
- A container is loaded from a warehouse to a ship with an intensity W (if a warehouse is not empty) if there is a ship on a berth;
- If a warehouse is empty, a loading process of a ship is interrupted until new cargo arrives at the warehouse;
- The cargo quantity to be loaded from a warehouse on a ship is a random number denoted by $B(x)$;
- The total time of a trip of a ship to unloading in a destination port is a random quantity with a distribution function $A(t)$.

The considered system (Fig. 16) is 2-phase queuing system, where the first phase is "gate processing" (single channel system) and the second phase is "berth for ship loading" (as well single channel system). The particularity of the mentioned queuing system is that the operations on the second phase can be interrupted for the random time if a ship is absent at the point of loading.

The current state of the system at time t can be described by random vector

$\vec{G}(t) = (\gamma_1(t), \xi(t), \gamma(t))$

where $\gamma_1(t)$ is the number of containers in a queue at a gate in time moment *t*;

$\gamma(t)$ is the number of ships at a berth at time moment t, i.e. $\gamma(t) = 0$ or 1;

$\xi(t)$ is the number of cargo at a warehouse at time moment *t*.

The process $\vec{G}(t)$ is not Markov. It becomes Markov if:

$$A(t) = 1 - e^{-\alpha t}$$

$$B(x) = 1 - e^{-xb} \tag{16}$$

We assume that the above conditions hold true and introduce the following notation:

$$F_{k,i}(x,t) = P\{\gamma_1(t) = k, \gamma(t) = i, \xi(t) \leq x\}, \qquad k = 0,1,2 \dots; i = 0,1; x \geq 0$$

For practical applications, the most interesting quantity is the limit distribution of probabilities:

$$F_{k,i}(x,t) = \lim_{t\to\infty} F_{k,i}(x,t)$$

i.e., the steady-state distribution, which will hold after a transition time period.

To calculate the function $F_{k,i}(x,t)$ by standard methods, we introduce the following system of integral-differential equations:

$$0 = -(\lambda + \alpha + \mu u(k))F_{k,0}(x) + \lambda F_{k-1,0}(x)u(k) + b(x)F_{k,1}(x) + \mu \int_0^x F_{k+1,0}(x-y)dG(y) \tag{17}$$

$$-WF'_{k,1} = -(\lambda + \mu u(k) + b(x))F_{k,1}(x) + \lambda F_{k-1,1}(x)u(k) + \alpha(x)F_{k,0}(x) + \mu \int_0^x F_{k+1,1}(x-y)dG(y) \tag{18}$$

$k = 0,1,2 \dots; x \geq 0$

where $u(k) = 1$, if $k > 0$, $u(0) = 0$; $b(x) = b_{min}(0,x)$

From equations (17) with x=0 we obtain

$$F_{k,0}(0) = 0, k = 0,1,2 \ldots \tag{19}$$

Similarly from equation (18) with x = 0 we find

$$WF'_{k,1}(o) = (\lambda + \mu)F_{k,1}(0) + \lambda F_{k-1,1}(0)u(k) \tag{20}$$

$\frac{1}{b}$ is the mean time for ship loading under condition that there are sufficient quantity of the cargo at the warehouse.

The system of equations (17) and (18) can be solved by the method of method of generative functions and Laplace transformation. We introduce derivative of functions

$$P_i(z,x) = \sum_{k=0}^{\infty} z^k F_{k,i}(x), i = 0,1;\ |z| \leq 1$$

and transform them by means of the system (17) and (18):

$$-W\frac{d}{dx}P_1(z,x) = -[\lambda(1-z) + \mu + b(x)]P_1(z,x) + \alpha P_0(z,x) +$$

$$+\frac{\mu}{z}\int_0^x \left[P_0(z,x-y) - F_{0,0}(x-y)\right]dG(y) + \mu F_{0,0}(x) \tag{21}$$

$$+\frac{\mu}{z}\int_0^x \left[P_1(z,x-y) - F_{0,1}(x-y)\right]dG(y) + \mu F_{0,1}(x) \tag{22}$$

We apply the Laplace transformation to equations (20) and (21) with respect to the variable x and use the known rule of transformation of convolution. As a result we got the following set of equations:

$$0 = -\left[\lambda(1-z) + \mu(1-\frac{g(s)}{z}) + \alpha\right]P_0(z,s) + bP_1(z,s) + \mu(1-\frac{g(s)}{z})F^*_{0,0}(s) \tag{23}$$

$$WP_1(z,0) = -\left[\lambda(1-z) + \mu(1-\frac{g(s)}{z}) - Ws + b\right]P^*_1(z,s) + \alpha P^*_0(z,s) + \mu(1-\frac{g(s)}{z})F^*_{0,1}(s) \tag{24}$$

where $P^*_1(z,s) = \int_0^{\infty} P_i\ (z,s)e^{-sx}dx$, $Res > 0, i = 0,1$.

By direct substitution in (20) and (21) we can be sure that under condition $\lambda<\mu$ (it is the condition of existing steady-state regime of 1st phase of our system) the following correlation holds:

$$P_i(z,s) = \frac{\mu-\lambda}{\mu-\lambda z} F_i(x), i = 0,1$$

where function $F_i(x)$ satisfies the next system of integral-differential equations:

$$-WF_1'(x) = -(\lambda+b)F_1(x) + \lambda\int_0^x F_1(x-y)dG(y) + \alpha F_0(x),\ \ x \geq 0 \tag{25}$$

We apply the Laplace transformation to system (25) and obtain the following:

$$0 = -F_0^*(s)[\lambda(1-g(s))+\alpha] + bF_1^*(s)$$

$$WF_1(0) = \alpha F_0(s) - [\lambda(1-g(s)) + b - Ws]F_1^*(s) \tag{26}$$

$$F_i^*(s) = \int_0^\infty e^{-sx} F_i(x)dx$$

$$Res > 0, i = 0,1.$$

The solution of the system (26) has the following form:

$$F_0^*(s) = \frac{b}{\lambda(1-g(s)+\alpha} F_1^*(s) \tag{27}$$

$$F_1^*(s) = \frac{WF_1(0)[\lambda(1-g(s))+\alpha]}{[\lambda(1-g(s))+\alpha][sW-b-\lambda(1-g(s))]+ab}$$

The constant mean of $F_1(0)$ is the probability that a ship at a random time is at a berth and there is no cargo at a warehouse, i.e. it is the probability of non-productive ship berthing and can be calculated from the condition of normalization:

$$F_0(\infty) + F_1(\infty) = 1 \tag{28}$$

Taking into account that $F_i(0) = \lim_{s\to 0} sF_i^*(s), i = 0,1$ from equations (27) and (28) we find (applying the Lapthal's rule):

$$F_1(0) = \frac{a}{\alpha+b} - \frac{\lambda g_1}{W} \tag{29}$$

$$g_1 = \int_0^\infty xdG(x) < \infty$$

where g_1 is the mean capacity of one container.

Since we require $F_1(0) > 0$ from equation (29), it follows that condition:

$$\lambda < \frac{W\alpha}{g_1(\alpha + b)}$$

Thus, is necessary for ergodicity of the process $\vec{G}(t)$ it is required to satisfy the inequality:

$$\lambda < \min\left(\frac{W\alpha}{g_1(\alpha + b)}\right) \tag{30}$$

The representation of the system of equations (20) and (21) in product-form (24) is a property known in the queuing theory as Berke theorem (17). By means of the mentioned theorem the output flow from a queuing system M/M/n in the steady-state regime is a Poisson process and it is congruent with the input flow.

It has also of practical interest to find time instants of limiting distribution for cargo quantity of the warehouse $\xi(t)$, which is denoted by $F(x)$. Laplace transformation of this distribution is specified by the following formula:

$$F^*(s) = F_0^*(s) + F_1^*(s)$$

The Laplace-Stieltjes transformation (18) is specified by formula:

$$\varphi(s) = \int_{0+}^{\infty} e^{-sx} dF(x) + F_1(0) = S(\,F_0^*(s) + F_1^*(s)) + F_1(0) \tag{31}$$

From equations (27) and (31) we find, for instance, the mean cargo quantity at a warehouse:

$$M\xi = -\varphi'(0) = \frac{\lambda g_2(\alpha + b) + 2\lambda g_1(W - \lambda_1)}{2[\alpha W - \alpha g_1(\alpha + b)]} \tag{32}$$

$$g_2 = \int_0^{\infty} x^2 dG(x) < \infty$$

where g_2 represents the second initial distributing moment of discharge of the containers.

5.2.3 Two-phase queuing system with and without e-seals

In the second case the gate at port entering is equipped with RFID readers for containers with e-seals. The general flow of containers consists of two sub flows: the first of them is a flow of containers which are equipped with e-seals, and the second one is a flow of containers without e-seals (Fig. 17).

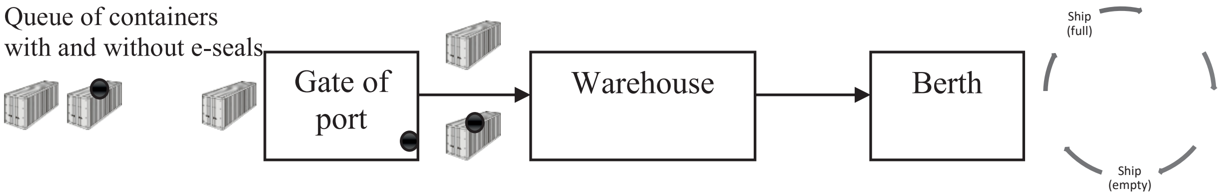

Fig. 17 Structure of 2-phase queuing system in a port "gate-warehouse-ship" for containers with and without e-seals; the port gate is equipped with e-seals reading infrastructure

RFID readers on the port gate allow to speed up the control process for the containers at the gate and influence also the velocity of general container flow in the port.

For substantiation of appropriateness of investments in RFID reader infrastructure and speeding-up a procedure container entering to the port it is necessary to compare the efficiency of gate work in the both cases on a list of criteria. The base criteria could be some economical or time indicators. For example, the probability $F_1(0)$ in the previous case could be interpreted as a time ratio over the long period of time (e.g. year), when a ship is non-productive berthing through low rate of port gate throughput. Consider high value of ship berthing costs per day, we can appreciate in monetary expression appearing in this case lost.

Now we describe the formal language the work of 2-phase queuing system with two types of requirements corresponding to the flow of containers with and without e-seals. We assume that the sequence of service in the 1st phase (i.e. gate) is without any priority for containers with e-seals, e.g. FIFO (first in – first out). We assume as well that a time of gate control for any container with e-seal is randomly distributed by exponential law with parameter μ_1; and a time of gate control for any container without e-seal is randomly distributed as well by exponential law but with parameter μ_2, where $\mu_2 < \mu_1$.

General flow of containers entering a port, as earlier, will be considered to follow the Poisson distribution with parameter λ. This flow is generated by means of superposition two independent Poisson flows of containers: the first of each is described the process of container arrivals which are equipped with e-seals (its parameter is equal μ_1), and second – the process of arrivals of containers without e-seals (the parameter of this flow will be considered to be equal μ_2). The rest of the assumptions mentioned above remain unchanged.

Now let us introduce a random process.

$\vec{G}(t) = (\gamma_1(t), m(t), \xi(t), \gamma(t))$

where $\gamma_1(t)$ – the mean number of containers in the first phase at a time moment t;

$m(t)$ – number of containers' flow at a gate at a time moment t, i.e.

$m(t)$=1 or 2, if $\gamma_1(t) \neq 0$; if $\gamma_1(t) = 0$ then component $m(t)$ should be omitted.

The parameters $\gamma(t)$and $\xi(t)$ keep the previous meaning.

We identify that:

$F_{0,i}(x,t) = P\{\gamma_1(t) = 0, \gamma(t) = i, \xi(t) \leq x\}$

$F_{k,m,i}(x,t) = P\{\gamma_1(t) = k, m(t) = m, \gamma(t) = i, \xi(t) \leq x\}$

$k > 0;\ m = 1,2; i = 0,1; x \geq 0$

For the limited distribution:

$F_{0,i}(x) = \lim_{t\to\infty} F_{0,i}(x,t)$

$F_{k,m,i}(x) = \lim_{t\to\infty} F_{k,m,i}(x,t)$

By the means of common probability of argumentation (1) we can derive the following system of integral-differential equations, where $\lambda = \lambda_1 + \lambda_2$:

$$0 = -(\lambda + \alpha)F_{0,0}(x) + \mu_1 \int_0^x F_{1,1,0}(x-y)dG(y) + \mu_2 \int_0^x F_{1,2,0}(x-y)dG(y) + b(x)F_{0,1}(x) \tag{33}$$

$$\begin{aligned} 0 = &-(\lambda + \alpha + \mu_m)F_{1,m,0}(x) + \mu_m F_{0,0}(x) \\ &+ \frac{\lambda_m}{\lambda}\mu_1 \int_0^x F_{2,1,0}(x-y)dG(y) + \frac{\lambda_m}{\lambda}\mu_2 \int_0^x F_{2,2,0}(x-y)dG(y) + b(x)F_{1,m,1}(x) \end{aligned} \tag{34}$$

$m = 1,2$

$$\begin{aligned} 0 = &-(\lambda + \alpha + \mu_m)F_{k,m,0}(x) + \lambda F_{k+1,m,0}(x) \\ &+ \frac{\lambda_m}{\lambda}\mu_1 \int_0^x F_{k+1,1,0}(x-y)dG(y) \\ &+ \frac{\lambda_m}{\lambda}\mu_2 \int_0^x F_{k+1,2,0}(x-y)dG(y) + b(x)F_{k,m,1}(x) \end{aligned} \tag{35}$$

$m = 1,2; k > 1$

$$-WF_{0,1}^{'}(x) = -(\lambda + b(x))F_{0,1}(x) + \mu_1 \int_0^x F_{1,1,1}(x-y)dG(y) + \mu_2 \int_0^x F_{1,2,1}(x-y)dG(y) + \alpha F_{0,0}(x) \quad (36)$$

$$-WF_{1,m,1}^{'}(x) = -(\lambda + b(x) + \mu_m)F_{1,m,1}(x) + \lambda_m F_{0,1}(x) + \frac{\lambda_m}{\lambda}\mu_1 \int_0^x F_{2,1,1}(x-y)dG(y) + \frac{\lambda_m}{\lambda}\mu_2 \int_0^x F_{1,2,1}(x-y)dG(y) + \alpha F_{1,m,0}(x) \quad (37)$$

$$-WF_{k,m,1}^{'}(x) = -(\lambda + b(x) + \mu_m)F_{k,m,1}(x) + \lambda_m F_{k-1,m,1}(x) + \frac{\lambda_m}{\lambda}\mu_1 \int_0^x F_{k+1,1,1}(x-y)dG(y) + \frac{\lambda_m}{\lambda}\mu_2 \int_0^x F_{k+1,2,1}(x-y)dG(y) + \alpha F_{k,m,0}(x) \quad (38)$$

$m = 1,2; k > 1$

After getting the solution for the system of equations (33) – (38) we can calculate several parameters of work effectiveness for the 2-phase queuing system. For example:

- Stationary probability that a ship stands idle because of the lack of containers at a warehouse:

  $$F_1(0) = \sum_{k=1}^{\infty} \sum_{m=1}^{2} F_{k,m,1}(0) + F_{0,1}(0)$$

- mean number of containers at a warehouse:

  $$M\xi = \int_0^{\infty} x dF(x)$$

  where $F(x) = \sum_{k=1}^{\infty} \sum_{m=1}^{2} (F_{k,m,0}(x) + F_{k,m,1}(x)) + F_{0,0}(x) + F_{0,1}(x)$

- Distribution of an interval of a warehouse unloading, i.e. time from the moment of the beginning of empty warehouse infill up to the next the same moment.

The system (33) – (38) is an infinite system of linear integral-differential equations. It can be solved analytically using the method of course-of-value function and Laplace transformation; however its solution is connected with huge analytical difficulties.

For its numerical solution it is required to cast out the equation for k > R where R is a tolerance length of containers queue. The equations (35) and (38) for k = R in this case has the following form:

$$0 = -(\alpha + \mu_m)F_{R,m,0}(x) + \lambda F_{R-1,m,0}(x) + b(x)F_{R,m,1}(x)$$

$$-WF'_{R,m,1}(x) = -(\alpha + b(x) + \mu_m)F_{R,m,1}(x) + \lambda F_{R-1,m,1}(x) + \alpha F_{R,m,0}(x)$$

$$m = 1,2$$

If we assume that a loading of all containers is constant and equal to g_1, i.e.

$$G(x) = \begin{cases} 1, & x \geq g_1 \\ 0, & x < g_1 \end{cases}$$

Then the integral remainders in equations (33) – (38) are interchanged to the following:

$$\frac{\lambda_m}{\lambda}\mu_1 F_{k+1,m,i}(x - g_1) + \frac{\lambda_m}{\lambda}\mu_2 F_{k+1,m,i}(x - g_1)$$

and we get the finite system of delay differential equations for $x \geq g_1$.

System (33) – (38) and the derived finite system should be solved subject to condition of normalization:

$$\sum_{k=1}^{\infty}\sum_{m=1}^{2}\sum_{i=0}^{1} F_{k,m,i}(\Delta) + \sum_{i=0}^{1} F_{0,i}(\Delta) = 1$$

Variation 3

In the third case we have 2 gates, one of them is equipped with e-seals reader, and the second gate is a standard gate (Fig. 18).

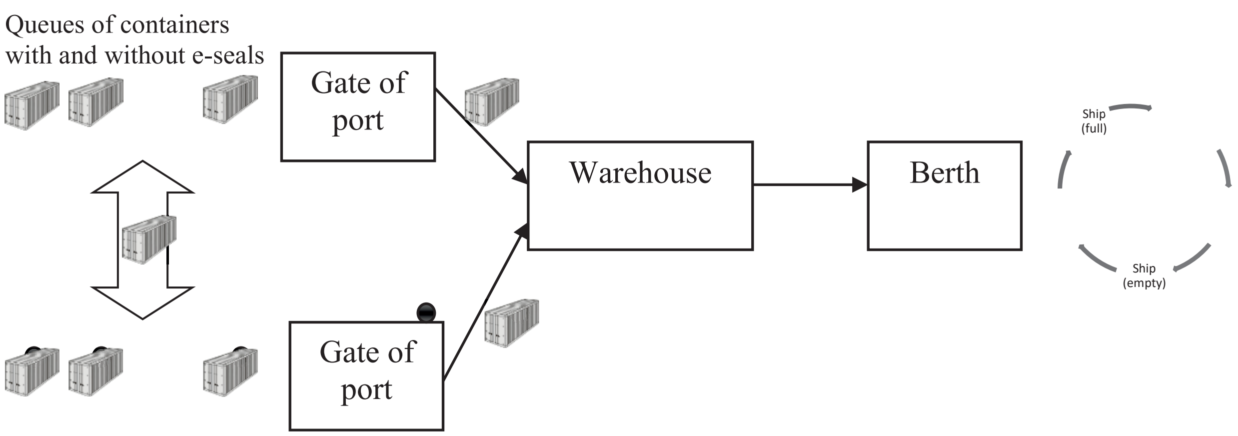

Fig. 18 Structure of 2-phase queuing system in a port "gate-warehouse-ship" for containers with and without e-seals; the port gate is equipped with e-seals reading infrastructure

Containers with e-seals go directly to the gate which is equipped with necessary reading infrastructure, and containers without any e-seal can enter a port from both gates.

For described situation, as for the variation 2, different priorities in operational services on the gates for containers with and without e-seals might be determined. Then we can investigate their influence on parameters of work effectiveness of 2-phase queuing system. From a theoretical point of view, it is easier to limit ourselves to any non-priority discipline, e.g. FIFO.

In that case we can similarly derive the respective infinite or finite system of integral-differential equations.

In this section we have modelled several cases of transportation flows of containers with and without security devices via the port gates by using of the queuing theory techniques. We have seen that this method leads to rather complex systems of equations already in the case of simple scenarios with one-two nodes. Writing down the counterpart system of equations for the case of a larger number of nodes, say more than ten nodes, becomes very cumbersome and its solution may be intractable. However, in a realistic network the number of nodes can be much larger. An alternative way to investigate dynamics in this case is to use discrete-event simulations executed on the computer. This approach is frequently used as a low-cost way of gathering information for decision making (Fishman, 2001).

5.3 Discrete-event simulation

In discrete-event simulation, the operation of a system is represented as a chronological sequence of events. Each event occurs at an instant in time and marks a change of state in the system (Robinson, 2004). Discrete-event simulation is a powerful computing technique for understanding the behaviour of dynamical systems. It offers many advantages that make this tool an attractive for analysis (Fishman, 2001):

- Ability to compress time, expand time
- Ability to control sources of variation
- Avoid errors in measurement
- Ability to stop and review
- Ability to restore the systems state
- Facilitates replication
- Possibility to adjust the level of detail

By a system we understand a collection of entities (e.g., people and machines) that interact over time. A classical system example is a queuing system with a single server. Here, customers arrive with certain service requirements, get served in some order, say first-come-first-served, and depart when their service is completed.

Note that a customer who arrives when the server is busy has to wait (in a queue). For this system, we can determine the average waiting time for customers, the average number of customers in the system, the fraction of time the server is busy, etc.

In general, to determine whether a system satisfies a certain property, we have to come up with a mathematical model of the system. In discrete-event simulation, the models are restricted to so-called discrete-event models. Here, a set of system states is specified for the system, and the evolution of the system is viewed as a sequence of the form: $s_0, (e_0, t_0), s_1, (e_1, t_1), s_2 \dots$, where the s_i are system states, the e_i are system events, and the t_i are nonnegative numbers representing event occurrence times. Informally, the above sequence means that the system started at time 0, in state s_0; then event e_0 occurred at time t_0 taking the system to state s_1; then event e_1 occurred at time t_1 taking the system t_1 state s_2;and so on. Each event occurrence is assumed to take zero time. The t_i are required to be non-decreasing, i.e., $t_i \leq t_i + 1$ for every i. In the discrete-event models there are at most a finite number of transitions over any finite time interval.

Given the evolution of a system, we can determine its properties (e.g., steady state, is it cyclic, etc.) and evaluate appropriate performance measures (e.g., the steady state values, the cycle period, etc.).

There is a set of system parameters, referred to as input parameters, that determines the evolution of the system, and hence the properties and performance measures. For example, the input parameters to the queuing system are the customer service requirements and arrival times. Typically, the input parameters of a system are described stochastically (or probabilistically), instead of deterministically. That is, instead of fixing the input parameter values deterministically, we let them be random variables, taking values from some domain with some probability distribution. Each set of input parameter values gives rise to a unique evolution.

In a real-life system there are no exact characterizations of the input parameters. Hence, using probabilistic inputs makes the results of the analysis more robust. Second, even if we do have an exact characterization of the input parameters, it is often computationally too expensive or analytically intractable to take them into account.

The problem in discrete-event simulation is similar to that for any mathematical optimization problem. Given an objective function (expressed in terms of the simulation outputs), the aim is to find the optimum value of some decision variables (simulation model inputs), subject to a set of constraints (allowable range for the simulation model inputs). The difference from mathematical optimization is that no algorithms exist that guarantee an optimal solution will be found. Simulations are normally developed because a system is too complex to be represented in any other way. If the systems that are being modelled are complex, the simulations themselves must involve some level of complexity, although at a level of abstraction from the system. It may, therefore, not be the simulation tools that are difficult to use, but the systems that are being modelled that are difficult to represent. In this respect, “difficulty-in-use” is almost to be welcomed since it means that simulation is succeeding in helping with difficult problems that could not be addressed otherwise (Robinson, 2005).

5.3.1 Description of simulation scenario and its goals

Container terminals are crucial connections between modes: a bottleneck in terminal operations may affect both inbound and outbound traffic. Inspection is a significant, yet bureaucratic and time-consuming procedure (Tsilingiris, Psaraftis & Lyrdis, 2007a) in container port processing. No more than 2-3% of all the ocean incoming containers are checked for security purposes. Truck incoming containers are usually not checked. This check is not homogeneous in the sense that the majority of certain sets of “suspect” containers may be inspected while other non-suspect sets may not be opened at all. This is performed via a decision-support inspection system, which produces a probability inspection function. Variables of the function are cargo data like origin, destination, etc. In essence, this program resolves the containers that will be checked. The inspection takes place only after the container has been stacked, the operator has adduced declarative documents to the customs, and the container has been stored in the port information system as a stored container. If the decision support system suggests the inspection of the container, the customs broker/clearer communicates with the customs the inspection command. Promptly, the container is “blocked” and the container operator is informed via an XML message. Then, the container is moved to the area where the inspection takes place. When the inspection finishes, a new seal is put to the cleared container, the customs “unblock” the container, and the container is again stacked. Thus, the unblocked container can be retrieved by a trucker.

Whether the initiatives for increased safety, security, and environmental protection are contradictory with operational excellence or not, it is certain that these initiatives will be the drivers for change in container transport. Thus, the ocean container carriers and the port terminals that will deliver enhanced safety and security will attain a competitive advantage. Although RFID utilization is not mandatory, RFID and other innovative IT technologies can assist in regulatory compliance as regards safety, security, and environmental protection.

This *thesis describes* a model for container transhipment through the terminal which is developed considering new coming regulations for security and safety of container transport chains. The method for the measurement of the effect of the container secure devices (active RFID e-seals) on logistics container network was evaluated.

The work is based on the assumption that a typical electronic seal with a small chip inside and some sensors can contain some logistic data which can be used during the transportation of a cargo. We consider 3 types of container seals that can have an effect on container flows in global network. After that we compare container networks with these deferent types of seals.

The first type of container seal that is used in our model is mechanical seal or high secure container bolt that provides the customs officer with information about container number mentioned in container manifest in a non-electronic form.

Second type is an electronic seal. Its task is only to provide electronic evidence that container was not tampered with or to inform the authorized person about the electronic number and status of e-seal.

The third one is the most advanced container security device. Here we assume that with help of an RFID chip a container seal can transmit and receive information. The electronic seal attached to a container can be read at key checkpoints (terminal gates, quay container loaders). The read information from advanced e-seal can be sent via Internet or some other networks directly to container operators, 3PL operators, forwarders etc. Through the obtained real-time information the person responsible for container delivery may take a routing decision for the container trip. These possibilities are not available in the simplest electronic seal mentioned above.

In this section the description of simulation scenario is given. The developed scenario is introduced in Fig. 19. The model consists of 20 nodes. Through each of the ten port nodes (Port 21-25 and Port 31-35) of the presented container network we consider complex container flows under customs inspections. The container flows, as in a real port situation, are going in both directions, i.e., we consider specifically import and export container flows. This means that each port is modelled as a subnetwork with terminals and gates described below.

The ten distribution centres (DC11-15 and DC41-45) are the points of origin and accordingly the destinations for container flows in the container network. The connections between the nodes show the container flows inside the network. To make the simulation model more realistic we consider the main directions of container flows in the world. The main container flows connect Europe with Asia; and Asia with North America (Christ, Crass & Miyake, 2005); obviously, there are many other major cargo flows in the world economy, however for our modelling process it is sufficient to consider only 3 from many others.

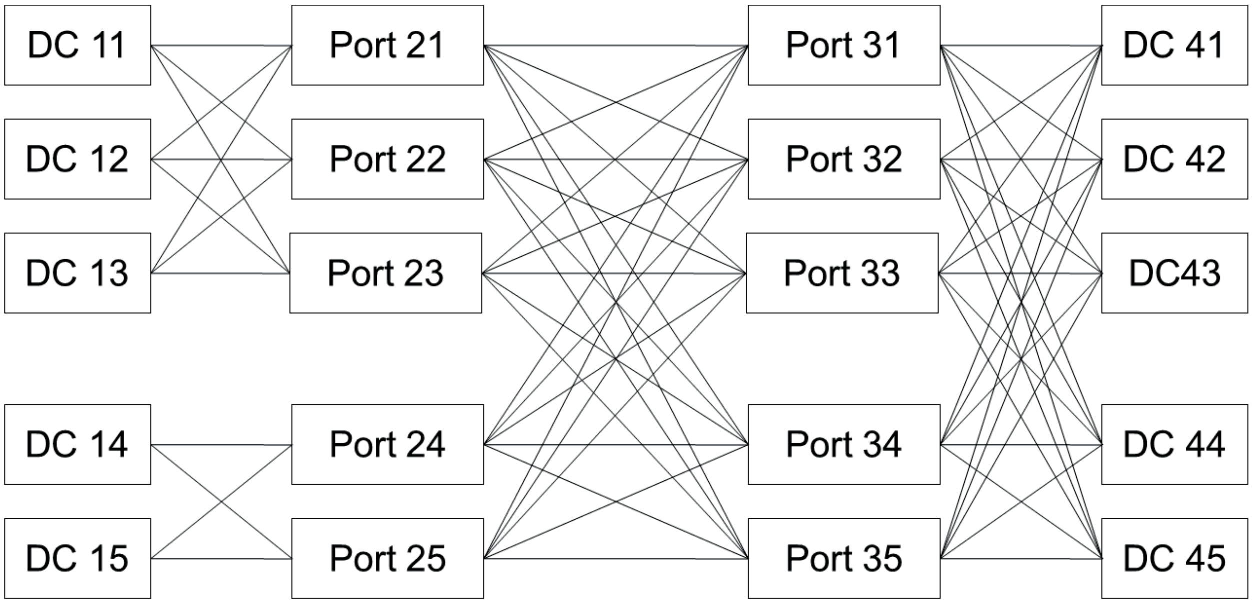

Fig. 19 Container logistics network

For the modelling purposes we decided to consider the busiest world container ports (in the bracket the port abbreviation for the model):

Europe (EU):

- Rotterdam (Port 21)
- Hamburg (Port 22)
- Antwerp (Port 23)

North America (USA):

- Los Angeles (Port 24)
- New York/New Jersey (Port 25)

Asia (China):

- Shanghai (Port 31)
- Hong Kong (Port 32)
- Shenzhen (Port 33)
- Qingdao (Port 34)
- Ningbo-Zhoushan (Port 35)

The distribution centre was chosen by the principle of good road port accessing and the opportunity to transport the container in the most attractive port.

The attractiveness of the port is an option for the advanced transport units with smart RFID secure device. Containers with smart e-seals are able to make decisions based on:

1. Information about queues at the port gates, i.e. the container can change the route if the queues are too long and to go to another more attractive port;

2. Information about ship arrival times in the nearest ports, i.e. the container can estimate the travel and waiting time and make a decision about the shortest alternative;
3. Information obtained at the point of origin (distribution centre) and at the port of loading.

The container equipped with conventional or simple e-seal cannot make routing decisions. They are following the principle to choose the nearest port, considering the point of destination.

The structure of container flows inside a port is described as follows. There are several queues inside the port area; in particular there are different queues for containers with e-seals and for other containers (Fig. 20).

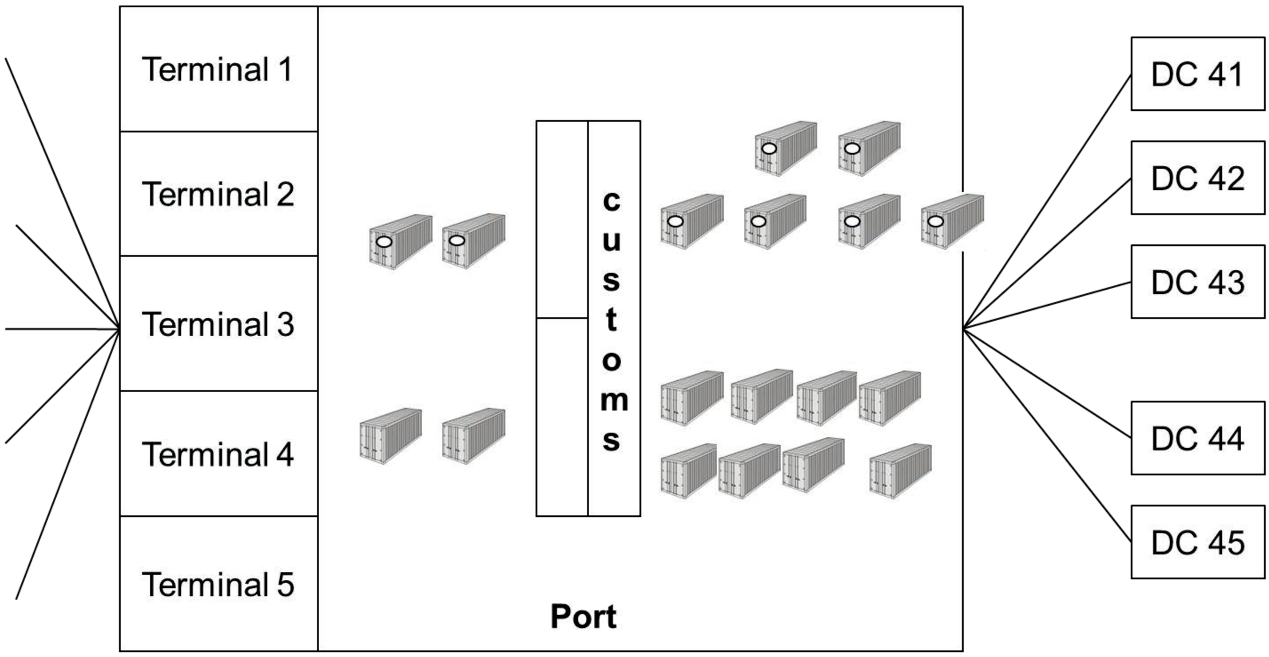

Fig. 20 Network of container flows inside a port node

The container flows in the whole network and inside the port nodes are considered in both directions (import & export container flows). The grey blocks with red dots on the graph are the containers with any type of e-seals; they have their own queues at the port gates as well as for customs proceeding, and during the loading/unloading processes at the berth. For the containers with mechanical seals (grey blocks) the same procedure is assumed but separately from containers with e-seals. In this simulation model there are two types of entering gates at the transit points (ports): one type of gates serves only the containers equipped with electronic device; another type of entering gates serves only containers with mechanical seals.

The goal of the simulation is to estimate the influence of each type of container seal on global container flows. The flows of containers with mechanical seals will show the conventional situation and will be compared with flows in case containers with electronic seals. The developed model will present the impact of active RFID electronic seals on the dynamics of container logistics processes at the container terminal and provides the evaluation of changes in dynamics of physical container flows through a maritime terminal. The implementation of new types of container seals, i.e. electronic seals, in transportation process should be approved by any feasible impact to make container system more effective, sustainable, and secure. Our aim is also to proof the economical effectiveness to invest in new container secure devices; i.e. to evaluate whether the more security for container flows will bring as well the business efficiency for private sector.

5.3.2 Initial data for simulation

In discrete-event simulation, the operation of a system is represented as a chronological sequence of events. Each event occurs at an instant in time and marks a change of state in the system (Robinson S. , 2004). The container network model is in the discrete-event form. For its solving, we apply appropriate simulation tool programmed in MATLAB. MATLAB (meaning "**mat**rix **lab**oratory")) is a language for technical computing. It can be used for mathematical computations, modelling and simulations, data analysis and processing, visualization and graphics, and algorithm development (Gilat, 2007). The simulation is presented for the above mentioned three types of container seals. It is assumed that containers equipped with electronic seals can use the GreenLane advantage (free moving through the ports or border crossing with minimum stops for security checks by customs).

The initial data was taken from statistical sources (Sea-Rates.com, 2009; Maps.google, 2009) and by author estimations. The container traveling time inside the system and between the particular port nodes is represented in table form (Table 5):

	21	22	23	24	25	41	42	43	44	45
11	1	2	1	0	0					
12	2	1	2	0	0					
13	1	2	1	0	0					
14	0	0	0	2	4					
15	0	0	0	3	1					
31	16,93	17,46	16,93	9,53	16,91	1	1,5	1	0,2	2
32	15,79	15,70	15,79	10,20	18,03	1,5	1	1	1,5	0,1
33	15,79	16,32	15,79	10,20	18,04	1,5	1	1	1,5	0,1
34	17,47	17,99	17,47	9,53	17,38	1,5	2	1,5	0,5	2
35	16,90	17,43	16,90	9,52	17,36	1	1	0,5	0,5	2

Table 5 Transportation time between the nodes in container network, in days (Maps.google, 2009; Sea-Rates.com, 2009)

After completing the simulation we are interested in the final transportation time inside the network between the point of origin and the destination point.

Additionally we required to know the average number of containers living the warehouses or distribution centres every day in the system (Table 6):

	11	12	13	14	15	41	42	43	44	45
11	0	0	0	0	0	20	10	25	20	10
12	0	0	0	0	0	20	20	25	10	10
13	0	0	0	0	0	15	10	5	15	30
14	0	0	0	0	0	10	20	10	15	15
15	0	0	0	0	0	10	15	5	10	30
41	30	20	15	15	10	0	0	0	0	0
42	15	30	10	40	10	0	0	0	0	0
43	30	15	5	30	15	0	0	0	0	0
44	10	15	25	20	30	0	0	0	0	0
45	10	10	25	10	40	0	0	0	0	0

Table 6 Number of containers living each distribution centre per day; authors estimations

It is natural to assume that the time to process a container through the customs scrutiny is different for containers equipped with e-seals and for containers with conventional seals. This time depends on different abilities of customs authorities to check the information about container content, information about supplier of this cargo and any shipment data. With electronic version of information about container content, the customs officer is able to speed up the container processing through the port. Subsequently, we defined the average customs processing for containers without e-seal in different countries and make estimations for containers equipped with new electronic secure device (Table 7):

Ports	E-seal, hours*	Mechanical seal, days**
China (Shanghai, Hong Kong, Shenzhen, Qingdao, Ningbo-Zhoushan)	2; 4; 8; 16; 24	4
Rotterdam, Hamburg	2; 4; 8; 16; 24	2
Antwerp	2; 4; 8; 16; 24	1
USA (Los Angeles, New York/New Jersey)	2; 4; 8; 16; 24	15

Table 7 Customs clearance time; *authors estimations and ** (IELA, 2009)

In the simulation model we consider two scenarios:

1. for containers equipped with smart seals the scenario with routing decisions was simulated;
2. for containers equipped with mechanical or simple e-seals a scenario without possibility to change the route was developed.

There exist shipping lines between the ports in the network; ships enter the port weekly. Hence, if a container is 1 day late then it has to wait 1 week for the next ship.

5.4 Analysis of simulation results

The simulation of model for containers transhipment through the network is developed with discrete-event method by using MATLAB software (see the program in Appendix).

5.4.1 Global container turnover

The model was simulated 20 times in order to get average results then. Each simulation was completed for two possible situations: when e-seals have ability for routing decisions and for container equipped with seals without smart functions, i.e., e-seals or mechanical seals without routing decisions. For the situation when all containers are equipped with conventional seals or 100 % of all containers have e-seal, as well as 100% of containers can be equipped with smart seals, were obtained the following results (Fig. 21):

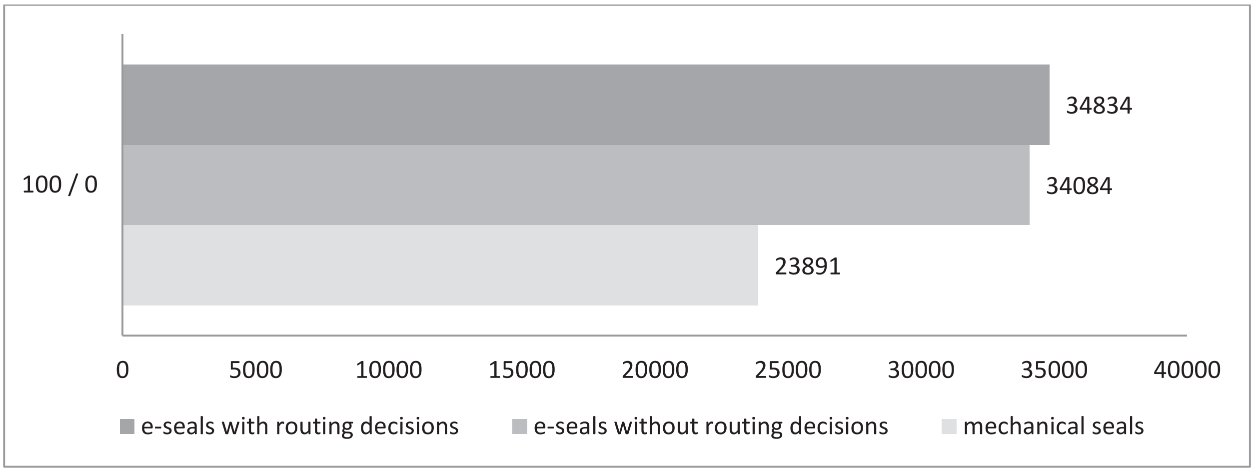

Fig. 21 Network containers turnover when 100% of containers equipped with one type of seal

This result shows that even the simple electronic version of conventional container seal may improve the global container operation system. The variation in global container turnover comparing container volumes with mechanical seals and operations with e-seals is almost 30%. Accordingly, the growth in container turnover when container equipped with smart seals with routing decisions is 32%. As presented below (Fig. 22 and Fig. 23) the simulation was accomplished for 2 scenarios and for different conditions of container checking process in the ports: the containers with e-seals are processed by the customs in 2, 4, 8, 16 and 24 hours respectively. For conventional seals these data is accounted in days, 1, 2, 4 and 15 days accordingly.

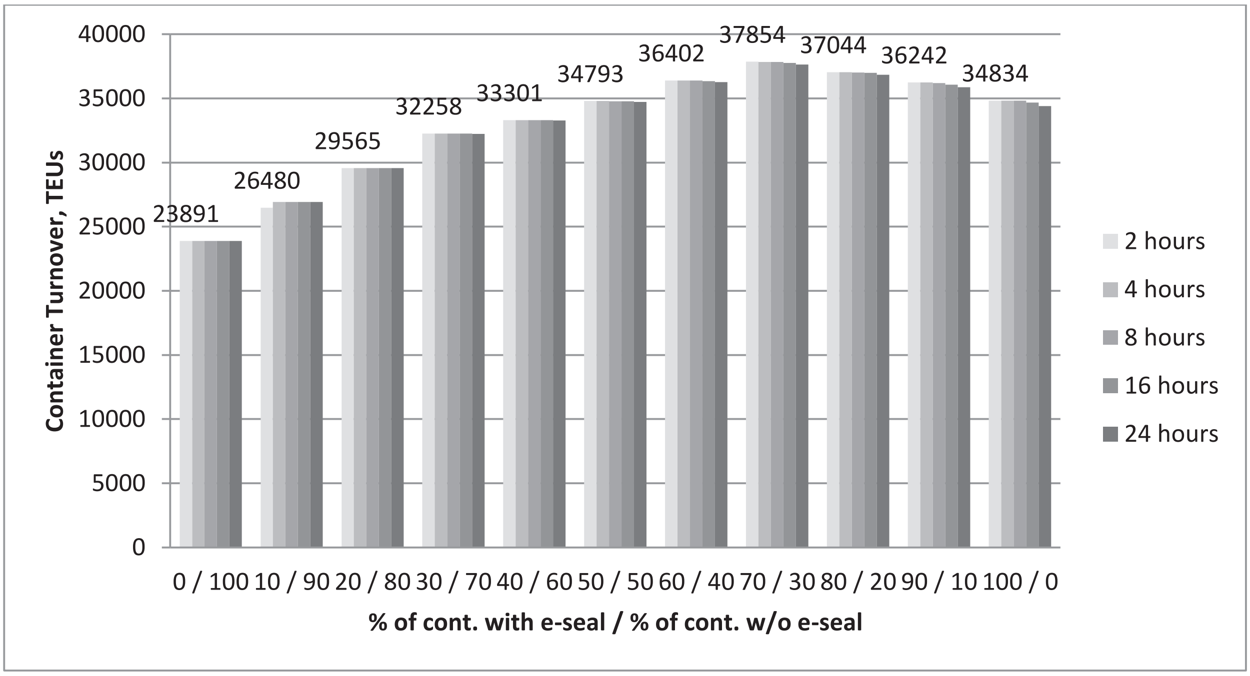

Fig. 22 Scenario 1: containers are equipped with e-seals with routing decisions

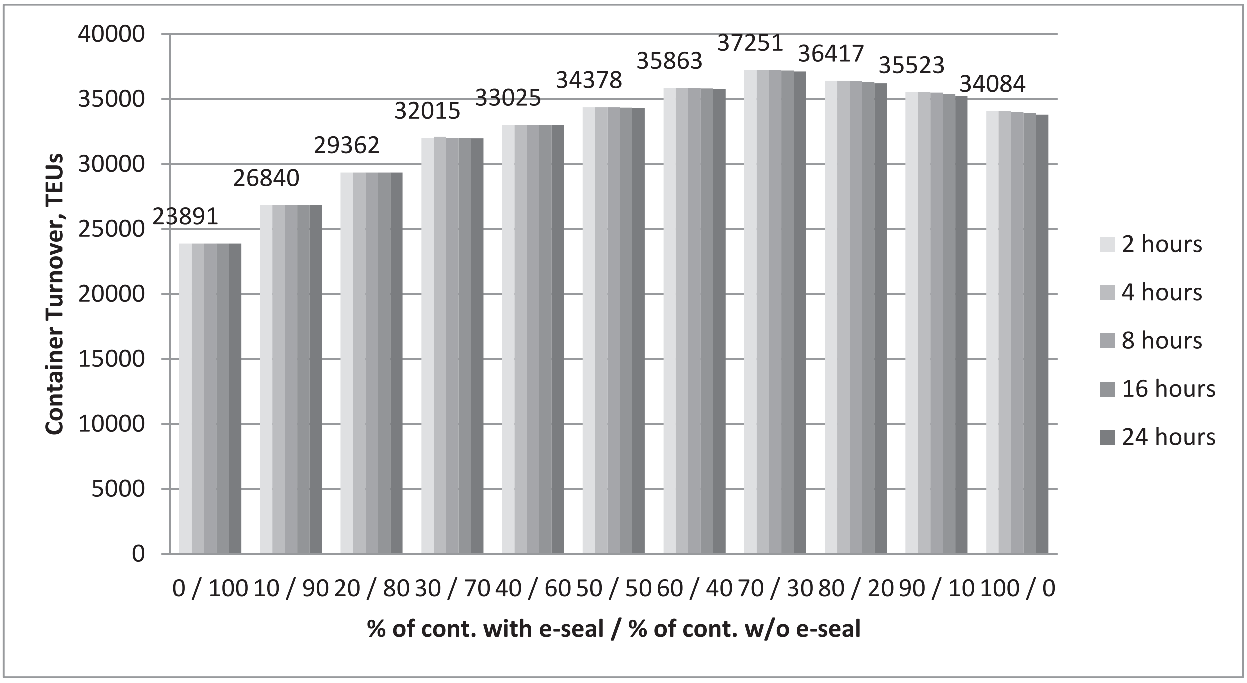

Fig. 23 Scenario 2: containers are equipped with e-seals without routing decisions

The best simulation results for container turnover are achieved when 70% of all containers are equipped with e-seal and the rest 30% are with mechanical seals. The reason is that in this simulation scenario it is not stipulated that container can change the entering gate to the port; and even one of the gates for containers with mechanical seals is free the container with e-seal cannot enter the port through this gate. At certain moments, like in the situation with 70/30 proportion of containers with and without e-seal, the gate with e-seals reading infrastructure reached the maximum throughput limit. At the next moment when the number of containers with e-seals is increasing and container flow of containers with mechanical seals appropriate decreasing, the total container throughput at terminal gate is decreasing as well. That is why on the next step when the number of containers with e-seals is 80%, the total throughput of the terminal gates is less then when it was in the case of 70% of electronic devices were on containers.

From the model evaluation we have calculated the number of containers that passed the system under the following particular conditions:

- different quantity of containers equipped with various types of seals;
- container can pass the customs control with different time durations;
- E-seals are able to make a routing decisions.

The following details of achievable container turnover in the global container system were obtained considering the conditions described above (Table 8 and Table 9):

% of cont. with e-seal / % of cont. without e-seal	2 hours	4 hours	8 hours	16 hours	24 hours
0 / 100	0 / 23891	0 / 23891	0 / 23891	0 / 23891	0 / 23891
10 / 90	4270 / 22210	4721 / 22210	4721 / 22210	4721 / 22210	4721 / 22210
20 / 80	8930 / 20635	8929 / 20635	8929 / 20635	8925 / 20635	8922 / 20635
30 / 70	12696 / 19562	12695 / 19562	12696 / 19562	12690 / 19562	12682 / 19562
40 / 60	16345 / 16956	16348 / 16956	16348 / 16956	16338 / 16956	16317 / 16956
50 / 50	19420 / 15373	19422 / 15373	19411 / 15373	19401 / 15373	19365 / 15373
60 / 40	22807 / 13595	22802 / 13595	22805 / 13595	22760 / 13595	22676 / 13595
70 / 30	26421 / 11433	26418 / 11433	26398 / 11433	26345 / 11433	26203 / 11433
80 / 20	28565 / 8479	28560 / 8479	28550 / 8479	28527 / 8479	28373 / 8479
90 / 10	31634 / 4608	31628 / 4608	31594 / 4608	31465 / 4608	31258 / 4608
100 / 0	34834 / 0	34827 / 0	34814 / 0	34666 / 0	34400 / 0

Table 8 Scenario 1: containers are equipped with e-seals with routing decisions

% of cont. with e-seal / % of cont. without e-seal	2 hours	4 hours	8 hours	16 hours	24 hours
0 / 100	0 / 23891	0 / 23891	0 / 23891	0 / 23891	0 / 23891
10 / 90	4630 / 22210	4630 / 22210	4630 / 22210	4629 / 22210	4628 / 22210
20 / 80	8727 / 20635	8727 / 20635	8727 / 20635	8721 / 20635	8715 / 20635
30 / 70	12453 / 19562	12543 / 19562	12452 / 19562	12442 / 19562	12433 / 19562
40 / 60	16069 / 16956	16069 / 16956	16064 / 16956	16050 / 16956	16035 / 16956
50 / 50	19005 / 15373	19005 / 15373	18997 / 15373	18975 / 15373	18946 / 15373
60 / 40	22268 / 13595	22268 / 13595	22256 / 13595	22224 / 13595	22169 / 13595
70 / 30	25818 / 11433	25817 / 11433	25805 / 11433	25766 / 11433	25685 / 11433
80 / 20	27938 / 8479	27937 / 8479	27909 / 8479	27842 / 8479	27740 / 8479
90 / 10	30915 / 4608	30912 / 4608	30889 / 4608	30795 / 4608	30662 / 4608
100 / 0	34084 / 0	34079 / 0	34027 / 0	33936 / 0	33817 / 0

Table 9 Scenario 2: containers are equipped with e-seals without routing decisions

In these tables we present the average total turnover of containers of each type in one simulation period for different constellations of shares of these types of containers in the system. For example, in the case the share of containers with e-seals is 0%, all 23891 containers with mechanical seals have arrived to their destinations. In case 10% of all containers are equipped with electronic seal 4270 of them will reach their destination and 22210 containers with mechanical seals will arrive at their destination. The total turnover in this case is 26480, i.e. larger than in the previous case.

The distribution of containers equipped with e-seals and without e-seals for different shares of the container types entering the system is given on Fig. 24. The simulation results show a significant influence of electronic devices on container turnover in total.

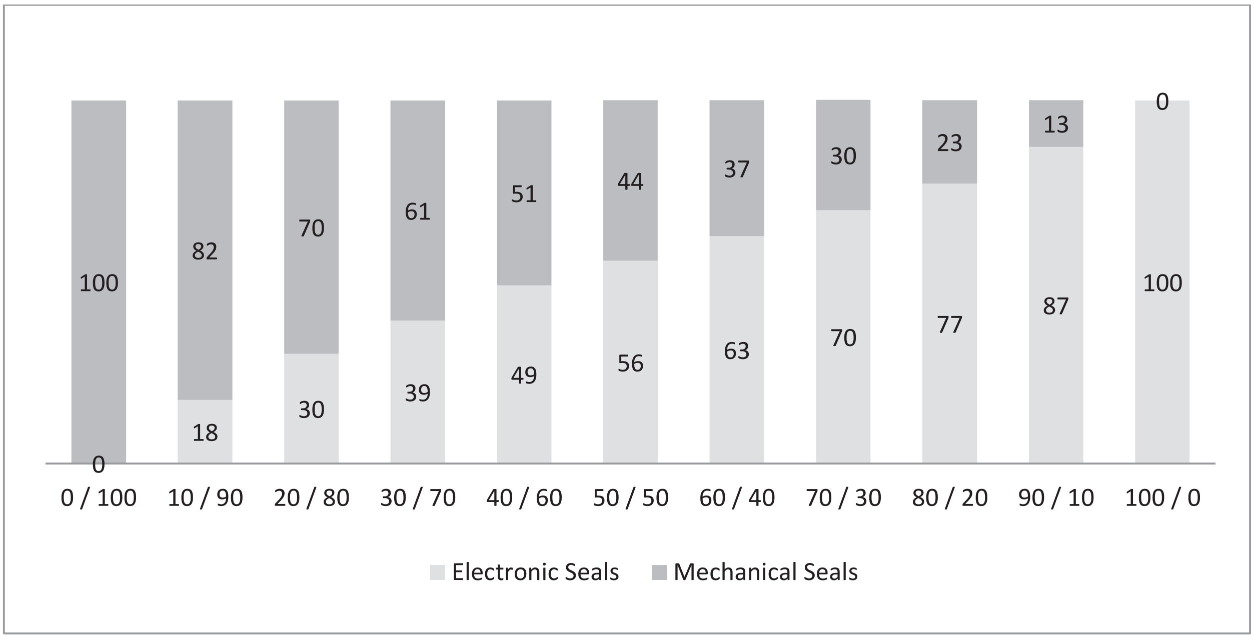

Fig. 24 Comparing of container turnover in per cent

The acquired results will be used in section 5.5 “Cost-Benefit Analyses of container secure network” to evaluate investments efficiency for such a new device like electronic seal or smart seal.

5.4.2 Time savings

The time factor is very important component for the model results evaluation. In this section we will describe the main data that play a significant role in the judgment of new technology impacts on existing container transportation processes. Since container flows depend on “just-in-time” principle the time criteria should force the decision in which technology to invest – e-seals/smart seals or stay with old mechanical bolts?

The next observed data are concerning the time that containers spent in the network at its different points. As the results show, this time depends on customs clearance time as well as on the queues at the transit points. The time that containers spent in different queues, i.e. the time a container waits at the gates of the port terminal or the time a container has to wait for its customs control after it has arrived at a harbour, are observed during the simulation of the model processing as well as the total time of a container in the system.

- The first factor that we will discuss is the time that container waits before the entering the terminal and how it depends on the type of securing device.

Figure 25 demonstrates the time distribution for containers which are equipped with simple e-seals (without routing decisions) and with mechanical seals in the terminal that they spent for the entering the terminal. Here we present the time graphs for containers for different situations: when container is under customs control for 2, 4, 8, 16 and 24 hours respectively or when it is without e-seal and follows the conventional procedure for customs scrutiny. The minimum waiting time to pass through the terminal gates is 5.08 days. In the figure 25 we can see that the minimum time difference that container spent awaiting for passing the gate is in port 21, which is 0.09 days. The maximum time that containers have to wait at the terminal is 10.51 days. These data show the time distribution for containers equipped with simple e-seals and containers that have mechanical seals.

The next graph presents the situation with time distribution at the terminal for containers waiting for entrance to the terminal if 50% of all containers were equipped with electronic seals and 50% containers are not equipped with e-seals (Fig. 26).

As represented by these figures, the time that a container waits at the entrance of the terminal has no consequential influence on the total transportation time. This holds true for both scenarios, i.e. for container flows with e-seals as well as for container flows with conventional seals.

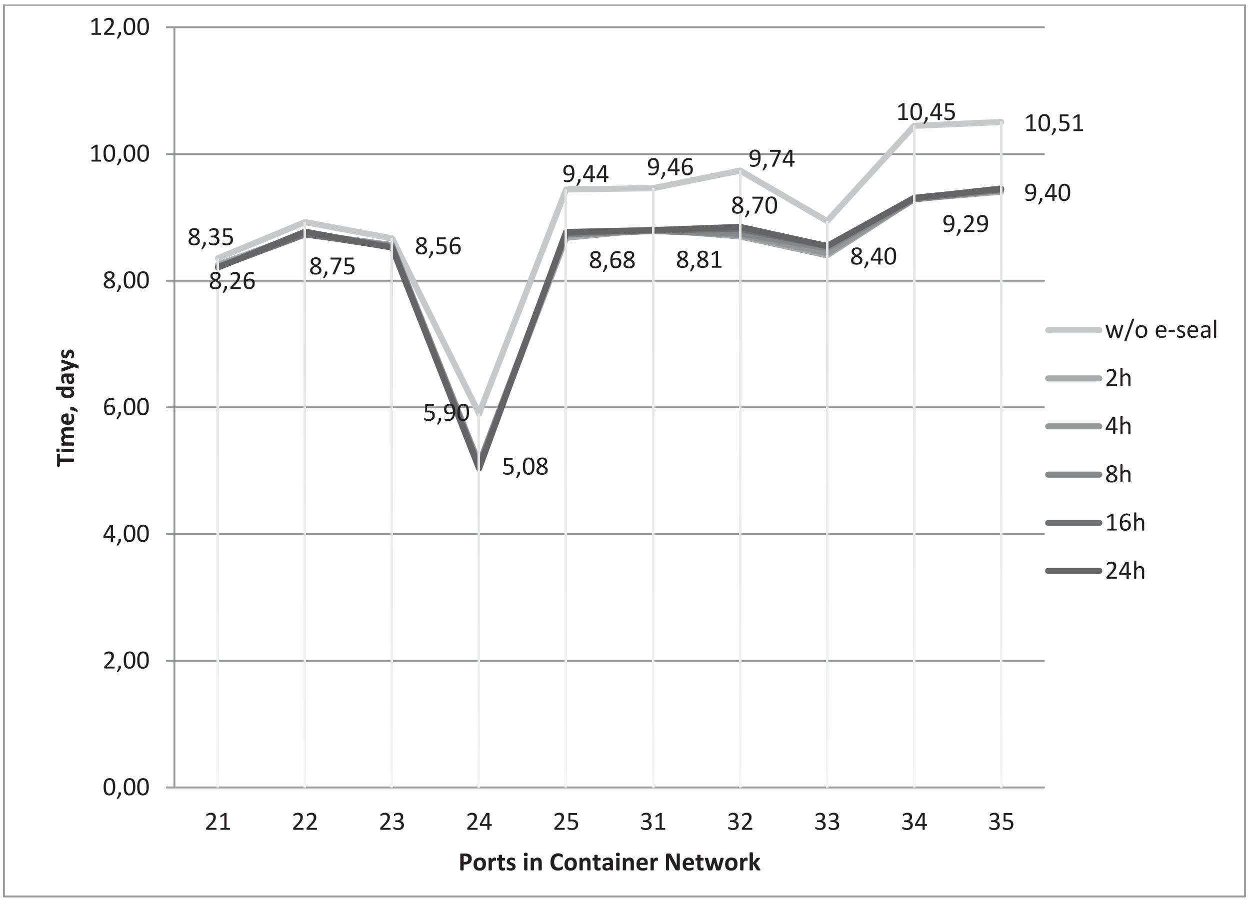

Fig. 25 Time at the terminal if 100% of containers are with e-seals (without routing decisions) or 100% of containers with mechanical seals (w/o seals)

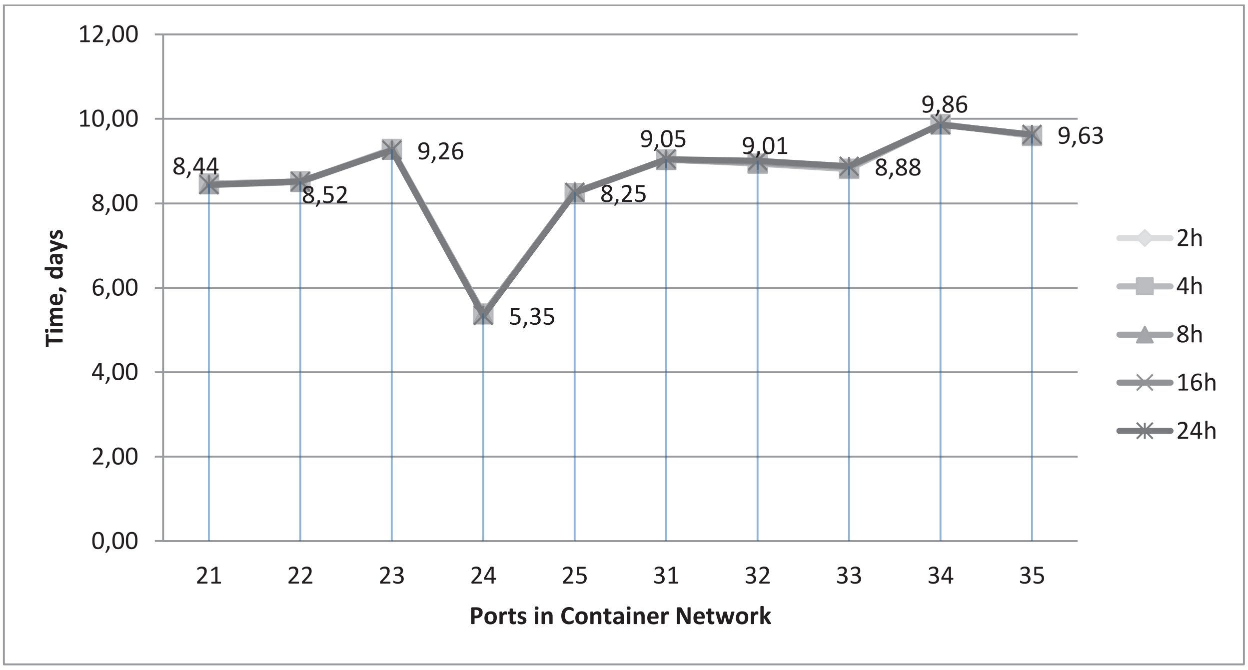

Fig. 26 Time at the terminal if 50% of containers are with e-seals (without routing decisions) and 50% of containers with mechanical seals

Next we investigate the time spent at the terminal for the situation when a container is equipped with a smart seal (Fig. 27). The simulation outcome for the scenario with smart seals is essentially different from the results in simulations for container processes with simple e-seal or with mechanical bolts. The smart functions of e-seals, like communication ability, contribute to the speeding up of transportation processes and impact the efficiency of container flows. The time spend by each container in front of the territory of the port only waiting for the entrance is significant differs to the previously discussed results. The minimum time difference for container with smart seal and for standard equipped container is 0.72 day (point 24); the maximum variation in time is 8.35 days.

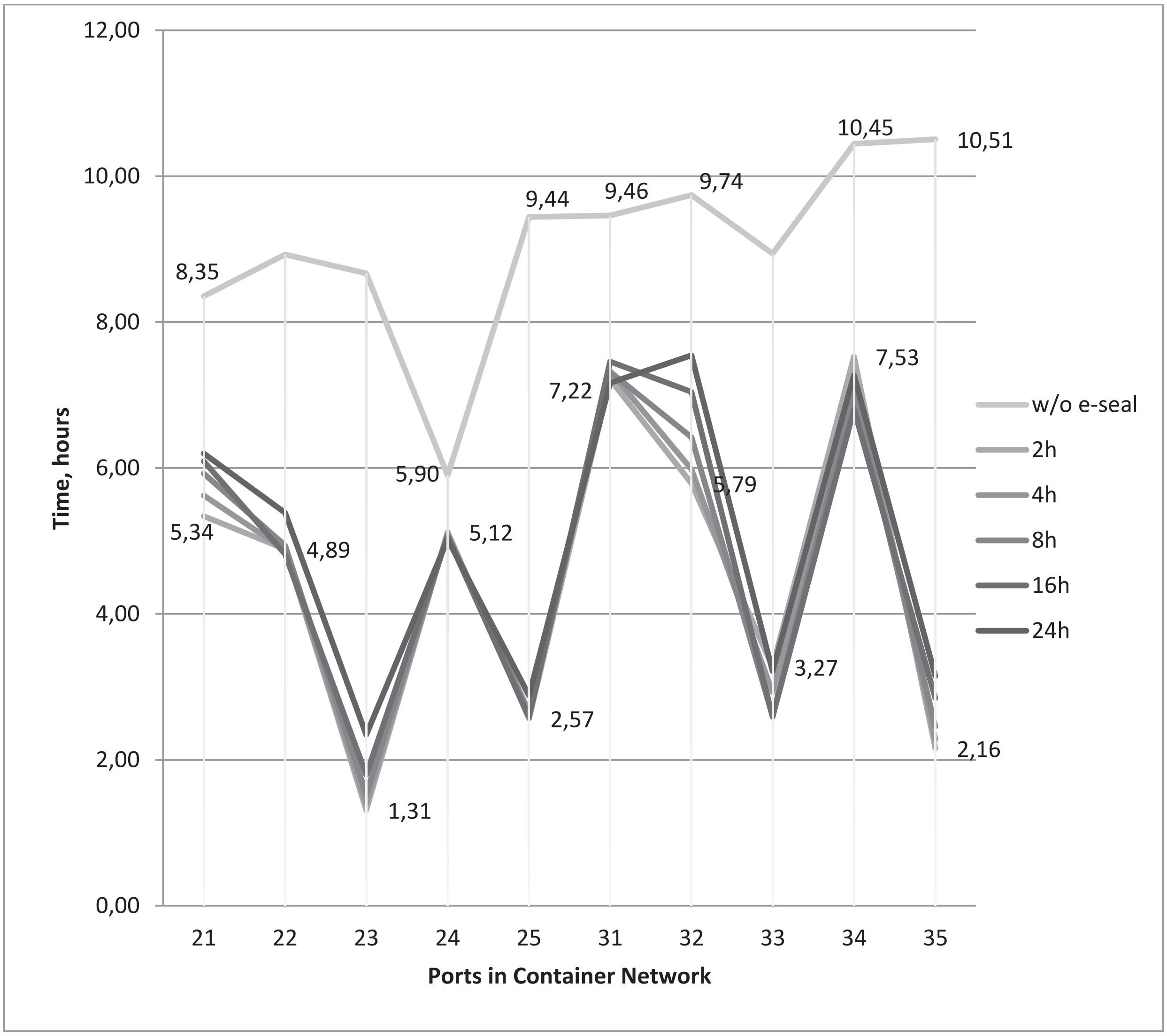

Fig. 27 Time at the terminal if 100% of containers are with smart e-seals (with routing decisions) or 100% of containers with mechanical seals (w/o seals)

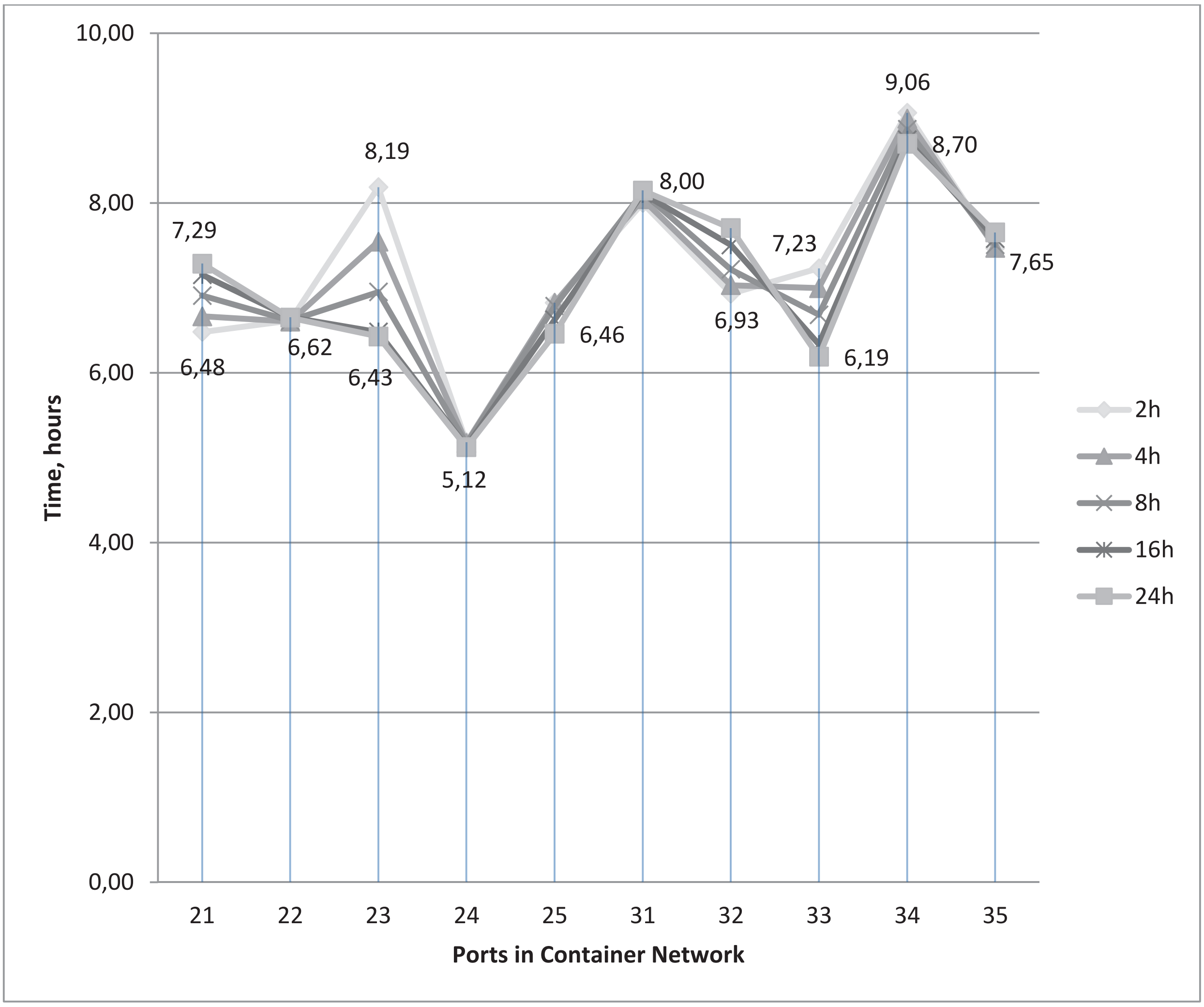

Fig. 28 Time at the terminal if 50% of containers are with smart e-seals (with routing decisions) and 50% of containers with mechanical seals (w/o seals)

As demonstrated in Figure 28, even in the system where 50% of all containers are equipped with smart seal the difference between waiting time in queue in front of the terminal can be more the 1.5 hours (point 23).

- Second time parameter that was aggregated in the simulation model is the time a container has to wait for its customs control after it has arrived at a harbour.

After a container passes the gate control to the terminal, it is required to complete customs formalities. Some documents about the container can be sent to the customs authorities in advance to be approved. In some cases a container needs to wait at the harbour under the customs control up to 2-3 weeks; in other cases it passes the customs scrutiny in several hours.

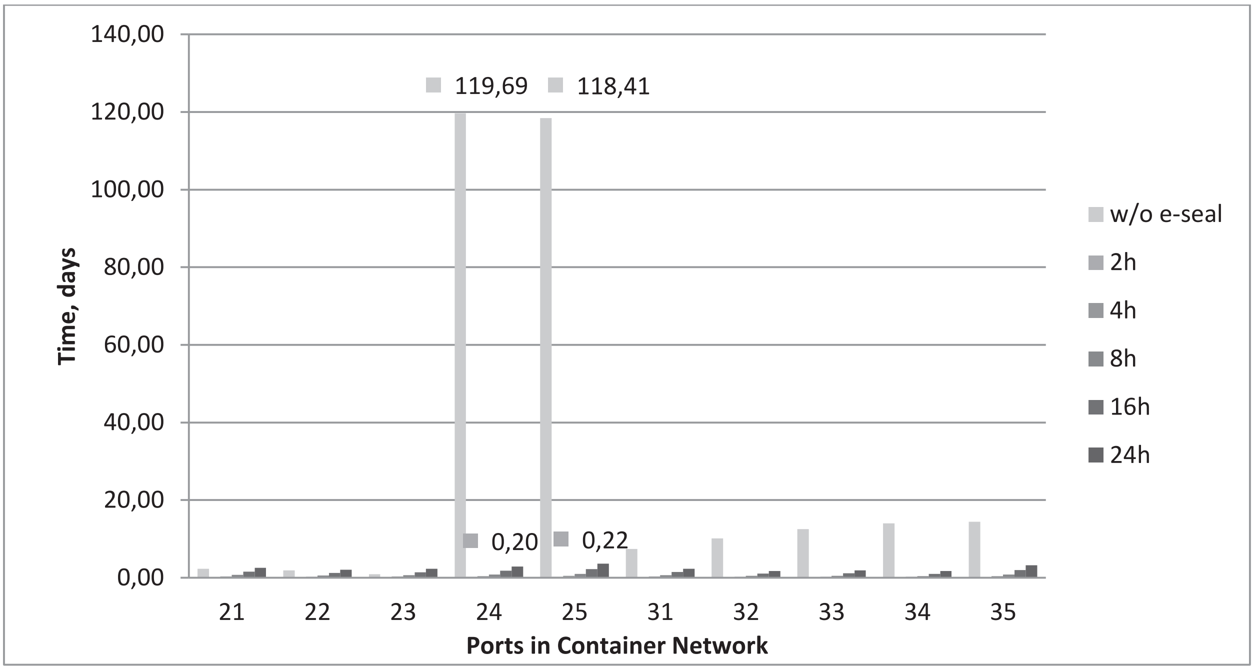

Fig. 29 Time duration in the queue at the terminal waiting for completing customs formalities, if 100% of all containers are equipped with e-seals (without routing decisions) or 100% of all containers are equipped with mechanical seals (w/o seals)

In Figure 29 we present the simulation results for the situation when 100% of containers are equipped with simple e-seals and customs control for them takes 2, 4, 8, 16 and 24 hours respectively. In this case the customs processing time is very low, 0.20 day. The situation is different for the scenario when containers have conventional seals. Under such conditions the containers are subject to intensive examination that takes in extreme case up to 119.69 days (point 24).

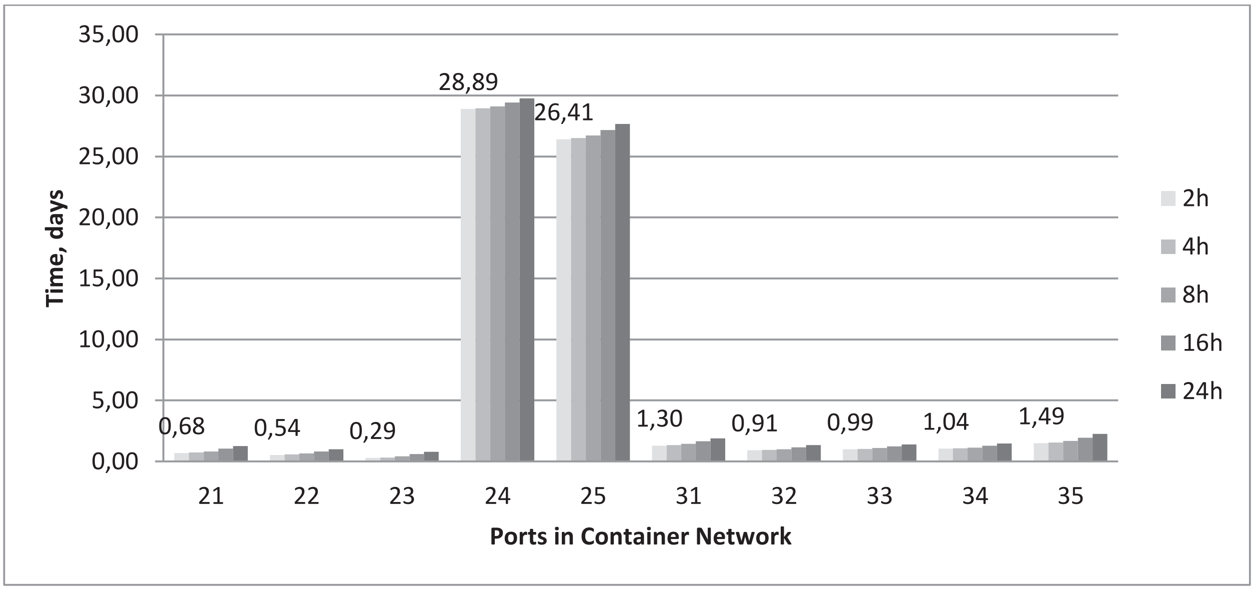

Fig. 30 Time duration in the queue at the terminal waiting for completing customs formalities, if 50% of all containers are equipped with e-seals (without routing decisions) and other 50% of containers are equipped with mechanical seals

The next diagram (Fig. 30) demonstrates the situation in the scenario when 50% of all containers are equipped with simple e-seals and the other 50% are the containers with mechanical seals. Under these conditions the customs waiting time is significantly dropped in the case of point 24, i.e. 28.89 hours instead of 119.69 hours. These results show how the implementation of the new technology can impact the current situation with customs clearance.

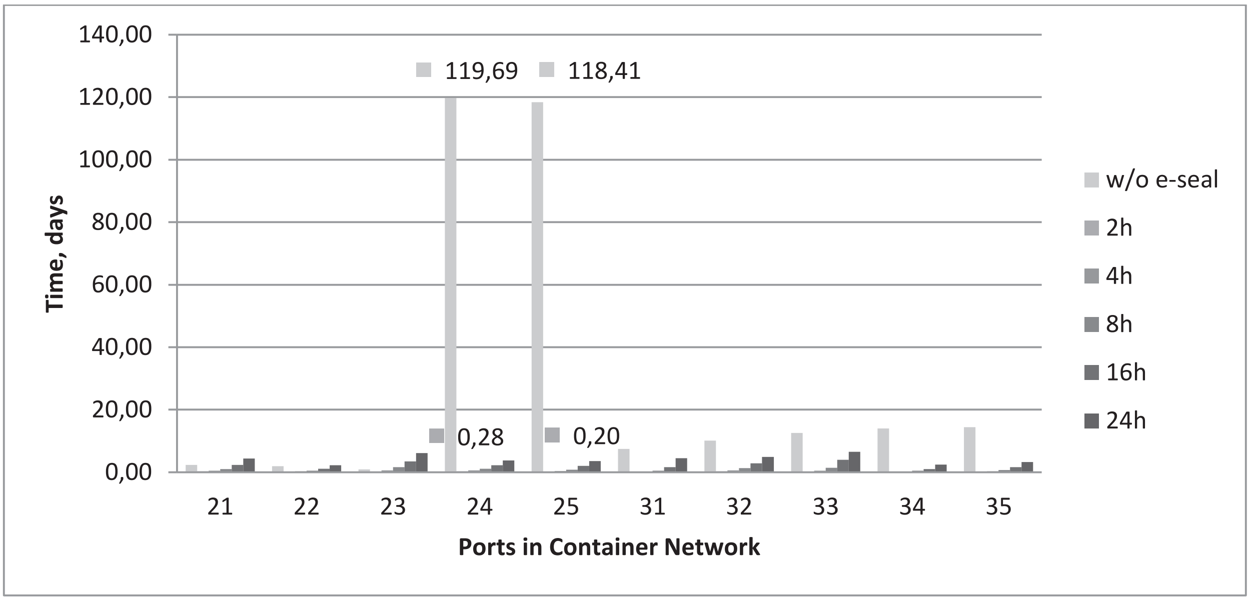

Fig. 31 Time duration in the queue at the terminal waiting for the customs c completing customs formalities, if 100% of all containers are equipped with smart e-seals (with routing decisions) or 100% of all containers are equipped with mechanical seals (w/o seals)

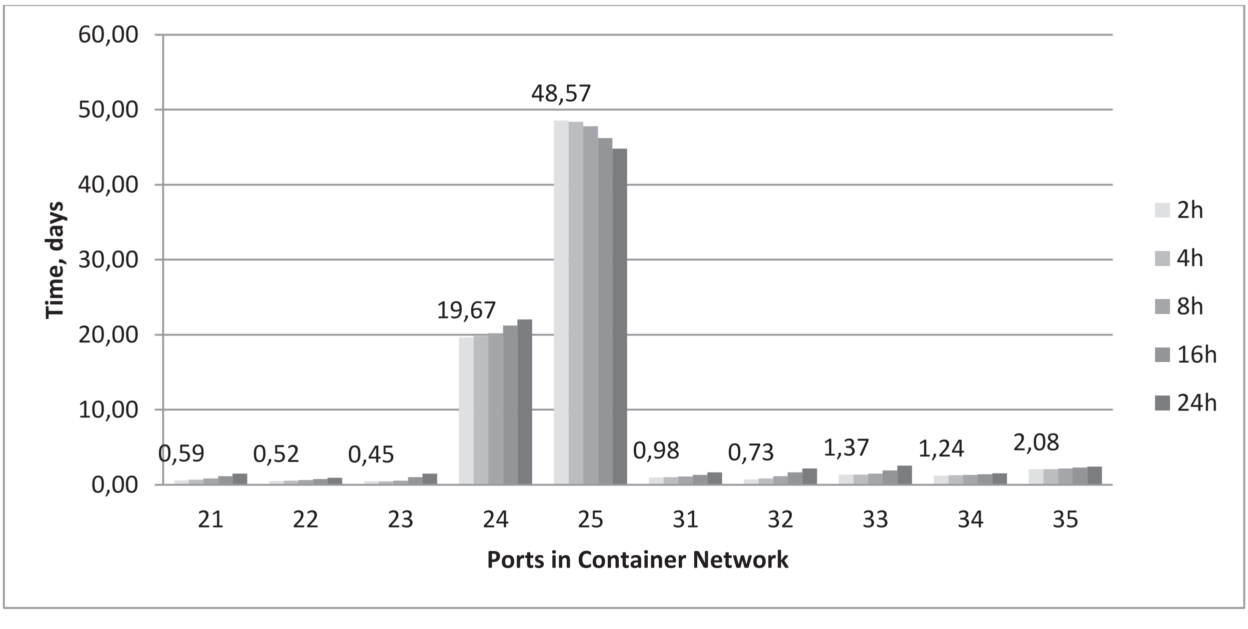

Fig. 32 Time duration in the queue at the terminal waiting for completing customs formalities, if 50% of all containers are equipped with smart e-seals (with routing decisions) and other 50% of containers are equipped with mechanical seals

The distribution of the time that smart containers spent at a terminal waiting for the customs decision is similar to the containers that are equipped with simple e-seal (Fig. 31-32). The reason is that the procedure for customs clearance does not depend on the type of electronic secure device on the container. The customs inspection process depends strongly on the possibility to approve the container integrity in electronic form or not. That is why for containers with mechanical bolt the customs scrutiny takes much more time.

- The third time factor that was obtained from the simulations is the total transportation time of a container in the system.

This factor is crucial for the answer on the most important question of the thesis: How does the choice of particular seal's type impact the dynamics and effectiveness of the whole transportation process in container network?

	DC41	DC42	DC3	DC44	DC45
DC11	43,38	41,389	43,96	44,787	44,561
DC12	45,787	41,472	44,158	46,951	51,219
DC13	44,523	40,982	41,675	46,679	47,023
DC14	113,5	120,53	133,18	116,45	117,75
DC15	111,58	121,28	135,92	130,11	132,58

Table 10 Time duration of a container in the system if 100% of containers are equipped with mechanical seals, days

We have simulated the container flows with actual time for customs processing and imitated situation with container queues during the transportation process. The obtained results are presented in the Table 10. The next Tables 11 and 12 present the detailed information about the total container transportation time in the system for the following scenarios: container equipped with e-seals without routing decisions and container equipped with smart e-seals with routing decisions. As an example, we used 2 scenarios introduced below where 100% of all containers have e-seal and when 24-hour time for customs control was applied for container flows.

	DC41	DC42	DC43	DC44	DC45
DC11	40,53	38,127	39,519	40,702	42,265
DC12	42,238	38,11	39,759	42,194	45,713
DC13	41,257	38,01	38,515	41,84	43,505
DC14	42,171	44,106	44,845	40,589	47,344
DC15	53,767	54,966	57,181	54,631	58,629

Table 11 Time duration in the system when 100 % of containers equipped with e-seals (without routing decisions) under 24 hours customs control

	DC41	DC42	DC43	DC44	DC45
DC11	35,149	34,599	34,749	34,576	34,437
DC12	35,095	34,232	33,946	34,974	34,287
DC13	35,26	34,356	34,479	35,292	34,269
DC14	35,047	36,083	35,091	32,354	37,038
DC15	37,204	36,293	36,966	35,869	38,03

Table 12 Time duration in the system when 100 % of containers equipped with smart e-seals (with routing decisions) under 24 hours customs control

Tables 9, 10, 11 present different transportation times from any point of origin in the container network to any final destination point. Following the data represented in the tables, the tendency to the decreasing of the total transportation time depending on which type of container secure device was used in the transportation process can be seen.

The total transportation time consist of transportation time from DC to Port and from Port to the final destination (DC), transit time on the containership, time spent by the container on the customs and time that container waited in front of terminal.

On the next diagram we illustrated the difference between the total transportation times, for instance, from distribution centre (DC) 43 in China to the DC12 in EU and as other example the total transportation time from DC 41 in China to the DC15 in USA.

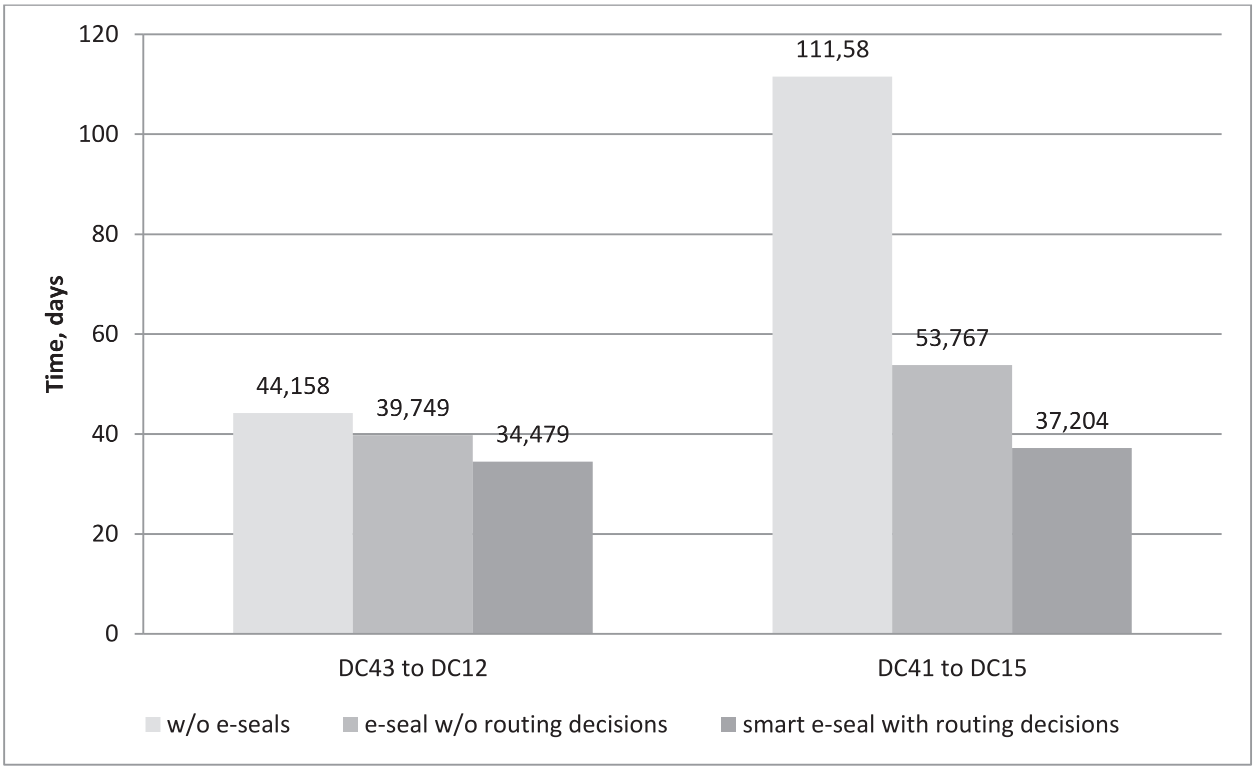

Fig. 33 Total transportation time for container in the network (without e-seals and with e-seal under 24 hour's customs control)

Figure 33 demonstrates a strong tendency to decrease transportation time in dependence on which secure device was chosen for container integrity. This data shows that even in cases when customs control can be passed during the optimal time slot (in EU customs border control may takes less than 0.5 day), it is still possible to improve the whole container transportation process. In the situation when the customs scrutiny is a significant part of delivery time (as in a second illustration for DC41 to DC15; in USA customs formalities may take up to 15 days for each container shipment), it is a meaningful effect from electronic container intrusion detection technology that can shorten a transportation time and speed the delivery time of containers.

The above considerations prove and make it evident that implementation of electronic devices can essentially accelerate the global container turnover.

5.4.3 Impact on storage places

Storage is an important constraining factor in logistics management for many ports. The terminal storage capacity depends on stacking heights, net storage area available, storage density (containers per acre), dwell times for empty containers, and break-bulk cargo (Chen, Fu, & Lim, 2004). The obtained simulation results do not affect directly the optimization of container storage in the ports.

Nevertheless, the fact, that application of electronic intrusion detection technology decreases the throughput time at terminals and in the whole system, it allows to estimate the indirect impact on the optimization processes in the port, in particular in communication sphere and in solving of optimization problems. In the case of dramatic drop down of time for customs checks in the ports (from the maximum of 118.41 days to the maximum of 28.89 days) and a reduced time that containers spent in the stay-going-process in the queues in front of the terminal (more than 8 days less) as it is simulated in the work, the storage places in the ports can be more effectively used by more containers. In our case, the simulation results show that under the same conditions in the ports but using the new securing and at the same time communication technology (e-seals) the container turnover in the port can increase by 30-32% annually. In other words, using the same port storage territory the port can get higher utilization rate already on the storage places.

Creation of new area for container storage territories requires very expensive investments for many ports. Moreover in many cases there are no more free spaces nearby a lot of mega-ports. Due to these reasons it is extremely difficult to build new container storage areas. Investments in new infrastructure for more secure container trade can bring a new utilization rate for port storage territory without any investments in its expansion or re-organization.
The globalization of the world economy by which locations of productions and consumptions has been diversified into nations has resulted in rapid growth of demands for the intermodal container transportation. Globalization in world trade has a great variety of environmental impacts extensively marked in numerous global change and climate change. The emergence of new markets, sectors, and new forms of competition results in an increase of trade and foreign direct investment. The general trend in international transport is clearly a growth in volume and distance and a modal shift to less environment friendly modes. If these trends continue, CO_2 emissions caused by transport will lead to increasingly unsustainable outcomes (van Veen-Groot & Nijkamp, 1999).

In general, four categories of technologies for improvement of global environment can be distinguished, namely, an improvement of existing transport modes, the development of new transport modes, improvement in the management of transport (such as logistics and route planning systems) and the development of alternative fuels (van Veen-Groot & Nijkamp, 1999). One of these directions is closely related to the enhancement of the safety and security situation in container logistics. Smart e-seals which are able to communicate with logistic operator/provider and react suitably on the real-time conditions during cargo transportation can improve the container transport management.

5.4.4 Environmental aspects

It is reality that the transport sector is a significant contributor to local air pollution, noise annoyance and intrusion of landscapes, congestion, and high fatality rates. Transport also damages the global environment. It contributes to two prominent global environmental problems, namely, the greenhouse effect (global warming) and the depletion of the ozone layer. Certainly the heavy traffic jams of trucks at the gates of container terminals negatively affect the ecology.

This thesis considers as well environmental damages caused by container congestions in ports. Our simulation results (from the model simulated with help of MATLAB) are used to investigate how implementation of advanced secure devices on containers can reduce the congestion of trucks at a gate of container terminal and impact on ecological aspects of port industry. Truck delays associated with operations at the Southern California ports (Giuliano & O'Brien, 2007); about 40% of all transactions, pick-ups or drop-offs of container, have an estimated wait times of over 2 h. Survey results showed that drivers spend a significant portion of their workday waiting at the ports (Giuliano & O'Brien, 2007).

The simulation model simulates two possible alternatives: when containers are equipped with very simple electronic seals and when containers are modernized with smart technology, like smart e-seals. Based on simulation outcome the time that container with difference types of e-seals spent in the queues in front of the terminal gates is different as well. Unnecessary idling of trucks with containers wastes fuel and results in emissions that degrade local air quality and contribute to climate change.

The percentage of shipments sent to the diverse U.S. secondary inspection stations varies from crossing to crossing but is generally consistent with the availability of inspection capacity. Customs strives to ensure that its NII equipment is kept continuously operating. The private-sector reports that, occasionally, port directors impose inspection blitzes where 100 percent of the vehicles entering the port during a given time period are sent to an NII station. Officials at smaller ports of entry that lack NII equipment typically conduct higher rates of canine and manual narcotics inspections. Approximately 10 to15 percent of shipments governed by the USDA are physically examined.

The length of time commercial vehicles spend waiting for and undergoing secondary inspections is also highly variable. NII inspections take between 2 and 12 minutes to complete but may require queuing times of 30 to 60 minutes. Delays for USDA and FDA inspections usually range from 20 to 45 minutes if an inspector is readily available.

Idling Time	1 hour	365 hours
Engine	Post 1995 Class 8 Diesel Truck Engine	Post 1995 Class 8 Diesel Truck Engine
RPM	800	800
Fuel Consumption	4 litres	1,460 litres
GHG Emissions	11.2 kg	4,008 kg
PM	1 - 5 g	365 - 1,835 g
NOx	140 g	51,000 g
Cost of Diesel (99.9 cents/liter)	$4.00	$1,458.54

Table 13 Examples of trucks' idling impact (EPA, 2009)

In the world the most giant container ports are situated near to the cities or inside them. Therefore, another important reason to reduce criteria air pollutants, carbon dioxide emissions, and toxic air emissions is an emerging issue for the transportation community in general and many metropolitan areas in particular. The resulting emissions related to truck idling include 163,000 metric tons (180,000 tons) of nitrogen oxides (NOx), 4,535 metric tons (5,000 tons) of particulate matter, and 9.98 million metric tons (11 million tons) of carbon dioxide (CO_2) per year. Environmental Protection Agency US (EPA) estimates that approximately 500,000 to 1 million long-haul trucks are in operation today, each idling anywhere from 1,800 to 2,400 hours per year. EPA data have shown that a long-haul truck at idle for 1 hour burns approximately 3.8 litters of diesel fuel. Cumulatively, idling wastes as much as 3.78 billion litters of fuel per year (EPA, 2009). Reducing unnecessary idling could save each truck over $3,000 in fuel costs, reduce air pollution, and cut 19 metric tons of carbon dioxide annually.

Hence, the simulated scenarios with using various types of container seals demonstrated the ability of more advanced secure devices to invest in the saving of global environment. The ability of innovative technology to react on the changes in container transportation situation in real-time and in need-time, promises to decrease the level of congestion at the port terminal gates.

5.5 Cost-Benefit Analysis of container secure network

The container industry has proven to be a remarkably efficient commercial system, designed to move goods through the international supply chain in the fastest way. The main drivers of the system are speed and low cost. The existing trend demonstrates the importance of development and implementation of new security detecting technology, like RFID e-seals in container transportation to achieve international secure and efficient global trade. Here we propose a model for cost-benefit analysis to estimate potential costs and direct benefits through the implementation and use of RFID container electronic seals in global secure container network. We have the aim to create a cost/benefit model to prove the benefits from container security devices in new kind of transport networks – secure container networks. The model is based on Cost-Benefit Analysis (CBA) and developed within the Excel framework for fast analysis of requested secure networks or supply chains. In the next sections we describe and discuss the cost-benefit model for secure networks and present final the results and conclusions.

5.5.1 General Description of Cost Benefit Model

We consider a container network that connects China and Europe through container transportation. In this network the containers are equipped with container security devices that use RFID technology. We assume that under such condition the container network will achieve several levels of safety and security. These security levels depend on the security/safety protection level of secure devices and their ability to provide container track-and-tracing during containers journey.

In the research we propose the analysis that intends to estimate possible costs and benefits through the implementation and use of RFID container electronic seals in global secure container network. All supply chain data and cost information can be modified based upon actual information. Each benefit is based upon anticipated changes in supply chain performance that may or may not be realized (i.e. reduced inspections, reduced security costs, etc.) from using RFID e-seals technology. In the cost-benefit model (CB Model) we assume that infrastructure costs for ports (RFID reading equipment, container security devices, software, etc.) and individual intra-infrastructure costs are accounted to the shippers and customers. In this case ports and container terminal operators do not need to finance the building of RFID infrastructure, although it would require the legal allowances from their authorities.

In this work we assume that all costs and further exploitation costs will be undertaken by private sector (shipper/customers/service providers). Therefore, in the analysis it is assumed that ports and terminal operators or customs administrations are not purchased for any charges to use the security devices/infrastructures. There are several qualitative benefits for supply chains participants that have not been included in CB Model. One of them is the ports competitive advantages from CSDs' detection infrastructure. Ports can provide new kind of service for the innovative customers, which has already use e-seals in the transportation process. Another gain is that such ports are more attractive among others for new companies looking for the partners that can provide higher level of security and visibility for their cargo flows. The benefits to shippers/customers such as brand protection and damage of reputation (contaminated goods or non-delivery of goods) or common benefits such as impact on global environment (i.e. reduction of port traffic congestion, reduction of air pollution via idling trucks at the ports etc.) have been not included as well.

Here we propose the analysis which is intended to estimate possible costs and benefits through the implementation and use of RFID container electronic seals in global secure container network (Scholz-Reiter, Haasis & Daschkovska, 2012).

5.5.2 Description of the initial conditions for Cost Benefit Model

In this research work we consider two types of container electronic secure devices:

- Electronic seal (simple e-seal) with basic functionality to detect container door breach and identify a location at pass points in container network via readers.
- Advanced container electronic secure device (smart e-seal) with functionality such as ability to send alarm information about container status in real time and make routing decisions autonomously. The temperature or humidity sensors that may have additional costs and benefits are not included.

Containerized cargo includes every commodity imaginable – retail such as clothing and electronics, foodstuffs, agricultural products and industrial goods. One 20' container can hold 6,192shoeboxes, which might be equal to 61,192 EUR. One 20' container can hold 27,755 cartons of filtered cigarettes; and they are equal already to 555,110 EUR (if one carton (10 boxes) costs 20 EUR). However, when we consider the costs for detection technology new infrastructure, then it is required to assume some data essential for calculations on return on investments.

Most benefits assigned primarily are to the shipper/consignee with some benefits being shared with container terminals and Customs administrations. The entire benefits obtained from using new technology in container logistics are interconnected with all partners in supply chain and cannot be achieved by individual company or industry. The infrastructure investments for ports (such as RFID reading equipment, software) are also taken inti account in this analysis as well as individual intra-infrastructure investments for shippers and customers. The investments for ports or terminals might come to zero in case when technology providers or shippers/customers invest in it. We assume that all investments and further exploitation will be undertaken by private sector (shipper/customers/service providers). Therefore, in the analysis we assume that ports and terminal operators or customs administrations do not invest in the security devices/infrastructures.

We included only the direct benefits which are on the top of the pyramid of the potential benefits from e-seals in container systems. In other words, the CBA deals with anticipated benefits from applying the RFID seals on containers such as reduced inspections, reduction in insurance costs and lead time variation costs, etc. Not all of these benefits might be realized in each supply chain based only on implementation of e-seals in container processes.

The qualitative benefits like ports competitive advantages from having RFID container e-seal detection infrastructure by providing new kind of service for own innovative customers, that using e-seals, and open the port gates for new companies looking for the partners that can provide higher level of security and visibility for their cargo flows, etc. have not been included. The benefits to shippers/customers such as brand protection and damage of reputation (contaminated goods or non-delivery of goods) or common benefits such as impact on global environment (i.e. reduction in port traffic congestion, reduction of air pollution via idling trucks at the ports etc.) have been not included as well.

We considered the results obtained from the simulated model of our container system and found that the total throughput through secure network from origin point to destination point is 23,891 TEUs (T) yearly for container equipped with mechanical seals. An important aspect is transportation time under the customs inspections in the ports. This value is changing depend on the country of origin and destination.

We apply the analysis to the various cases:

1. Containers are equipped with different types of e-seals (simple e-seal and smart e-seal);
2. Containers contain cargo with diverse cost values (namely, shoes and cigarettes);
3. Transportation time depends on shippers and customers geographical positions and the customs procedures in each country (two routes with container flows were chosen from China (DC 43) to Europe (DC12) and from China (DC41) to US (DC15) and vice versa).

Case 01: container is equipped with simple e-seal and carries the shoeboxes from China to EU.

Case 02: container is equipped with smart e-seal and carries the shoeboxes from China to EU.

Case 03: container is equipped with simple e-seal and carries the cigarettes from China to EU.

Case 04: container is equipped with smart e-seal and carries the cigarettes from China to EU.

Case 05: container is equipped with simple e-seal and carries the shoeboxes from China to US.

Case 06: container is equipped with smart e-seal and carries the shoeboxes from China to US.

Case 07: container is equipped with simple e-seal and carries the cigarettes from China to US.

Case 08: container is equipped with smart e-seal and carries the cigarettes from China to US.

The data for transportation time on different container routes were derived from the simulation model for container secure network (Table 14). The average values of transportation time information for two main global container flows China-Europe and China-US are used to evaluate the cost-benefit analysis for container secure devices.

Route	Without e-seals, t_1	With electronic seals, t_2	
		Simple e-seals,	Smart e-seals
China – EU	44 days	40 days	34 days
China – US	111 days	54 days	37 days

Table 14 Average trip duration per container, days (author's calculations)

Table 15 introduces the general supply chain data required for cost benefit analysis of secure container network. The data of Table 15 consider the structure of the model of our container system as well as customs formalities procedure and costs for inspections.

General Container Network Information	Abbr.	Data
Container turnover per year, TEU	N	23,891 TEUs
Average value of each container shipment, 2 types, €	V	61,192 € (cheap) 555,110 € (expensive)
Inventory costs, %	α	5 %
Insurance costs , %	β	5 %
Reduction in insurance costs due to e-seal use (expected), %	β_a	1 %
Average reduction in containers lost/theft per year, %	l	0,5 %
Avoiding safeguards costs in shipper budget for securing containers, €	$C_{sec.}$	200 €
Reduction in securing processes costs for shipper due to e-seal use, %	μ	20 % (simple seals) 75 % (smart seals)
Transaction costs for E-seal integrity verification per trip (at least 2 times per € 3), €	$C_{integ.}$	6 €
Current customs (noninvasive) inspection rate for containers, %	r	5 %
Customs inspection rate for containers with e-seals, %	r_a	2 % (simple seals) 0 % (smart seals)
Average costs for customs inspection , €	$C_{insp.}$	200 €
Current secondary (invasive) inspection rate (physically), %	r"	0,5 %
Customs secondary inspection rate for containers with e-seals, %	r''_a	0,2 % (simple seals) 0 % (smart seals)
Average costs for customs secondary inspection, €	$C''_{insp.}$	1000 €
Time delay via physical inspection, days	t_d	3 days

Table 15 General container network customs inspection information

To estimate the investment costs in network infrastructure it is required to analyse the structure of each port and possible changes in distribution centre equipment (handheld or fixed readers), the costs for container equipment with RFID seals and possible communication costs connected with system operation (Table 16).

E-seals Infrastructure Information	Abbr.	Data
Number of ports in the network	p	10
Number of gates per port to be equipped with fixed readers	p_f	20
Number handheld readers per port	p_h	20
Number of shippers/customers DCs	d	10
Number of fixed readers per DC	d_f	1
Number handheld readers per DC	d_h	1
Cost per fixed reader	C_f	3000 €/unit
Cost per handheld reader	C_h	500 €/unit
E-seal cost per trip	C_e	0,50 € (simple seal) € 50 € (smart seal)
Security fee per container per port	f	5 €
Data communications costs per reader per year	$C_{comm.}$	61,680 €/unit(simple seal) 69,668 €/unit(smart seal)
Cost of installation per fixed reader	$C_{inst.}$	1,500 €/unit
Cost of license for new service, other additional costs	C_o	€ 5,000 €

Table 16 E-seals infrastructure data in container network

Therefore, the cost benefit model in order to obtain the total profit from the implementation of secure infrastructure in the whole network can be given in the following form:

$$P = (R - C)/N_{cont.} \tag{39}$$

where R is the total savings in the secure network and C is the total costs associated with implementation of required infrastructure for the network.

Furthermore, we determine costs and savings in our model in order to evaluate the effect of implementation of container security devices to the logistic supply chain.

5.5.3 Evaluation of infrastructure costs in cost-benefit model

Here we introduce our model in order to evaluate total infrastructure, equipment (e-seals) and communication costs for the considered container network. The total infrastructure costs in the container network C consist of all costs needed to be assessed in order to build a fully functional secure network, except costs mentioned earlier:

$$C = \sum_{i=1}^{n} C_i \, , n = 5 \tag{40}$$

where C_i – different infrastructure costs; n – number of investment costs modules.

Total port infrastructure costs C_1 can be obtained from the following formula:

$$C_1 = p * \{p_f * (C_f + C_{inst} + C_o) + p_h * C_h\} \tag{41}$$

We evaluate the distribution centres equipment infrastructure costs C_2 via:

$$C_2 = d * \{d_f * (C_f + C_{inst} + C_o) + d_h * C_h\} \tag{42}$$

The next element of the total costs is container security device costs C_3 can be obtained from the following formula:

$$C_3 = C_e + 2 * f + C_{integr} \tag{43}$$

The e-seal's costs per trip after the 2^{nd} year of use should be evaluated with differentiation between two types of e-seals considered in this research. Namely, the costs for usage of simple e-seals in the second year $C_{6\ simple}$ are similar to each year. Simple e-seals cannot be applied for the second trip of the container as well as to be in operation after they are tampered with or broken by customs authorities for the physical checks of the containers.

In contrast to that, smart e-seals are able to stay in operation for many container trips. In the first year of usage the main component of costs C_3 for smart e-seals is the costs of the device itself. Therefore, during the usage of the container in 2^{nd} and the next years the costs, C_6 consist of "additional cost per trip per port for security fee in the ports, *f*" and "cost per trip to verify seal integrity or check container door in the terminal, *i*":

$$C_{6\,simple} = C_3 \quad (44)$$

$$C_{6\,smart} = f + i \quad (45)$$

Communication costs C_4 for ports in the network and for each distribution centre C_5 of same network we evaluate by mean of the following equations:

$$C_4 = C_{comm} * p * (p_f + p_h) \quad (46)$$

$$C_5 = C_{comm} * d * (d_f + d_h) \quad (47)$$

Taking into consideration the initial data for network infrastructure (Table 17), the general investments in the whole container system were evaluated.

E-seals Infrastructure Costs	Data	
	Simple e-seal	Smart e-seal
Total port infrastructure costs	2,020,000.00 €	2,020,000.00 €
Total distribution centres' infrastructure costs	101,000.00 €	101,000.00 €
E-seal costs per trip	16.50 €	316.00 €*
E-seal costs per trip after 2^{nd} year of use	16.50 €	16.00 €
Data communications costs for port	13,933,600.00 €	13,933,600.00 €
Data communications costs for distribution centres	696,680.00 €	696,680.00 €

Table 17 Total infrastructure costs for container secure network

In this section the fixed costs for acquisition of RFID devices and the appropriate equipment for reading and programming them as well as original costs of equipment have been indicated and calculated.

5.5.4 Evaluation of direct benefits from usage of electronic secure devices in secure container network

The total benefits that shipper/customers might acquire from investing in secure container network consist of reductions in inspection costs and securing the container transportation processes, as well decrease in lead time variation in container transport system and insurance rates per container and dropping down the number of lost or theft container over the container system. The data for total benefits or savings in the system evaluation are obtained by using following equations.

Total costs saving per container per trip in secure container network R savings per container per trip for each type of possible benefit R_1':

$$R = \sum_{j=1}^{k} R_j \, , k = 6 \tag{48}$$

$$R_j' = \frac{R_j}{N}, j = \overline{1,k}, k = 6 \tag{49}$$

where R_j– different infrastructure costs; k – number of saving costs elements.

One of the essential savings in secure container network can be achieved through the reductions in customs inspection costs R_1 and reductions in additional physical inspection costs R_2:

$$R_1 = N * C_{insp} * (r - r_a) \tag{50}$$

$$R_2 = N * C''_{insp} * (r'' - r_a'') + \frac{t_d}{365} * \alpha * V * r_a'' \tag{51}$$

We obtain the further advantages in secure network from the reductions in avoiding additional costs for container securing process R_3:

$$R_3 = N * C_{sec} * \mu \tag{52}$$

The improvement of the safety and security standards in the container transportation can impact the insurance rates for the container voyage. This benefit can be verified from the following equation R_4:

$$R_4 = N * V * \beta * \beta_a \tag{53}$$

Reliable and predictable container transportation processes will influence the supply chain lead time variation and can reduce the appropriate costs R_5:

$$R_5 = N * V * \frac{t_2 - t_1}{365} * \alpha \tag{54}$$

We consider reductions of supply chain container lost or theft costs R_6:

$$R_6 = N * V * l \tag{55}$$

After defining cost and benefit aspects of container secure network we make an analyses of our cost-benefit model.

Summary of Costs Savings in secure network	Data							
	Case 01	Case 02	Case 03	Case 04	Case 05	Case 06	Case 07	Case 08
Reduction in customs inspection costs per trip	6.00 €	10.00 €	6.00 €	10.00 €	6.00 €	10.00 €	6.00 €	10.00 €
Reduction in secondary inspection costs per trip	3.00 €	5.00 €	3.00 €	5.00 €	3.00 €	5.00 €	3.00 €	5.00 €
Reduction in avoiding additional security process costs	40.00 €	150.00 €	40.00 €	150.00 €	40.00 €	150.00 €	40.00 €	150.00 €
Reduction in insurance costs	30.96 €	30.96 €	277.56 €	277.56 €	30.96 €	30.96 €	277.56 €	277.56 €
Reduction in supply chain lead time variation costs	33.93€	84.82 €	304.17€	760.42€	483.48 €	483.48 €	4,334.42 €	5,627.14 €
Reduction in supply chain possible container lost or theft costs	- €	309.60 €	- €	309.60 €	- €	309.60 €	- €	309.60 €
Total Expected Savings/Benefit Per Container Trip	**113.89 €**	**590.38 €**	**630.72 €**	**1,512.58 €**	**563.44 €**	**989.04 €**	**4,660.98 €**	**6,379.30 €**

Table 18 Summary of Costs Savings in secure network

As illustrated in the Table 18 the parameters have always positive values. In other words, even if the changes in containers transportation due to use of secure device are not too significant, the total profit per container trip still exists. The benefits are obtained from the implementation of additional security tracking technology (e.g. e-seals) that helps to achieve the maximum savings of costs for the whole network. In some cases the savings are essential (cases 04-06) comparing to other ones. This situation occurs because of differences in transport/customs clearance durations on different transport routes. If there is a possibility to avoid or to minimize lead time variations, it comes to vital reductions in transport time / lead time variations in secure networks.

Nevertheless, to achieve these savings it is required first to invest in the container network infrastructure. By means of return on investment analysis we are able to evaluate the investment by comparing the magnitude and timing of expected gains to the investment costs.

5.5.5 Cost-benefit ratio for container secure networks

Previously we have defined cost and savings parameters of secure container network. In order to evaluate our model we consider the Cost Benefit Ratio of the whole transport system. The general formula the Ratio is following (Roulstone & Phillips, 2008):

$$CBR_{network} = Benefits/Costs_T \tag{56}$$

$Costs_T$ are expenses that have been spent during the particular evaluation period to create the secure container network.

T is a time period equal to 1 year. The CBRs are calculated taking into consideration a 3 year (T=1, 2, 3) evaluation period for the whole container secure network.

A proper Cost Benefit Ratio in the container network/container trip we can calculate as follows:

$$CBR\ per\ cont. = \frac{CBR_{network}}{Total\ Container\ Turnover} \tag{57}$$

The cost-benefit ratios has been calculated based on 3 years period. The obtained results are shown below for the previously introduced supply chain scenarios (Table 19).

Cases	Total Cost per container trip after 3 year period, €	Total Benefit per container trip after 3 year period, €	Profit per container trip after 3 year period, €
Case 01	660,41	113,89	-546,52
Case 02	659,51	590,38	-69,53
Case 03	660,41	630,72	-29,68
Case 04	659,91	1512,58	852,67
Case 05	660,41	563,44	-96,96
Case 06	659,91	989,04	329,14
Case 07	660,41	4660,98	4000,57
Case 08	659,91	6379,30	5719,39

Table 19 Results of cost benefit ratios

The profit values for each case have been acquired from the proposed cost-benefit model and presented in the following tables.

The analysis of cost-benefit ratio comparing between evaluated scenarios allows us to summarize that the last three cases 06-08 offer the best cost-benefit ratio values because of enormous dissimilarity in delivery time for each container before and after e-seals implementation in transportation process (Scholz-Reiter, Haasis & Daschkovska, 2012).

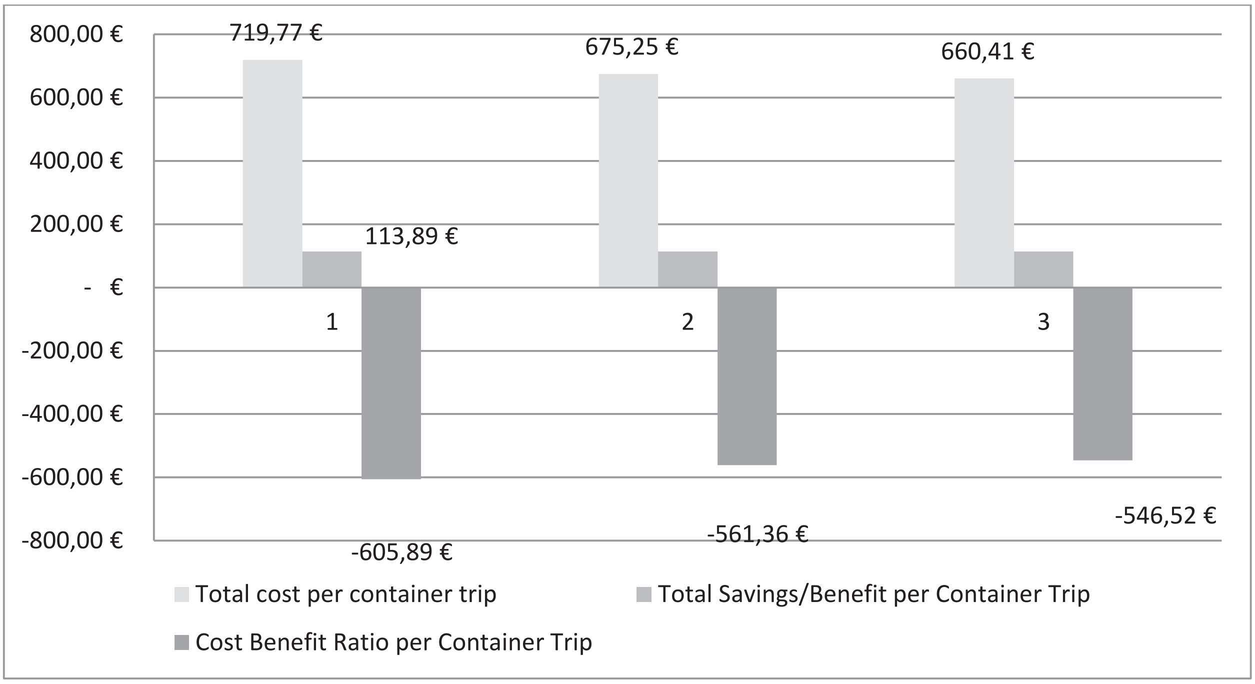

Fig. 34 Results of cost benefit analyses (case 01)

Case 02: container is equipped with smart e-seal and carries "cheap" cargo from China to EU.

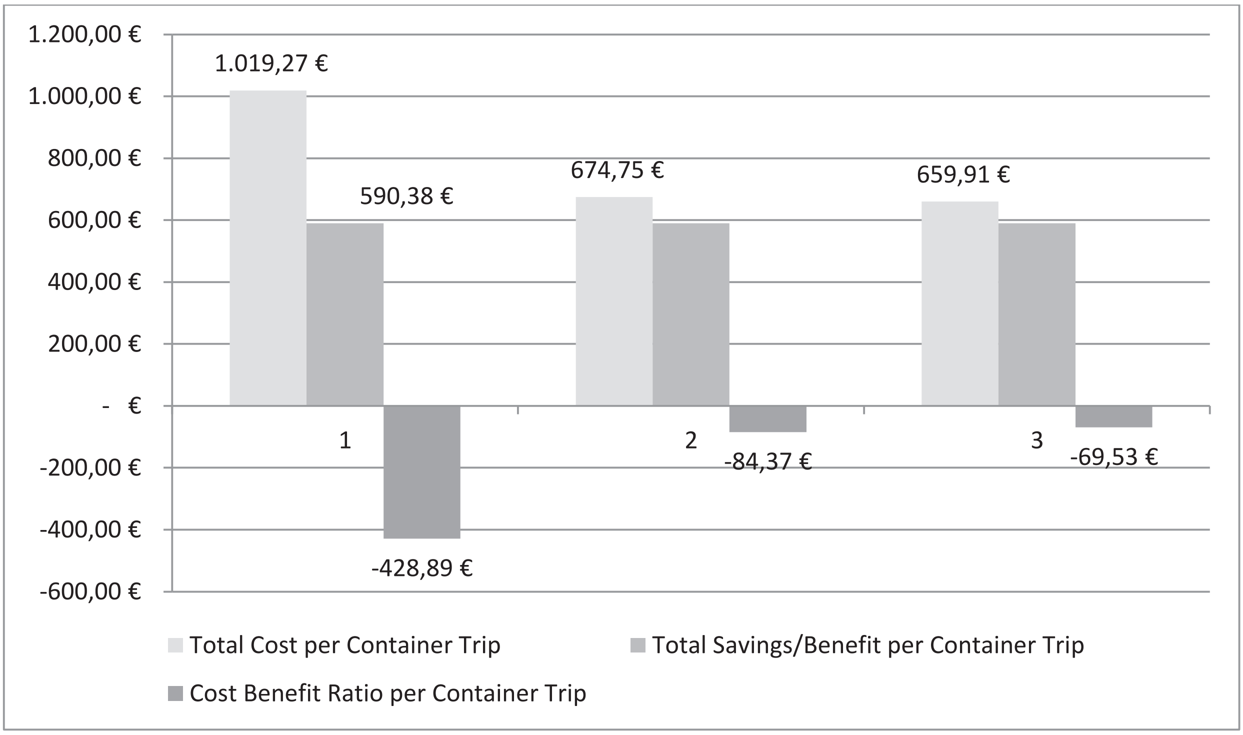

Fig. 35 Results of cost benefit analyses (case 01)

Case 03: container is equipped with simple e-seal and carries “expensive” cargo from China to EU.

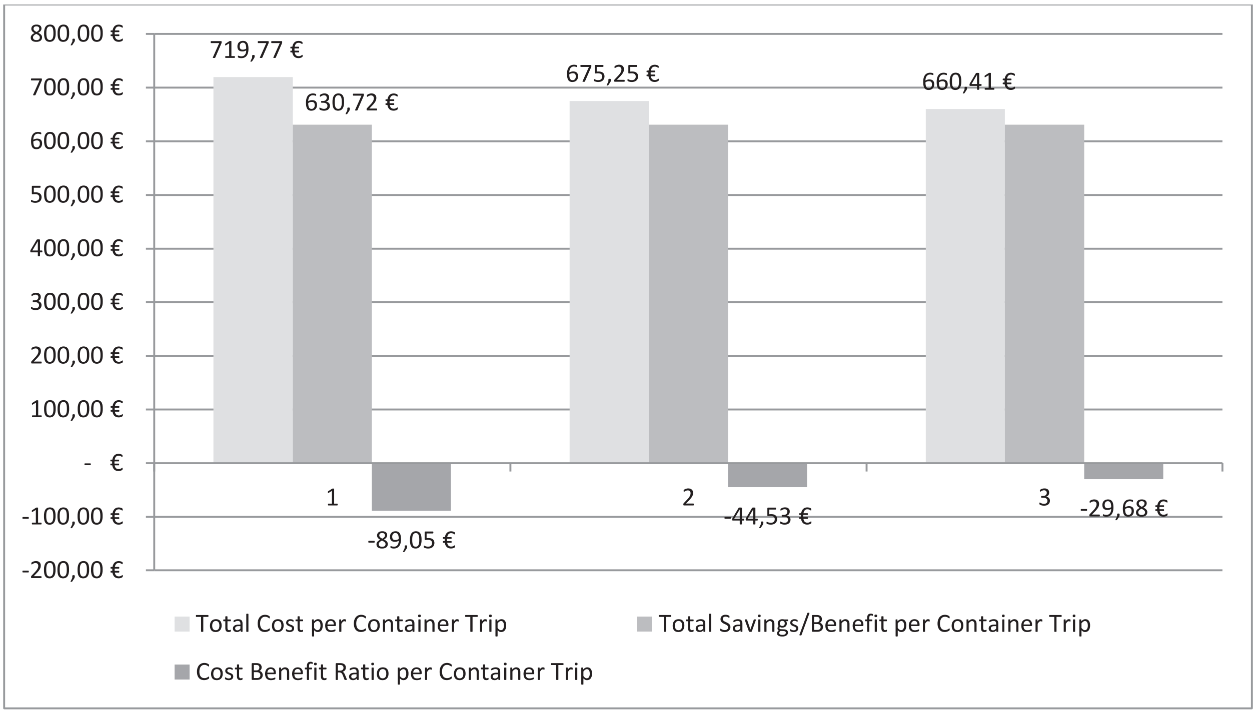

Fig. 36 Results of cost benefit analyses (case 03)

Case 04: container is equipped with smart e-seal and carries “expensive” cargo from China to EU.

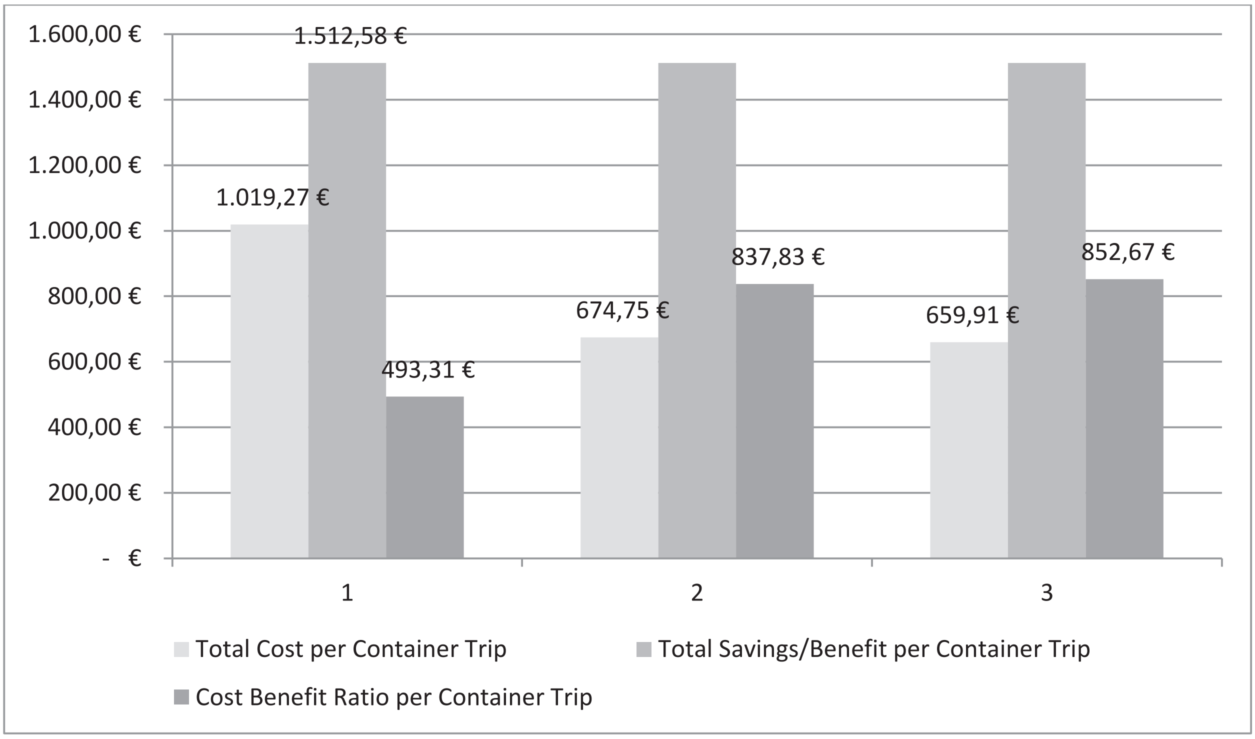

Fig. 37 Results of cost benefit analyses (case 04)

Case 05: container is equipped with simple e-seal and carries “cheap” cargo from China to US.

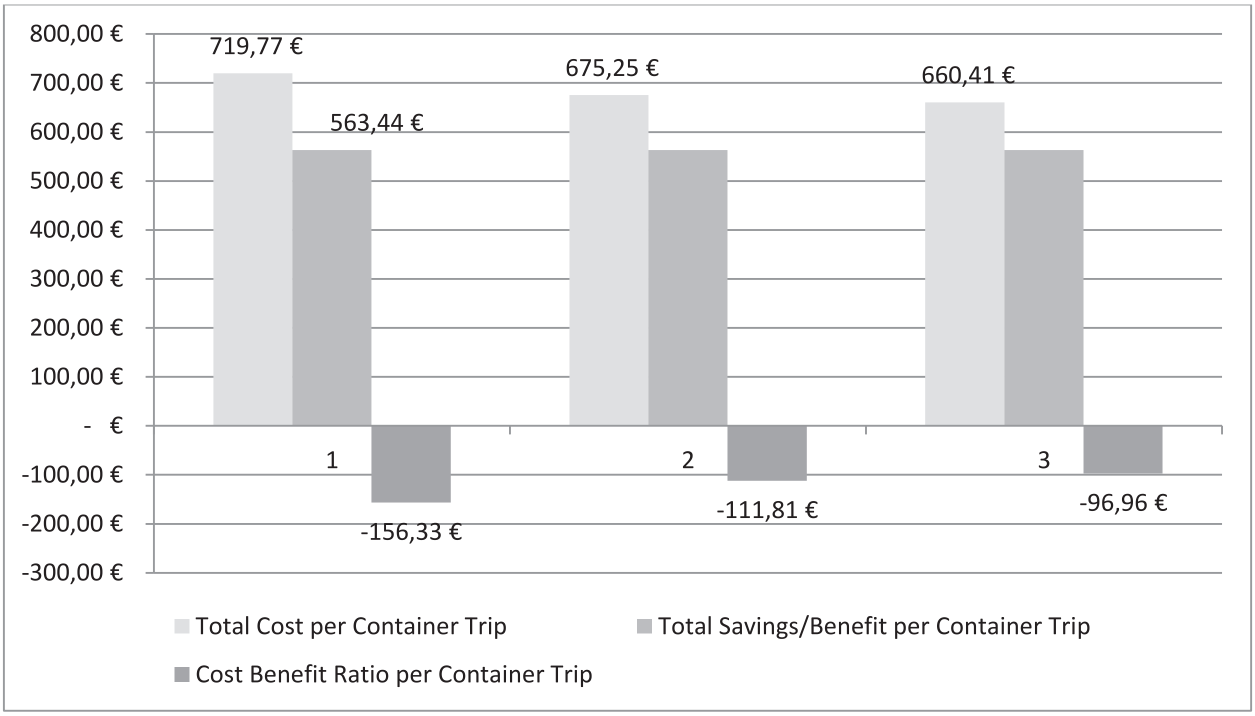

Fig. 38 Results of cost benefit analyses (case 05)

Case 06: container is equipped with smart e-seal and carries “cheap” cargo from China to US.

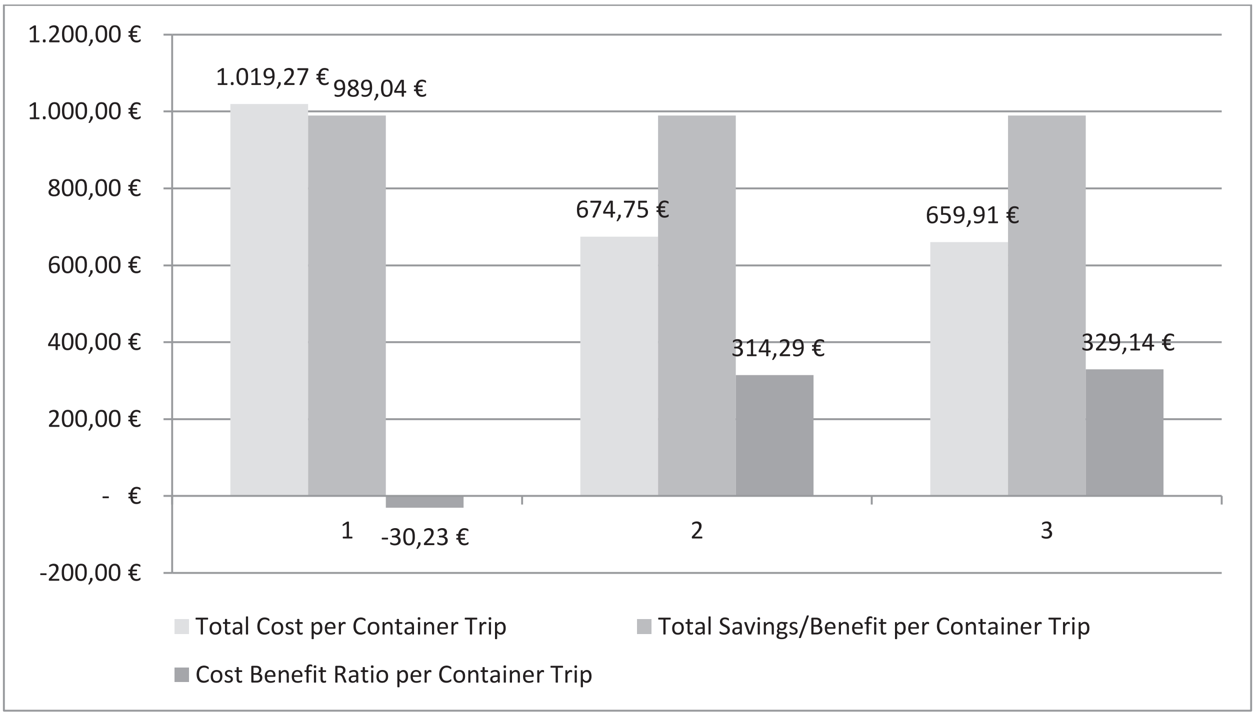

Fig. 39 Results of cost benefit analyses (case 06)

Case 07: container is equipped with simple e-seal and carries "expensive" cargo from China to US.

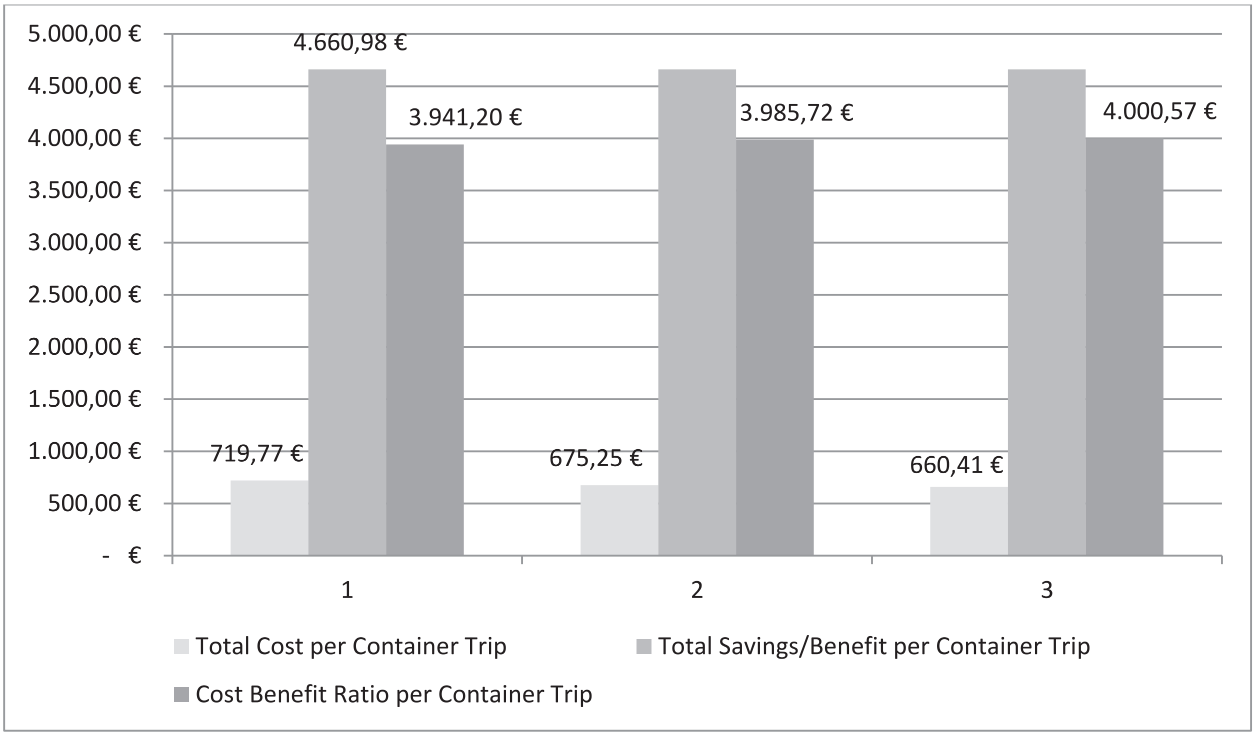

Fig. 40 Results of cost benefit analyses (case 07)

Case 08: container is equipped with smart e-seal and carries "expensive" cargo from China to US.

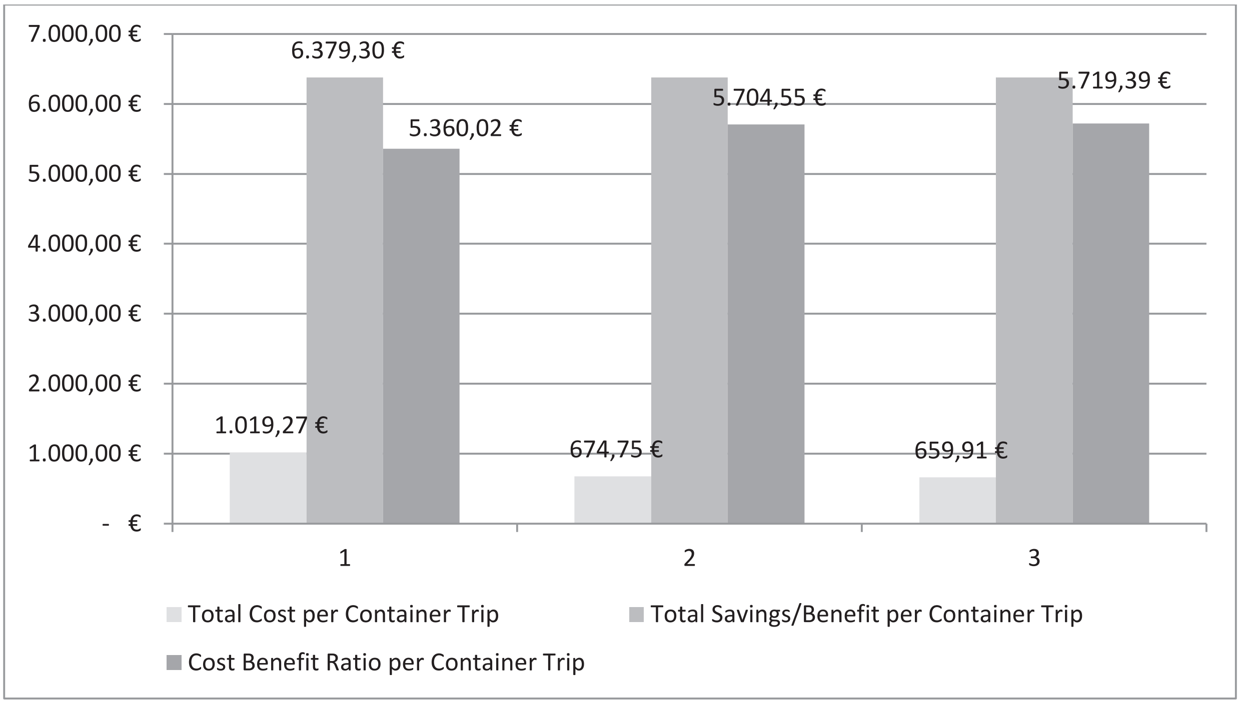

Fig. 41 Results of cost benefit analyses (case 08)

The analysis of cost-benefit ratios allows us to compare the considered scenarios. Table 7 demonstrates that, for instance, cases 07-08 have got the best cost-benefit ratios values. For one, this is due to enormous dissimilarity in delivery time for each container before and after e-seals implementation in transportation process. Secondly, in the last two cases the containers transport high-value goods, e.g. cigarettes. The value of transported goods is directly connected with evaluation of cost savings in secure model.

In the cases 05-06 the dissimilarity in delivery time is also observed. Nevertheless, the CBRs are not as big as in previously described cases. This is caused by the lower cost value of the transported goods. As it has been mentioned, the value of transported goods has an essential meaning in estimation of costs and savings in the proposed secure model. On the other hand, from the view of the profit for the whole network, case 05 is not successful because of a negative profit value after the third year of e-seals implementation.

The first four cases introduced in the Table 19 can be considered as the most objective. In those cases the distance factor, e.g. lead time variation savings, has no essential impact on the final results in the model. The tendency of increasing of CBRs (cases 01-04) after each year of e-seals usage is presented. Therefore, it is difficult to define the most attractive project for implementation of container secure model.

However, the results obtained from comparison of other cost-benefit ratio values make it obvious that currently the most attractive venture project is the case 04. In this case there is a combination of smart e-seals on the containers and “expensive” value of container itself. In this case there are positive CBR as well as positive profit per container trip after the three years period are existed. In contradiction to the case 04, for instance, in case 03 CBR has also the positive scoring. However, the profit value after the third year is still not positive. It is important to mention that in both cases (03 and 04) the container are shipping the same high value cargo in the same network configuration. Nevertheless, the benefits from smart e-seals that are applied in the cases 04 in order to secure the routes have more vital influences on the network in total.

However, it should be taken into account that each real-world element can affect the cost-benefit ratios in described modelling cases in positive or negative way.

5.6 Summary

In this chapter we have investigated dynamical properties of a container transportation system distributed over two continents and consisting of 10 ports and 10 distribution centres. Container flows from each distribution centres on one continent with a destination at a distribution centre on the other continent were considered. Depending on the container equipment these flows are split into different terminals in each port and go through different customs gates. The waiting queues at the terminals can be of different length, the customs processing times at different gates depend on the container equipment. Queuing theory was applied to study the dynamics of average queue lengths inside of a particular port, i.e. for a network with a small size. We have seen that even in this relatively simple case the analytic solution is very cumbersome and that its derivation for a larger network is hardly possible. However it can be used for the prediction or optimization of local dynamics. To study a global dynamics, i.e., transportation process in a large realistic network, a simulation program was written in MATLAB that models the container flows depending on the queue lengths at the terminals and on the equipment of containers that can use the information about the queue lengths. In our simulations we have calculated such important parameters as the average global and local waiting times of containers at nodes, the total average time from source to destination for different types of containers as well as the total container turnover per time unit. Three types of seals for containers were considered: usual mechanical seals, electronic seals without a possibility to make decisions and electronic seals with a possibility to make decision on the base of local information about the queue lengths at the nodes of their next transportation stage.

In our simulations we have demonstrated that electronic devices improve all the relevant parameters and that the most efficient transportation dynamics is achieved by use of smart electronic seals that can make a decision, which waiting queue to choose depending on its length. All the above mentioned parameters are quantified depending on the percentage of the containers with and without electronic seals. We have explained that the shortening of the transportation times by use of e-seals can positively affect the size of the needed container storage areas in the ports. The positive effect for the ecology was also discussed. The next important question is about the expenses of investments needed to equip containers with e-seals to be able to profit from the above mentioned advantages. We proposed a cost-benefit analysis which is intended to estimate possible costs and benefits through the implementation and use of RFID container electronic seals in global secure container network. We included only the direct benefits from e-seals in container systems. The cost-benefit analysis has been applied to eight different business cases and appropriate cost-benefit ratios values were calculated. The most cost-effective project for investment in security technology is when containers carry a so called "expensive" cargo, i.e. cigarettes, computers, alcohol bottles, or even dangerous cargo. Therefore, the investment in case of "expensive" cargo under such conditions becomes more attractive. We have shown that return of investments can be assured in this case within a few years.

6 Summary and Outlook

Currently the dynamics of global market and the complexity of container supply chains requires from their numerous participants to look for alternatives to increase efficiency and safety of container flows over the world and reduce costs, by organization of strong links in international supply chains. The role of new electronic devices to be implemented in global container transportation networks has been widely recognized as the potential of being driving forces in facilitation and acceleration of dynamic container flows. Simultaneously, the container industry has proven to be a remarkably efficient commercial system, designed to move goods through the international supply chain in the fastest way. Therefore, large capacity gains and substantial transit-time savings can be obtained from efficiency improvements and from the redefinition of the processes within transportation networks.

The existing tendency demonstrates the importance of development and implementation of new security container detecting intrusion technology, namely, container electronic seals. In order to define and to explore the trade-off between security international requirements and commerce companies, analysis of one of the technologies – RFID e-seals – promising to improve container transportation processes, have been evaluated in this doctoral research.

The unpredictable changes in international affairs after events 9/11 have affected the global container traffic rules. The huge volume of container traffic plus the normal controls over cargo packing and shipping provide opportunities to introduce weapons of mass destruction into a container at several stages of the supply chain. The amount of documentation, companies, and institutions involved overwhelmed the customs inspection processes aimed to discover any illegal activities including theft of goods and vehicles, fraud, illegal immigration, drug and contraband smuggling, potential targeting dangerous goods and terrorist activities. We have shown that e-seals can simplify and improve these processes.

Considering the benefits from RFID technology in container supply chains, there is still a lack of research about advantages from application of electronic seals on containers in logistics networks. However, there are numerous business benefits from implementation of new technology in container processes that have been examined and described within this work. E-seals allow importers, shipping companies, port officials and customs inspectors to determine, without a physical inspection, whether the container has been tampered with and the security of the container compromised. The challenges for e-seals implementation in global container system issue have been clarified as well.

It should be noted that the lack of a common global frequency for transmitting data as well as the high costs of electronic seals and supporting infrastructure represent significant barriers to implementation in private industry. Therefore, in this thesis the model for container transhipment through the terminal considering new regulations for security and safety of container transport chains is developed to investigate the possible impacts of container e-seal technology on container logistics and especially on the dynamics of container logistics processes in global transport networks and the evaluation of changes in dynamics of physical container flows through the global container supply chain. This model provides a possibility for costs-benefits analysis for implementation of e-seals.

6.1 Research contributions

The developed model in the doctoral work is based on the suggestion that the typical electronic seal with a small chip inside and some sensors can contain some logistics data which can be used during the transportation of a cargo. With help of an RFID chip a container can transmit and receive information. The electronic seal attached to a container can be read at key checkpoints (terminal or distribution centres gates). It has been assumed that containers equipped with electronic seals can use the GreenLane advantage (“semi-free” moving through the ports or border crossing with minimum stops for security checks by customs). Two types of e-seals have been considered: one is a simple e-seal, that to inform the authorized person about the electronic number and status of e-seal; a smart e-seal can transmit and receive information, the read information from advanced e-seal can be sent via the Internet or some other networks direct to the person, responsible for container delivery, who may take a routing decision for the container trip.

Several theoretical models have been developed in order to solve the task based on queuing theory and discrete event simulations. First, a small container transportation system with queues in front of port gates for the cases when containers are equipped with e-seals was derived in the queuing theory framework. This model was compared with a scenario when containers are not equipped with e-seals. We have shown that analytic solutions can be found in these small networks. The next step is to model a more realistic scenario with a large number of nodes in the transportation network. However, the complexity and size of modelling system do not allow to obtain solutions analytically. We have demonstrated that the queuing theory is hardly possible to apply for large-scale networks. Therefore, discrete-event simulations executed on the computer were performed for further analysis in our work.

A model for container transhipment network that consists of 10 ports and 10 distribution centres has been simulated with discrete-event method by using MATLAB software. The simulation has been presented for two alternative objectives: when containers transhipped through the maritime terminal are equipped with electronic seals (with and without routing decisions), and, when containers are equipped only with mechanical seals. The simulations have established what impact each type of the container seals (mechanical seal, simple e-seal, and smart e-seal) has on global container flows. The flows of containers with mechanical seals demonstrated the conventional situation and have been chosen as the basis for container turnover comparing when container equipped with different types of e-seals and in various proportions, e.g. 10% of container are with e-seals and the rest 90% with conventional mechanical seals. The implementation of new types of container seals, i.e. electronic seals, approved the feasible impact to make the global container system more effective, sustainable, and secure.

Nevertheless, the return on investment for smart seals is difficult to quantify at this stage of electronic devices development, while the electronic shipment monitoring might pay for itself by reducing cargo theft and supply chain interruptions. Importers, moreover, stand to benefit once Customs begins offering "fast lane" clearance for companies that use approved electronic seals on their inbound containers.

The obtained simulation outcome has been applied in the proposed cost-benefit analysis to estimate possible costs and benefits through the implementation and use of RFID container electronic seals in global secure container network. In this work, we have proposed the cost-benefit model that intends to estimate possible costs and benefits through the implementation and use of RFID container electronic seals in global secure container network. E-seals can be an important element of the complete solution for securing and improving of visibility for the shipments. We considered the e-seals' benefits that are on the top of the pyramid of the potential profit from e-seals in container systems. In other words, the CBA deals here with anticipated benefits from applying the RFID seals on containers such as reduced inspections, reduction in insurance costs and lead time variation costs, etc. Not each of these benefits can be achieved in each supply chain based only on implementation of e-seals in container processes.

The cost-benefit analysis has been applied to eight different business cases and appropriate cost-benefit ratios values were estimated. The most cost-effective project for investment is achieved when containers move "expensive" cargo, i.e. cigarettes, computers, alcohol bottles, or dangerous cargo, and are equipped with smart security technology. It is necessary to emphasize the critical influence of different factors as delivery time, different types of e-seals and different values of shipped goods on the decision for attractiveness of investment project. Another significant aspect is that most of the benefits in container secure model assigned primarily to the shipper/consignee can be shared with container terminals and customs administrations by indirect influence. The entire benefits obtained from the usage of the new technology in container logistics are interconnected with all partners in supply chain and cannot be achieved by individual company or industry.

The main contributions of the doctoral research can be summarized as follows:

(i) The most feasible advantages of new container security technology (e-seals) and the framework of its application have been determined.

(ii) The influence of different types of e-seals on the dynamics of container logistics flows in the global network has been simulated and modelled analytically; various scenarios have been developed and considered to include the most happened situations in the practical cases.

(iii) The evaluation model based on the cost-benefit analysis have been proposed and approved by different business cases for adoption of different types of e-seals in container system; the return on investment index have been calculated to compare investments in security electronic devices under different initial conditions.

As a final conclusion we can say that e-seals are worth implementation in container logistics as they provide many benefits such as acceleration of container turnover, improved security and visibility of logistics container processes, possibility for control and decision making. Moreover one can expect the return on investments in a reasonable time.

6.2 Further research

Our work has shown that implementation of e-seals improves the container turnover and provides monetary benefits. Further impacts as robustness properties in view of possible disturbances as accident route change or theft, impacts on ecology of environment, visibility effects are next possible directions of research. For example an investigation of the supply chain visibility level considering different types of e-seals is of interest. It is known that various electronic seals confirmed or not by the standardized organizations bring different level of container processes/operations visibility. The efficiency of the whole shipper-customer container chain depends on the ability of electronic device on the container alerts regarding any disturbances along the transportation process. The seals' inventory-tracking capabilities can provide shippers with enough benefits to cover the expense of implementing an electronic system.

Another research direction is to investigate the ecological impact of applying e-seals on maritime containers. As 90% of all cargo flows in the world is moving in maritime containers, any technology that can improve this transportation process has an influence on the global environment. In the world the most giant container port are cited near or inside urban areas. To reduce air pollutants, carbon dioxide emissions, and toxic air emissions are an emerging issue for the transportation community in general and many metropolitan areas in particular. As it has been investigated in this doctoral research the impact of e-seals on containers congestion in the ports is considerable. Therefore, further investigation to measure and to model the advantage from improvement of daily congested situation in the ports by equipment of containers with advanced communication and security devices on the containers should be in the focus of the research.

Moreover, the influence of container dynamics on the planning and allocation of containers in the port area have been considered in this research. The application of electronic intrusion detection technology has an effect on the decrease of the throughput time at terminals and in the whole system that has been computed in the research. This allows for estimation of the indirect impact of e-seals on the optimization processes in the port, in particular in communication sphere and in solving optimizing problems. In the case of dramatically dropping down of time for customs checks in the ports and a reduced time when containers are in idling process in the queues in front of the terminal as it has been simulated in the doctoral work, the storage places in the ports can be more effectively used by more containers In other words, using the same port storage territory, the port can get higher utilization rate already on the storage places. Investments in new infrastructure for more secure container trade can bring the new utilization rate for port storage territory without any investments in its expansion or re-organization.

Since electronic seals can be used for control purposes it is of interest to develop related methods and in particular to use them for optimization of the container flows. Which information should be stored at the e-seals for this purpose has to be investigated.

Finally, the new coming changes in security regulations of international container trade have already introduced the necessity to consider the smart container technology. The electronic seal device is an essential part of smart container design. Therefore, one of the next investigations could be the investments evaluation in new type of maritime containers as well as analysis of smart container technology influence on container dynamics and cost and benefits distribution between partners in supply chains.

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8 Appendix

8.1 Formulation and Formalization of Supply Network Model

```
function[]=supplynet
%SUPPLYNET()
%
%This function is the simulation for a supply network. This network
%has 4 columns and N1, N2, N3 and N4 rows. The rows are usually less or
%equal than 4, but the function has no boundaries for the number of rows.
%
%SUPPLYNET has no output variables. The results of this function are saved
%in the global variables NODE12, NODE23, NODE34, NODE43, NODE32 and NODE21
%of datatypestruct.NODExy save the accumulated client departures to node
%'y' from a node 'x'. NODExy.queuek1 (NODExy.queuek2) contains the
%accumulated departure number at the time NODExy.timek1 (NODExy.timek2) for
%the class k=1 (k=2).
%
%There are four families of input matrices:
%
%1.)lambdasdk
%
%lambda is the name for the input rate. The start column is denoted with
%'s' the destination column is denoted with 'd'. Each input produces two
%classes of clients which go through the network. The class is denoted with
%'k' and either 1 or 2.
%The row in lambdasdk denotes the row in column s in which the current
%client starts, the columns denote the row of the destination column.
%
%   lambdasdk \in IR^(Ns x Nd)
%
%
%2.)mucn
%
%mu is the name for the processing rate at each entry of the next supply
%node in the network. This entry only occur at the nodes of columns 2 and 3
%because at 1 and 4 the clients either leave the network or enter it. 'c'
%denotes the current column (either 2 or 3) and 'n' denotes the next
%column.mucn has two columns, the first contains the processing rates for
%class k=1 and the second for the class k=2.
%
%   mucn \in IR^(Nc x 2)
%
%
%3.& 4.)shipminst&shipmaxst
%
%'s' denotes one end-column, 't' the other end-column of a transport route,
%e.g. trans23. The time a transport needs is rectangle distributed with the
%minimum shipmin and the maximum shipmax. The rownumbers of shipmin
%(shipmax) denotes the row numbers in the 's'-column, the columns of
%shipmin (shipmax) denote the rows in the 't'-column.
%
%   shipminst,shipmaxst \in IR^(Ns x Nt)


%All time variables are saved as single floats and all counting variables
%are saved as int32 to save memory.

%------------------------------input variables-----------------------------
```

```
%standard variable to ease the definition of N1, N2, N3 and N4 in the case
%of N1=N2=N3=N4.
N=3;

%lambda_START_DESTINATION_K
global lambda14k1 lambda41k1 lambda14k2 lambda41k2;

lambda14k1=[ 0.1 , 0.1 , 0.1 ; 0.1 , 0.1 , 0.1 ; 0.1 , 0.1 , 0.1 ];%...
%              0.1 , 0.1 , 0.1 , 0.1 ;...
%              0.1 , 0.1 , 0.1 , 0.1 ;...
%              0.1 , 0.1 , 0.1 , 0.1 ];

lambda14k2=[ 0.1 , 0.1 , 0.1 ; 0.1 , 0.1 , 0.1 ; 0.1 , 0.1 , 0.1 ];%...
%              0.1 , 0.1 , 0.1 , 0.1 ;...
%              0.1 , 0.1 , 0.1 , 0.1 ;...
%              0.1 , 0.1 , 0.1 , 0.1 ];

lambda41k1=[ 0.1 , 0.1 , 0.1 ; 0.1 , 0.1 , 0.1 ; 0.1 , 0.1 , 0.1 ];%...
%              0.1 , 0.1 , 0.1 , 0.1 ; ...
%              0.1 , 0.1 , 0.1 , 0.1 ;...
%              0.1 , 0.1 , 0.1 , 0.1 ];

lambda41k2=[ 0.1 , 0.1 , 0.1 ; 0.1 , 0.1 , 0.1 ; 0.1 , 0.1 , 0.1 ];%...
%              0.1 , 0.1 , 0.1 , 0.1 ;...
%              0.1 , 0.1 , 0.1 , 0.1 ;...
%              0.1 , 0.1 , 0.1 , 0.1 ];

%mu_currentcolumn_nextcolmun
global mu23 mu34 mu21 mu32;

mu23=[ 0.01 , 0.01 ; ...
0.01 , 0.01 ; ...
0.01 , 0.01 ];% ...
%        0.01 , 0.01 ; ...
%        0.01 , 0.01 ];

mu34=[ 0.01 , 0.01 ; ...
0.01 , 0.01 ; ...
0.01 , 0.01 ];% ...
%        0.01 , 0.01 ; ...
%        0.01 , 0.01 ];

mu21=[ 0.01 , 0.01 ; ...
0.01 , 0.01 ; ...
0.01 , 0.01 ];% ...
%        0.01 , 0.01 ; ...
%        0.01 , 0.01 ];

mu32=[ 0.01 , 0.01 ; ...
0.01 , 0.01 ; ...
0.01 , 0.01 ]; %...
%        0.01 , 0.01 ; ...
%        0.01 , 0.01 ];

% shipmin_currentcolumn_nextcolumn
global shipmin12 shipmin23 shipmin34;

% shipmin12=[ 0.01 , 0.01 ; 0.01 , 0.01 ];
shipmin12=[ 0.4 , 0.4 , 0.4 ; 0.4 , 0.4 , 0.4 ; 0.4 , 0.4 , 0.4 ];% ...
%             0.4 , 0.4 , 0.4 , 0.4 ; ...
```

```
%             0.4 , 0.4 , 0.4 , 0.4 ; ...
%             0.4 , 0.4 , 0.4 , 0.4 ];

shipmin23=[ 0.1 , 0.2 , 0.6 ; ...
0.2 , 0.4 , 1.2 ; ...
0.6 , 1.2 , 1.5 ;];

% shipmin23=[ 5 , 1 , 2 , 7 ; ...
%             3 , 0.5 , 1 , 5 ; ...
%             5 , 1 , 0.5 , 3 ; ...
%             7 , 2 , 1 , 5 ];

shipmin34=shipmin12;
% shipmin34=[ 0.01, 0.01 ; 0.01 , 0.01];
% shipmin34=[ 0.3 , 0.4 , 0.5 , 0.6 ; ...
%             0.4 , 0.3 , 0.4 , 0.5 ; ...
%             0.5 , 0.4 , 0.3 , 0.4 ; ...
%             0.6 , 0.5 , 0.4 , 0.3 ];

%shipmax_currentcolumn_nextcolumn
global shipmax12 shipmax23 shipmax34;

% shipmax12=[ 0.02 , 0.02 ; 0.02 , 0.02];
shipmax12=[ 2 , 2 , 2 ; 2, 2 , 2 ; 2 , 2 , 2 ]; %...
%             2 , 2 , 2 , 2 ; ...
%             2 , 2 , 2 , 2 ; ...
%             2 , 2 , 2 , 2 ];

% shipmax23=shipmax12;
shipmax23=[ 0.4 , 0.6 ,   1 ; ...
0.6 , 1.2 , 1.8 ; ...
1 , 1.8 ,   3 ;];

% shipmax23=[  , 3 , 4 , 8 ; ...
%             4 , 2 , 3 , 6 ; ...
%             6 , 3 , 2 , 4 ; ...
%             8 , 4 , 3 , 6 ];

shipmax34=shipmax12;
% shipmax34=[ 0.02 , 0.02 ; 0.02 , 0.02];
% shipmax34=[ 0.5 , 0.6 , 0.7 , 0.8 ; ...
%             0.6 , 0.5 , 0.7 , 0.8 ; ...
%             0.7 , 0.6 , 0.5 , 0.6 ; ...
%             0.8 , 0.7 , 0.6 , 0.5 ];

%SIMEND defines the end of the simulation:
global SIMEND;
SIMEND=30;

%-----
global N1 N2 N3 N4;
N1=N;
N2=N;
N3=N;
N4=N;

%-----
%check whether all declarations are correct:
errorcheck(N1,N2,N3,N4);
disp('---');
```

```
disp('All input variables are checked, no errors were found.');
disp('---');
%-----

%----------------define simulation start values----------------------------
%The queue saves the times, when the last client at a node will be
%finished.
global queue;
queue=struct('p2d1',zeros(N2,2),'p2d3',zeros(N2,2),'p3d2',zeros(N3,2),'p3d4',
zeros(N3,2));

%The Q_LENGTH counts the number of clients in the processing queue in the
%entrance of each harbour.
global Q_LENGTH21 Q_LENGTH23 Q_LENGTH32 Q_LENGTH34;
Q_LENGTH21=struct('k1',int32(0),'time1',single(0),'k2',int32(0),'time2',singl
e(0));
Q_LENGTH23=struct('k1',int32(0),'time1',single(0),'k2',int32(0),'time2',singl
e(0));
Q_LENGTH32=struct('k1',int32(0),'time1',single(0),'k2',int32(0),'time2',singl
e(0));
Q_LENGTH34=struct('k1',int32(0),'time1',single(0),'k2',int32(0),'time2',singl
e(0));
for two=1:N1
    Q_LENGTH21(two).k1=int32(0);
    Q_LENGTH21(two).k2=int32(0);
    Q_LENGTH23(two).k1=int32(0);
    Q_LENGTH23(two).k2=int32(0);
    Q_LENGTH21(two).time1=single(0);
    Q_LENGTH21(two).time2=single(0);
    Q_LENGTH23(two).time1=single(0);
    Q_LENGTH23(two).time2=single(0);
end
for three=1:N3
    Q_LENGTH32(three).k1=int32(0);
    Q_LENGTH32(three).k2=int32(0);
    Q_LENGTH34(three).k1=int32(0);
    Q_LENGTH34(three).k2=int32(0);
    Q_LENGTH32(three).time1=single(0);
    Q_LENGTH32(three).time2=single(0);
    Q_LENGTH34(three).time1=single(0);
    Q_LENGTH34(three).time2=single(0);
end

%NODE saves the accumulated clients which have passed each node.
global NODE12 NODE21 NODE23 NODE32 NODE34 NODE43;
NODE12=makenode(N1,N2);
NODE21=makenode(N2,N1);
NODE23=makenode(N2,N3);
NODE32=makenode(N3,N2);
NODE34=makenode(N3,N4);
NODE43=makenode(N4,N3);

global LENGTH12 LENGTH21 LENGTH23 LENGTH32 LENGTH34 LENGTH43;
LENGTH12=makenode(N1,N2);
LENGTH21=makenode(N2,N1);
LENGTH23=makenode(N2,N3);
LENGTH32=makenode(N3,N2);
LENGTH34=makenode(N3,N4);
LENGTH43=makenode(N4,N3);

%-----make input times: inputtime(start,destination).k-----
disp('Start making input times.');
```

```
%global inputtime14 inputtime41;
inputtime14=makeinput(lambda14k1,lambda14k2,SIMEND);
inputtime41=makeinput(lambda41k1,lambda41k2,SIMEND);
disp('Input times are made.');
disp('---');

%---and make the INPPUTSAVE-----
global INPUTSAVE14 INPUTSAVE41;
INPUTSAVE14=struct('k1',0,'time1',0,'k2',0,'time2',0);
INPUTSAVE41=struct('k1',0,'time1',0,'k2',0,'time2',0);
for ind1=1:N1
for ind4=1:N4
INPUTSAVE14(ind1,ind4).k1=int32(0);
INPUTSAVE41(ind4,ind1).k1=int32(0);
INPUTSAVE14(ind1,ind4).k2=int32(0);
INPUTSAVE41(ind4,ind1).k2=int32(0);
INPUTSAVE14(ind1,ind4).time1=single(0);
INPUTSAVE41(ind4,ind1).time1=single(0);
INPUTSAVE14(ind1,ind4).time2=single(0);
INPUTSAVE41(ind4,ind1).time2=single(0);
end%for ind4=1:N4
end%for ind1=1:N1
%---and now the OUTPUTSAVE-----
global OUTPUTSAVE14 OUTPUTSAVE41;
OUTPUTSAVE14=INPUTSAVE14;%struct('k1',0,'time1',0,'k2',0,'time2',0);
OUTPUTSAVE41=INPUTSAVE41;%struct('k1',0,'time1',0,'k2',0,'time2',0);
% for ind1=1:N1
%     for ind4=1:N4
%         OUTPUTSAVE14(ind1,ind4).k1=int32(0);
%         OUTPUTSAVE41(ind4,ind1).k1=int32(0);
%         OUTPUTSAVE14(ind1,ind4).k2=int32(0);
%         OUTPUTSAVE41(ind4,ind1).k2=int32(0);
%         OUTPUTSAVE14(ind1,ind4).time1=single(0);
%         OUTPUTSAVE41(ind4,ind1).time1=single(0);
%         OUTPUTSAVE14(ind1,ind4).time2=single(0);
%         OUTPUTSAVE41(ind4,ind1).time2=single(0);
%     end %for ind4=1:N4
% end %for ind1=1:N1
global DURATION14 DURATION41;
DURATION14=INPUTSAVE14;
DURATION41=INPUTSAVE41;
for ind1=1:N1
for ind4=1:N4
DURATION14(ind1,ind4).k1=single(0);
DURATION41(ind4,ind1).k1=single(0);
DURATION14(ind1,ind4).k2=single(0);
DURATION41(ind4,ind1).k2=single(0);
end%for ind4=1:N4
end%for ind1=1:N1


%transxy contains the times a transport needs from x to y. If the time
%value is positive the transport goes from x to y, if the time value is
%negative the transport goes from y to x.
global trans12 trans23 trans34;
trans12=struct('arr',zeros(N1,N2),'dep',zeros(N1,N2));
trans23=struct('arr',zeros(N2,N3),'dep',zeros(N2,N3));
trans34=struct('arr',zeros(N3,N4),'dep',zeros(N3,N4));

%-----make processing times-----
%disp('Start making processing times.');
%global process;
```

```
process=makeprocess(mu21,mu23,mu32,mu34);
%disp('Processing times are made.');
%disp('---');

%---make shipment times---
disp('Start making shipment times');
global shipment12 shipment23 shipment34;
shipment12=makeshiptime(shipmin12,shipmax12,SIMEND);
shipment23=makeshiptime(shipmin23,shipmax23,SIMEND);
shipment34=makeshiptime(shipmin34,shipmax34,SIMEND);
disp('Shipment times are made.');
disp('---');

%---define matrices for easy time comparison---
prodtime14k1=zeros(N1,N4);
prodtime14k2=zeros(N1,N4);
prodtime41k1=zeros(N4,N1);
prodtime41k2=zeros(N4,N1);

for ind1=1:N1
for ind4=1:N4
%transfer values into the matrices:
prodtime14k1(ind1,ind4)=inputtime14(ind1,ind4).k1(1);
prodtime14k2(ind1,ind4)=inputtime14(ind1,ind4).k2(1);
prodtime41k1(ind4,ind1)=inputtime41(ind4,ind1).k1(1);
prodtime41k2(ind4,ind1)=inputtime41(ind4,ind1).k2(1);

%delete the transfered values:
inputtime14(ind1,ind4).k1=inputtime14(ind1,ind4).k1(2:end);
inputtime14(ind1,ind4).k2=inputtime14(ind1,ind4).k2(2:end);
inputtime41(ind4,ind1).k1=inputtime41(ind4,ind1).k1(2:end);
inputtime41(ind4,ind1).k2=inputtime41(ind4,ind1).k2(2:end);
end%for ind4
end%for ind1

prodtime14k1=single(prodtime14k1);
prodtime14k2=single(prodtime14k2);
prodtime41k1=single(prodtime41k1);
prodtime41k2=single(prodtime41k2);
%--------------------start values are defined------------------------------


%ontheway=[current                                                      col-
umn,currentrow,nextcolumn,nextrow,arrivaltime,destination column, destination
row,k-type, start column, start row, start time];
%if a client is waitin for a transport, the arrival time is set to SIMEND.
globalontheway;
ontheway=[0,0,0,0,SIMEND,0,0,0,0,0,0];
ontheway=single(ontheway);

%time is just the time
global time;
time=0;
time=single(time);

%theese two variables are for a time output during the simulation
counter=1;
factor=5;

disp(['The simulation has a duration of ',int2str(SIMEND),' time units.']);
disp(' ');
```

```
disp('Starting the simulation...');

while time<SIMEND

%This time output is only to be sure that the simulation is still
%runnig, especially if it needs long time.
if time>=counter*factor
counter=counter+1;
disp(['The current time is ',num2str(time),'.']);
end

%At the bottom of this main loop the next smallest event-time is chosen
%to be the new time.Whith this switch the event to time is searched.
switch time

%put the produced clients in the system
%first for k==1
case min(min(prodtime14k1))
%search the produced client
            [start,dest]=get_the_index(time,prodtime14k1,N1,N4);

%send the client:
            onthe-
way=[[1,start,2,start,SIMEND,4,dest,1,1,start,time];ontheway];

%set the next prodtime:
prodtime14k1(start,dest)=inputtime14(start,dest).k1(1);

%and delete that time:
inputtime14(start,dest).k1=inputtime14(start,dest).k1(2:end);

%increase the QUEUElength

NODE12(start,start).queuek1=[int32(NODE12(start,start).queuek1(1)+1);NODE12(s
tart,start).queuek1];
NODE12(start,start).timek1=[time;NODE12(start,start).timek1];

LENGTH12(start,start).queuek1=[int32(LENGTH12(start,start).queuek1(1)+1);LENG
TH12(start,start).queuek1];
LENGTH12(start,start).timek1=[time;LENGTH12(start,start).timek1];

%save the input clients to compare them with the output clients
            IN-
PUTSAVE14(start,dest).k1=[int32(INPUTSAVE14(start,dest).k1(1)+1);INPUTSAVE14(
start,dest).k1];
INPUTSAVE14(start,dest).time1=[time;INPUTSAVE14(start,dest).time1];

case min(min(prodtime41k1))
%search the produced client
            [start,dest]=get_the_index(time,prodtime41k1,N4,N1);

%send the client:
            onthe-
way=[[4,start,3,start,SIMEND,1,dest,1,4,start,time];ontheway];

%set the next prodtime:
prodtime41k1(start,dest)=inputtime41(start,dest).k1(1);

%and delete that time:
inputtime41(start,dest).k1=inputtime41(start,dest).k1(2:end);
```

```
%increase the QUEUElength

NODE43(start,start).queuek1=[int32(NODE43(start,start).queuek1(1)+1);NODE43(s
tart,start).queuek1];
NODE43(start,start).timek1=[time;NODE43(start,start).timek1];

LENGTH43(start,start).queuek1=[int32(LENGTH43(start,start).queuek1(1)+1);LENG
TH43(start,start).queuek1];
LENGTH43(start,start).timek1=[time;LENGTH43(start,start).timek1];

%save the input clients to compare them with the output clients
            IN-
PUTSAVE41(start,dest).k1=[int32(INPUTSAVE41(start,dest).k1(1)+1);INPUTSAVE41(
start,dest).k1];
INPUTSAVE41(start,dest).time1=[time;INPUTSAVE41(start,dest).time1];

%then for k==2
case min(min(prodtime14k2))
%search the produced client:
            [start,dest]=get_the_index(time,prodtime14k2,N1,N4);

%search the fastest route:
next=best_route(1,start,4,dest);

%send the client:
            onthe-
way=[[1,start,2,next,SIMEND,4,dest,2,1,start,time];ontheway];

%set the next prodtime:
prodtime14k2(start,dest)=inputtime14(start,dest).k2(1);

%and delete that time:
inputtime14(start,dest).k2=inputtime14(start,dest).k2(2:end);

%increase the QUEUElength

NODE12(start,next).queuek2=[int32(NODE12(start,next).queuek2(1)+1);NODE12(sta
rt,next).queuek2];
NODE12(start,next).timek2=[time;NODE12(start,next).timek2];

LENGTH12(start,next).queuek2=[int32(LENGTH12(start,next).queuek2(1)+1);LENGTH
12(start,next).queuek2];
LENGTH12(start,next).timek2=[time;LENGTH12(start,next).timek2];

%save the input clients to compare them with the output clients
            IN-
PUTSAVE14(start,dest).k2=[int32(INPUTSAVE14(start,dest).k2(1)+1);INPUTSAVE14(
start,dest).k2];
INPUTSAVE14(start,dest).time2=[time;INPUTSAVE14(start,dest).time2];

case min(min(prodtime41k2))
%search the produced client:
            [start,dest]=get_the_index(time,prodtime41k2,N4,N1);

%search the fastest route:
next=best_route(4,start,1,dest);

%send the client:
```

```
            onthe-
way=[[4,start,3,next,SIMEND,1,dest,2,4,start,time];ontheway];

%set the next prodtime:
prodtime41k2(start,dest)=inputtime41(start,dest).k2(1);

%and delete that time:
inputtime41(start,dest).k2=inputtime41(start,dest).k2(2:end);

%increase the QUEUElength

NODE43(start,next).queuek2=[int32(NODE43(start,next).queuek2(1)+1);NODE43(sta
rt,next).queuek2];
NODE43(start,next).timek2=[time;NODE43(start,next).timek2];

LENGTH43(start,next).queuek2=[int32(LENGTH43(start,next).queuek2(1)+1);LENGTH
43(start,next).queuek2];
LENGTH43(start,next).timek2=[time;LENGTH43(start,next).timek2];

%save the input clients to compare them with the output clients
            IN-
PUTSAVE41(start,dest).k2=[int32(INPUTSAVE41(start,dest).k2(1)+1);INPUTSAVE41(
start,dest).k2];
INPUTSAVE41(start,dest).time2=[time;INPUTSAVE41(start,dest).time2];

%arrival of a transport

case min(min(abs(trans12.arr)))
%search the arriving transporter
            [one,two]=get_the_index(time,abs(trans12.arr),N1,N2);

%finding out how much clients are on the way:
            ALL=size(ontheway);
            ALL=ALL(1);

if trans12.arr(one,two)>0 %if it started at 1 and is arriving at 2

%checking the queues at that node:
queue.p2d3(two,1)=max(queue.p2d3(two,1),time);
queue.p2d3(two,2)=max(queue.p2d3(two,2),time);



%processing the arriving clients
for cl=1:ALL
ifontheway(cl,1:5)==[1,one,2,two,time]

%set the new processing time:
                        onthe-
way(cl,1:5)=[2,two,2,two,queue.p2d3(two,ontheway(cl,8))+process(two,ontheway(
cl,8)).p2d3(1)];
%make a new processing time:
                        pro-
cess(two,ontheway(cl,8)).p2d3=single(expval(mu23(two,ontheway(cl,8))));
%                         %and delete the old one:
%                         if size(process(two,ontheway(cl,8)).p2d3)>=[1,2]
%                                                                         pro-
cess(two,ontheway(cl,8)).p2d3=process(two,ontheway(cl,8)).p2d3(2:end);
%                         else
%                                warning('Simulation has run out of processing
times. New times are being calculated now.');
```

```
%                                                                        new-
proc=makeprocess(mu21,mu23,mu32,mu34,0.2*SIMEND);
%                                                                        pro-
cess(two,ontheway(cl,8)).p2d3=newproc(two,ontheway(cl,8)).p2d3;
%                              newproc=[];
%                                         disp(['New processing times for pro-
cess(',int2str(two),',',int2str(ontheway(cl,8)),').p2d3 are calculated. time:
',num2str(time)]);
%                          end

%do not forget to give the queue a new finishing
%time:
queue.p2d3(two,ontheway(cl,8))=ontheway(cl,5);

%and to count it as freshly arrived:
ifontheway(cl,8)==1
if Q_LENGTH23(two).time1(1)~=time

Q_LENGTH23(two).k1=[int32(Q_LENGTH23(two).k1(1)+1);Q_LENGTH23(two).k1];

Q_LENGTH23(two).time1=[time;Q_LENGTH23(two).time1];
else%i.e. more than one client arrive at the same time

Q_LENGTH23(two).k1(1)=Q_LENGTH23(two).k1(1)+1;
end

else%i.e. ontheway(cl,8)==2
if Q_LENGTH23(two).time2(1)~=time

Q_LENGTH23(two).k2=[int32(Q_LENGTH23(two).k2(1)+1);Q_LENGTH23(two).k2];

Q_LENGTH23(two).time2=[time;Q_LENGTH23(two).time2];
else%i.e. more than one client arrive at the same time

Q_LENGTH23(two).k2(1)=Q_LENGTH23(two).k2(1)+1;
end
end

end
end



%new arrival time for the transporter:
trans12.arr(one,two)=-(time+shipment12(one,two).time(1));
trans12.dep(one,two)=time;

%and delete that time:
shipment12(one,two).time=shipment12(one,two).time(2:end);

%catch the clients which leaves to 1
for cl=1:ALL
ifontheway(cl,1:5)==[2,two,1,one,SIMEND];
ontheway(cl,5)=-trans12.arr(one,two);

%decrease the (LENGTH.)queuelength
ifontheway(cl,8)==1
if time~=LENGTH21(two,one).timek1(1) %This if asks whether this event occurs
on an new time point, othwise the events are batched to need less space

LENGTH21(two,one).queuek1=[int32(LENGTH21(two,one).queuek1(1)-
1);LENGTH21(two,one).queuek1];
```

```
LENGTH21(two,one).timek1=[time;LENGTH21(two,one).timek1];
else
LENGTH21(two,one).queuek1(1)=LENGTH21(two,one).queuek1(1)-1;
end%if time~=
if sum(size(LENGTH21(two,one).queuek1))~=sum(size(LENGTH21(two,one).timek1))
error('Size Matters! line 349');
end%if size~=size
else
if time~=LENGTH21(two,one).timek2(1) %This if asks whether this event occurs
on an new time point, othwise the events are batched to need less space

LENGTH21(two,one).queuek2=[int32(LENGTH21(two,one).queuek2(1)-
1);LENGTH21(two,one).queuek2];
LENGTH21(two,one).timek2=[time;LENGTH21(two,one).timek2];
else
LENGTH21(two,one).queuek2(1)=LENGTH21(two,one).queuek2(1)-1;
end%if time~=
if sum(size(LENGTH21(two,one).queuek2))~=sum(size(LENGTH21(two,one).timek2))
error('Size Matters! line 359');
end%if size~=size
end%ontheway(cl,8)==1
end
end



else%then it started at 2 and is arriving at 1

%processing the arriving clients
for cl=ALL:-1:1
ifontheway(cl,1:7)==[2,two,1,one,time,1,one]
%Every deleted client is counted:
ifontheway(cl,8)==1
                            OUT-
PUTSAVE41(ontheway(cl,10),one).k1=[OUTPUTSAVE41(ontheway(cl,10),one).k1(1)+1;
OUTPUTSAVE41(ontheway(cl,10),one).k1];
                            OUT-
PUTSAVE41(ontheway(cl,10),one).time1=[time;OUTPUTSAVE41(ontheway(cl,10),one).
time1];

%save the trip duration:
                            DURATION41(ontheway(cl,10),one).k1=[time-
ontheway(cl,11);DURATION41(ontheway(cl,10),one).k1];
                            DURA-
TION41(ontheway(cl,10),one).time1=[time;DURATION41(ontheway(cl,10),one).time1
];

else
                            OUT-
PUTSAVE41(ontheway(cl,10),one).k2=[OUTPUTSAVE41(ontheway(cl,10),one).k2(1)+1;
OUTPUTSAVE41(ontheway(cl,10),one).k2];
                            OUT-
PUTSAVE41(ontheway(cl,10),one).time2=[time;OUTPUTSAVE41(ontheway(cl,10),one).
time2];

%save the trip duration:
                            DURATION41(ontheway(cl,10),one).k2=[time-
ontheway(cl,11);DURATION41(ontheway(cl,10),one).k2];
                            DURA-
TION41(ontheway(cl,10),one).time2=[time;DURATION41(ontheway(cl,10),one).time2
];
```

```
end%if ontheway(cl,8)==1



%deleting the client from 'ontheway', because they
%are arriving at their final destination
ontheway=[ontheway(1:cl-1,:);ontheway(cl+1:end,:)];

end%if
end%for

%size of 'ontheway' could have changed in the lines above:
                ALL=size(ontheway);
                ALL=ALL(1);

%new arrival time for the transporter:
trans12.arr(one,two)=time+shipment12(one,two).time(1);
trans12.dep(one,two)=time;

%and delete that damn old time:
shipment12(one,two).time=shipment12(one,two).time(2:end);

%catch the clients which leaves to 2
for cl=1:ALL
ifontheway(cl,1:5)==[1,one,2,two,SIMEND];
ontheway(cl,5)=trans12.arr(one,two);

%decrease the (LENGTH.)queuelength
ifontheway(cl,8)==1
if time~=LENGTH12(one,two).timek1(1) %This if asks whether this event occurs
on an new time point, othwise the events are batched to need less space

LENGTH12(one,two).queuek1=[int32(LENGTH12(one,two).queuek1(1)-
1);LENGTH12(one,two).queuek1];
LENGTH12(one,two).timek1=[time;LENGTH12(one,two).timek1];
else
LENGTH12(one,two).queuek1(1)=LENGTH12(one,two).queuek1(1)-1;
end%if time~=
if sum(size(LENGTH12(one,two).queuek1))~=sum(size(LENGTH12(one,two).timek1))
error('Size Matters! line 403');
end%if size~=size
else
if time~=LENGTH12(one,two).timek2(1) %This if asks whether this event occurs
on an new time point, othwise the events are batched to need less space

LENGTH12(one,two).queuek2=[int32(LENGTH12(one,two).queuek2(1)-
1);LENGTH12(one,two).queuek2];
LENGTH12(one,two).timek2=[time;LENGTH12(one,two).timek2];
else
LENGTH12(one,two).queuek2(1)=LENGTH12(one,two).queuek2(1)-1;
end%if time~=
if sum(size(LENGTH12(one,two).queuek2))~=sum(size(LENGTH12(one,two).timek2))
error('Size Matters! line 413');
end%if size~=size
end%if ontheway(cl,8)==1
end
end
end
```

```
case min(min(abs(trans23.arr)))
%search the arriving transporter
            [two,three]=get_the_index(time,abs(trans23.arr),N2,N3);

%finding out how much clients are on the way:
            ALL=size(ontheway);
            ALL=ALL(1);

if trans23.arr(two,three)>0 %if it started at 2 and is arriving at 3

%checking the quenes at that node:
queue.p3d4(three,1)=max(queue.p3d4(three,1),time);
queue.p3d4(three,2)=max(queue.p3d4(three,2),time);

%processing the arriving clients
for cl=1:ALL
ifontheway(cl,1:5)==[2,two,3,three,time]
%give a processing time two the arriving clients
                        onthe-
way(cl,1:5)=[3,three,3,three,queue.p3d4(three,ontheway(cl,8))+process(three,o
ntheway(cl,8)).p3d4(1)];
%make a new processing time:
                        pro-
cess(three,ontheway(cl,8)).p3d4=single(expval(mu34(three,ontheway(cl,8))));
%                         %and delete that time from the process stack:
%                         if size(process(three,ontheway(cl,8)).p3d4)>=[1,2]
%                                                                        pro-
cess(three,ontheway(cl,8)).p3d4=process(three,ontheway(cl,8)).p3d4(2:end);
%                         else
%                                 warning('Simulation has run out of processing
times. New times are being calculated now.');
%                                                                        new-
proc=makeprocess(mu21,mu23,mu32,mu34,0.2*SIMEND);
%                                                                        pro-
cess(three,ontheway(cl,8)).p3d4=newproc(three,ontheway(cl,8)).p3d4;
%                              newproc=[];
%                                           disp(['New processing times for pro-
cess(',int2str(three),',',int2str(ontheway(cl,8)),').p3d4   are   calculated.
time: ',num2str(time)]);
%                         end
%new queue time:
queue.p3d4(three,ontheway(cl,8))=ontheway(cl,5);

%and to count it as freshly arrived:
ifontheway(cl,8)==1
if Q_LENGTH34(three).time1(1)~=time

Q_LENGTH34(three).k1=[int32(Q_LENGTH34(three).k1(1)+1);Q_LENGTH34(three).k1];

Q_LENGTH34(three).time1=[time;Q_LENGTH34(three).time1];
else%i.e. more than one client arrive at the same time

Q_LENGTH34(three).k1(1)=Q_LENGTH34(three).k1(1)+1;
end

else%i.e. ontheway(cl,8)==2
if Q_LENGTH34(three).time2(1)~=time

Q_LENGTH34(three).k2=[int32(Q_LENGTH34(three).k2(1)+1);Q_LENGTH34(three).k2];
```

```
Q_LENGTH34(three).time2=[time;Q_LENGTH34(three).time2];
else%i.e. more than one client arrive at the same time

Q_LENGTH34(three).k2(1)=Q_LENGTH34(three).k2(1)+1;
end
end

end
end



%new arrival time for the transporter:
trans23.arr(two,three)=-(time+shipment23(two,three).time(1));
trans23.dep(two,three)=time;

%and delete ... - you know it, buddy!
shipment23(two,three).time=shipment23(two,three).time(2:end);

%catch the clients which leaves to 2
for cl=1:ALL
ifontheway(cl,1:5)==[3,three,2,two,SIMEND];
ontheway(cl,5)=-trans23.arr(two,three);

%decrease the (LENGTH.)queuelength
ifontheway(cl,8)==1
if time~=LENGTH32(three,two).timek1(1) %This if asks whether this event oc-
curs on an new time point, othwise the events are batched to need less space

LENGTH32(three,two).queuek1=[int32(LENGTH32(three,two).queuek1(1)-
1);LENGTH32(three,two).queuek1];
LENGTH32(three,two).timek1=[time;LENGTH32(three,two).timek1];
else
LENGTH32(three,two).queuek1(1)=LENGTH32(three,two).queuek1(1)-1;
end%if time~=
if
sum(size(LENGTH32(three,two).queuek1))~=sum(size(LENGTH32(three,two).timek1))
error('Size Matters! line 478');
end%if size~=size
else
if time~=LENGTH32(three,two).timek2(1) %This if asks whether this event oc-
curs on an new time point, othwise the events are batched to need less space

LENGTH32(three,two).queuek2=[int32(LENGTH32(three,two).queuek2(1)-
1);LENGTH32(three,two).queuek2];
LENGTH32(three,two).timek2=[time;LENGTH32(three,two).timek2];
else
LENGTH32(three,two).queuek2(1)=LENGTH32(three,two).queuek2(1)-1;
end%if time~=
if
sum(size(LENGTH32(three,two).queuek2))~=sum(size(LENGTH32(three,two).timek2))
error('Size Matters! line 488');
end%if size~=size
end%if ontheway(cl,8)==1
end
end

else%then it started at 3 and is arriving at 2

%checking the quenes at that node:
queue.p2d1(two,1)=max(queue.p2d1(two,1),time);
```

```
queue.p2d1(two,2)=max(queue.p2d1(two,2),time);


%processing the arriving clients
for cl=1:ALL
ifontheway(cl,1:5)==[3,three,2,two,time]
%check this out: yeah, like before...
                        onthe-
way(cl,1:5)=[2,two,2,two,queue.p2d1(two,ontheway(cl,8))+process(two,ontheway(
cl,8)).p2d1(1)];
%make a new processing time:
                        pro-
cess(two,ontheway(cl,8)).p2d1=single(expval(mu21(two,ontheway(cl,8))));
%                         %and delete it:
%                         if size(process(two,ontheway(cl,8)).p2d1)>=[1,2]
%                                                                      pro-
cess(two,ontheway(cl,8)).p2d1=process(two,ontheway(cl,8)).p2d1(2:end);
%                         else
%                                warning('Simulation has run out of processing
times. New times are being calculated now.');
%                                                                      new-
proc=makeprocess(mu21,mu23,mu32,mu34,0.2*SIMEND);
%                                                                      pro-
cess(two,ontheway(cl,8)).p2d1=newproc(two,ontheway(cl,8)).p2d1;
%                             newproc=[];
%                                       disp(['New processing times for pro-
cess(',int2str(two),',',int2str(ontheway(cl,8)),').p2d1 are calculated. time:
',num2str(time)]);
%                         end
%the new queue time:
queue.p2d1(two,ontheway(cl,8))=ontheway(cl,5);

%and to count it as freshly arrived:
ifontheway(cl,8)==1
if Q_LENGTH21(two).time1(1)~=time

Q_LENGTH21(two).k1=[int32(Q_LENGTH21(two).k1(1)+1);Q_LENGTH21(two).k1];

Q_LENGTH21(two).time1=[time;Q_LENGTH21(two).time1];
else%i.e. more than one client arrive at the same time

Q_LENGTH21(two).k1(1)=Q_LENGTH21(two).k1(1)+1;
end

else%i.e. ontheway(cl,8)==2
if Q_LENGTH21(two).time2(1)~=time

Q_LENGTH21(two).k2=[int32(Q_LENGTH21(two).k2(1)+1);Q_LENGTH21(two).k2];

Q_LENGTH21(two).time2=[time;Q_LENGTH21(two).time2];
else%i.e. more than one client arrive at the same time

Q_LENGTH21(two).k2(1)=Q_LENGTH21(two).k2(1)+1;
end
end

end
end

%new arrival time for the transporter:
trans23.arr(two,three)=time+shipment23(two,three).time(1);
```

```
trans23.dep(two,three)=time;

%and delete that time:
shipment23(two,three).time=shipment23(two,three).time(2:end);



%catch the clients which leaves to 3
for cl=1:ALL
ifontheway(cl,1:5)==[2,two,3,three,SIMEND];
ontheway(cl,5)=trans23.arr(two,three);

%decrease the (LENGTH.)queuelength
ifontheway(cl,8)==1
if time~=LENGTH23(two,three).timek1(1) %This if asks whether this event oc-
curs on an new time point, otherwise the events are batched to need less
space

LENGTH23(two,three).queuek1=[int32(LENGTH23(two,three).queuek1(1)-
1);LENGTH23(two,three).queuek1];
LENGTH23(two,three).timek1=[time;LENGTH23(two,three).timek1];
else
LENGTH23(two,three).queuek1(1)=LENGTH23(two,three).queuek1(1)-1;
end%if time~=
if
sum(size(LENGTH23(two,three).queuek1))~=sum(size(LENGTH23(two,three).timek1))
error('Size Matters! line 544');
end%if size~=size
else
if time~=LENGTH23(two,three).timek2(1) %This if asks whether this event oc-
curs on an new time point, otherwise the events are batched to need less
space

LENGTH23(two,three).queuek2=[int32(LENGTH23(two,three).queuek2(1)-
1);LENGTH23(two,three).queuek2];
LENGTH23(two,three).timek2=[time;LENGTH23(two,three).timek2];
else
LENGTH23(two,three).queuek2(1)=LENGTH23(two,three).queuek2(1)-1;
end%if time~=
if
sum(size(LENGTH23(two,three).queuek2))~=sum(size(LENGTH23(two,three).timek2))
error('Size Matters! line 554');
end%if size~=size
end%if ontheway(cl,8)==1
end
end
end



case min(min(abs(trans34.arr)))
%search the arriving transporter
            [three,four]=get_the_index(time,abs(trans34.arr),N3,N4);

%finding out how much clients are on the way:
            ALL=size(ontheway);
            ALL=ALL(1);

if trans34.arr(three,four)>0 %if it started at 3 and is arriving at 4

%processing the arriving clients
for cl=ALL:-1:1
ifontheway(cl,1:7)==[3,three,4,four,time,4,four]
```

```
%Every deleted client is counted:
ifontheway(cl,8)==1
                            OUT-
PUTSAVE14(ontheway(cl,10),four).k1=[OUTPUTSAVE14(ontheway(cl,10),four).k1(1)+
1;OUTPUTSAVE14(ontheway(cl,10),four).k1];
                            OUT-
PUTSAVE14(ontheway(cl,10),four).time1=[time;OUTPUTSAVE14(ontheway(cl,10),four
).time1];

%save the trip duration:
                            DURATION14(ontheway(cl,10),four).k1=[time-
ontheway(cl,11);DURATION14(ontheway(cl,10),four).k1];
                            DURA-
TION14(ontheway(cl,10),four).time1=[time;DURATION14(ontheway(cl,10),four).tim
e1];

else
                            OUT-
PUTSAVE14(ontheway(cl,10),four).k2=[OUTPUTSAVE14(ontheway(cl,10),four).k2(1)+
1;OUTPUTSAVE14(ontheway(cl,10),four).k2];
                            OUT-
PUTSAVE14(ontheway(cl,10),four).time2=[time;OUTPUTSAVE14(ontheway(cl,10),four
).time2];

%save the trip duration:
                            DURATION14(ontheway(cl,10),four).k2=[time-
ontheway(cl,11);DURATION14(ontheway(cl,10),four).k2];
                            DURA-
TION14(ontheway(cl,10),four).time2=[time;DURATION14(ontheway(cl,10),four).tim
e2];

end%if ontheway(cl,8)==1

%deleting the client from 'ontheway', because they
%are arriving at their final destination
ontheway=[ontheway(1:cl-1,:);ontheway(cl+1:end,:)];
end%if
end%for

%size of 'ontheway' could have changed in the lines above:
                ALL=size(ontheway);
                ALL=ALL(1);

%new arrival time for the transporter:
trans34.arr(three,four)=-(time+shipment34(three,four).time(1));
trans34.dep(three,four)=time;

%and delete the old one:
shipment34(three,four).time=shipment34(three,four).time(2:end);

%catch the clients which leaves to 3
for cl=1:ALL
ifontheway(cl,1:5)==[4,four,3,three,SIMEND];
ontheway(cl,5)=-trans34.arr(three,four);

%decrease the (LENGTH.)queuelength
ifontheway(cl,8)==1
if time~=LENGTH43(four,three).timek1(1) %This if asks whether this event oc-
curs on an new time point, othwise the events are batched to need less space
```

```
LENGTH43(four,three).queuek1=[int32(LENGTH43(four,three).queuek1(1)-
1);LENGTH43(four,three).queuek1];
LENGTH43(four,three).timek1=[time;LENGTH43(four,three).timek1];
else
LENGTH43(four,three).queuek1(1)=LENGTH43(four,three).queuek1(1)-1;
end%if time~=
if
sum(size(LENGTH43(four,three).queuek1))~=sum(size(LENGTH43(four,three).timek1
))
error('Size Matters! line 606');
end%if size~=size
else
if time~=LENGTH43(four,three).timek2(1) %This if asks whether this event oc-
curs on an new time point, othwise the events are batched to need less space

LENGTH43(four,three).queuek2=[int32(LENGTH43(four,three).queuek2(1)-
1);LENGTH43(four,three).queuek2];
LENGTH43(four,three).timek2=[time;LENGTH43(four,three).timek2];
else
LENGTH43(four,three).queuek2(1)=LENGTH43(four,three).queuek2(1)-1;
end%if time~=
if
sum(size(LENGTH43(four,three).queuek2))~=sum(size(LENGTH43(four,three).timek2
))
error('Size Matters! line 616');
end%if size~=size
end%if ontheway(cl,8)==1
end
end

else%then it started at 4 and is arriving at 3

%checking the queues at that node:
queue.p3d2(three,1)=max(queue.p3d2(three,1),time);
queue.p3d2(three,2)=max(queue.p3d2(three,2),time);

%processing the arriving clients
for cl=1:ALL
ifontheway(cl,1:5)==[4,four,3,three,time]
%the processing procedure:
                        onthe-
way(cl,1:5)=[3,three,3,three,queue.p3d2(three,ontheway(cl,8))+process(three,o
ntheway(cl,8)).p3d2(1)];
%make a new processing time:
                        pro-
cess(three,ontheway(cl,8)).p3d2=single(expval(mu32(three,ontheway(cl,8))));
%                          %deleeeeeeete:
%                          if size(process(three,ontheway(cl,8)).p3d2)>=[1,2]
%                                                                         pro-
cess(three,ontheway(cl,8)).p3d2=process(three,ontheway(cl,8)).p3d2(2:end);
%                          else
%                                 warning('Simulation has run out of processing
times. New times are being calculated now.');
%                                                                         new-
proc=makeprocess(mu21,mu23,mu32,mu34,0.2*SIMEND);
%                                                                         pro-
cess(three,ontheway(cl,8)).p3d2=newproc(three,ontheway(cl,8)).p3d2;
%                              newproc=[];
%                                         disp(['New processing times for pro-
cess(',int2str(three),',',int2str(ontheway(cl,8)),').p3d2    are    calculated.
time: ',num2str(time)]);
```

```
%                          end
%the new queue time:
queue.p3d2(three,ontheway(cl,8))=ontheway(cl,5);

%and to count it as freshly arrived:
ifontheway(cl,8)==1
if Q_LENGTH32(three).time1(1)~=time

Q_LENGTH32(three).k1=[int32(Q_LENGTH32(three).k1(1)+1);Q_LENGTH32(three).k1];

Q_LENGTH32(three).time1=[time;Q_LENGTH32(three).time1];
else%i.e. more than one client arrive at the same time

Q_LENGTH32(three).k1(1)=Q_LENGTH32(three).k1(1)+1;
end

else%i.e. ontheway(cl,8)==2
if Q_LENGTH32(three).time2(1)~=time

Q_LENGTH32(three).k2=[int32(Q_LENGTH32(three).k2(1)+1);Q_LENGTH32(three).k2];

Q_LENGTH32(three).time2=[time;Q_LENGTH32(three).time2];
else%i.e. more than one client arrive at the same time

Q_LENGTH32(three).k2(1)=Q_LENGTH32(three).k2(1)+1;
end
end

end
end


%new arrival time for the transporter:
trans34.arr(three,four)=time+shipment34(three,four).time(1);
trans34.dep(three,four)=time;

%You think I am bored? I think you think too much; delete
%it:
shipment34(three,four).time=shipment34(three,four).time(2:end);

%catch the clients which leaves to 4
for cl=1:ALL
ifontheway(cl,1:5)==[3,three,4,four,SIMEND];
ontheway(cl,5)=trans34.arr(three,four);

%decrease the (LENGTH.)queuelength
ifontheway(cl,8)==1
if time~=LENGTH34(three,four).timek1(1) %This if asks whether this event oc-
curs on an new time point, othwise the events are batched to need less space

LENGTH34(three,four).queuek1=[int32(LENGTH34(three,four).queuek1(1)-
1);LENGTH34(three,four).queuek1];
LENGTH34(three,four).timek1=[time;LENGTH34(three,four).timek1];
else
LENGTH34(three,four).queuek1(1)=LENGTH34(three,four).queuek1(1)-1;
end%if time~=
if
sum(size(LENGTH34(three,four).queuek1))~=sum(size(LENGTH34(three,four).timek1
))
error('Size Matters! line 672');
end%if size~=size
```

```
else
if time~=LENGTH34(three,four).timek2(1) %This if asks whether this event oc-
curs on an new time point, othwise the events are batched to need less space

LENGTH34(three,four).queuek2=[int32(LENGTH34(three,four).queuek2(1)-
1);LENGTH34(three,four).queuek2];
LENGTH34(three,four).timek2=[time;LENGTH34(three,four).timek2];
else
LENGTH34(three,four).queuek2(1)=LENGTH34(three,four).queuek2(1)-1;
end%if time~=
if
sum(size(LENGTH34(three,four).queuek2))~=sum(size(LENGTH34(three,four).timek2
))
error('Size Matters! line 682');
end%if size~=size
end%if ontheway(cl,8)==1
end
end
end



case min(ontheway(:,5))
%this has to stand at the bottom, to be sure that the algorithm
%does not work with a client on a transport. (The clients on
%the transport have also a ontheway(5,*)-time which is proper
%smaller than SIMEND.)

            ALL=size(ontheway);
            ALL=ALL(1);

            [cl,two]=get_the_index(time,ontheway(:,5),ALL,1);

ifontheway(cl,1:2)==ontheway(cl,3:4) %only then the client is in a processing
state
ifontheway(cl,8)==1
%take the simplest route
next=ontheway(cl,7);
else%i.e. ontheway==k==2
%search the fastest route:

next=best_route(ontheway(cl,1),ontheway(cl,2),ontheway(cl,6),ontheway(cl,7));
end%if ontheway(8)==k==1

ifontheway(cl,6)==4 %check the destination
ontheway(cl,3:5)=[ontheway(cl,3)+1,next,SIMEND];
else%i.e. the destination column is 1
ontheway(cl,3:5)=[ontheway(cl,3)-1,next,SIMEND];
end%if ontheway(6)==4

%increase the queuelength
ifontheway(cl,1)==2 %First distinguish between the current columns
ifontheway(cl,3)==3 %and then between the next columns,
ifontheway(cl,8)==1 %last, differ between the classes.

NODE23(ontheway(cl,2),ontheway(cl,4)).queuek1=[int32(NODE23(ontheway(cl,2),on
theway(cl,4)).queuek1(1)+1);NODE23(ontheway(cl,2),ontheway(cl,4)).queuek1];

NODE23(ontheway(cl,2),ontheway(cl,4)).timek1=[time;NODE23(ontheway(cl,2),onth
eway(cl,4)).timek1];
```

```
LENGTH23(ontheway(cl,2),ontheway(cl,4)).queuek1=[int32(LENGTH23(ontheway(cl,2
),ontheway(cl,4)).queuek1(1)+1);LENGTH23(ontheway(cl,2),ontheway(cl,4)).queue
k1];

LENGTH23(ontheway(cl,2),ontheway(cl,4)).timek1=[time;LENGTH23(ontheway(cl,2),
ontheway(cl,4)).timek1];


Q_LENGTH23(ontheway(cl,2)).k1=[int32(Q_LENGTH23(ontheway(cl,2)).k1(1)-
1);Q_LENGTH23(ontheway(cl,2)).k1];

Q_LENGTH23(ontheway(cl,2)).time1=[time;Q_LENGTH23(ontheway(cl,2)).time1];
else

NODE23(ontheway(cl,2),ontheway(cl,4)).queuek2=[int32(NODE23(ontheway(cl,2),on
theway(cl,4)).queuek2(1)+1);NODE23(ontheway(cl,2),ontheway(cl,4)).queuek2];

NODE23(ontheway(cl,2),ontheway(cl,4)).timek2=[time;NODE23(ontheway(cl,2),onth
eway(cl,4)).timek2];


LENGTH23(ontheway(cl,2),ontheway(cl,4)).queuek2=[int32(LENGTH23(ontheway(cl,2
),ontheway(cl,4)).queuek2(1)+1);LENGTH23(ontheway(cl,2),ontheway(cl,4)).queue
k2];

LENGTH23(ontheway(cl,2),ontheway(cl,4)).timek2=[time;LENGTH23(ontheway(cl,2),
ontheway(cl,4)).timek2];


Q_LENGTH23(ontheway(cl,2)).k2=[int32(Q_LENGTH23(ontheway(cl,2)).k2(1)-
1);Q_LENGTH23(ontheway(cl,2)).k2];

Q_LENGTH23(ontheway(cl,2)).time2=[time;Q_LENGTH23(ontheway(cl,2)).time2];
end%if otheway(cl,8)==1
end
ifontheway(cl,3)==1
ifontheway(cl,8)==1

NODE21(ontheway(cl,2),ontheway(cl,4)).queuek1=[int32(NODE21(ontheway(cl,2),on
theway(cl,4)).queuek1(1)+1);NODE21(ontheway(cl,2),ontheway(cl,4)).queuek1];

NODE21(ontheway(cl,2),ontheway(cl,4)).timek1=[time;NODE21(ontheway(cl,2),onth
eway(cl,4)).timek1];


LENGTH21(ontheway(cl,2),ontheway(cl,4)).queuek1=[int32(LENGTH21(ontheway(cl,2
),ontheway(cl,4)).queuek1(1)+1);LENGTH21(ontheway(cl,2),ontheway(cl,4)).queue
k1];

LENGTH21(ontheway(cl,2),ontheway(cl,4)).timek1=[time;LENGTH21(ontheway(cl,2),
ontheway(cl,4)).timek1];


Q_LENGTH21(ontheway(cl,2)).k1=[int32(Q_LENGTH21(ontheway(cl,2)).k1(1)-
1);Q_LENGTH21(ontheway(cl,2)).k1];

Q_LENGTH21(ontheway(cl,2)).time1=[time;Q_LENGTH21(ontheway(cl,2)).time1];
else

NODE21(ontheway(cl,2),ontheway(cl,4)).queuek2=[int32(NODE21(ontheway(cl,2),on
theway(cl,4)).queuek2(1)+1);NODE21(ontheway(cl,2),ontheway(cl,4)).queuek2];
```

```
NODE21(ontheway(cl,2),ontheway(cl,4)).timek2=[time;NODE21(ontheway(cl,2),onth
eway(cl,4)).timek2];


LENGTH21(ontheway(cl,2),ontheway(cl,4)).queuek2=[int32(LENGTH21(ontheway(cl,2
),ontheway(cl,4)).queuek2(1)+1);LENGTH21(ontheway(cl,2),ontheway(cl,4)).queue
k2];

LENGTH21(ontheway(cl,2),ontheway(cl,4)).timek2=[time;LENGTH21(ontheway(cl,2),
ontheway(cl,4)).timek2];


Q_LENGTH21(ontheway(cl,2)).k2=[int32(Q_LENGTH21(ontheway(cl,2)).k2(1)-
1);Q_LENGTH21(ontheway(cl,2)).k2];

Q_LENGTH21(ontheway(cl,2)).time2=[time;Q_LENGTH21(ontheway(cl,2)).time2];
end%if otheway(cl,8)==1
end
end%if ontheway(cl,1)==2
ifontheway(cl,1)==3
ifontheway(cl,3)==2
ifontheway(cl,8)==1

NODE32(ontheway(cl,2),ontheway(cl,4)).queuek1=[int32(NODE32(ontheway(cl,2),on
theway(cl,4)).queuek1(1)+1);NODE32(ontheway(cl,2),ontheway(cl,4)).queuek1];

NODE32(ontheway(cl,2),ontheway(cl,4)).timek1=[time;NODE32(ontheway(cl,2),onth
eway(cl,4)).timek1];


LENGTH32(ontheway(cl,2),ontheway(cl,4)).queuek1=[int32(LENGTH32(ontheway(cl,2
),ontheway(cl,4)).queuek1(1)+1);LENGTH32(ontheway(cl,2),ontheway(cl,4)).queue
k1];

LENGTH32(ontheway(cl,2),ontheway(cl,4)).timek1=[time;LENGTH32(ontheway(cl,2),
ontheway(cl,4)).timek1];


Q_LENGTH32(ontheway(cl,2)).k1=[int32(Q_LENGTH32(ontheway(cl,2)).k1(1)-
1);Q_LENGTH32(ontheway(cl,2)).k1];

Q_LENGTH32(ontheway(cl,2)).time1=[time;Q_LENGTH32(ontheway(cl,2)).time1];
else

NODE32(ontheway(cl,2),ontheway(cl,4)).queuek2=[int32(NODE32(ontheway(cl,2),on
theway(cl,4)).queuek2(1)+1);NODE32(ontheway(cl,2),ontheway(cl,4)).queuek2];

NODE32(ontheway(cl,2),ontheway(cl,4)).timek2=[time;NODE32(ontheway(cl,2),onth
eway(cl,4)).timek2];


LENGTH32(ontheway(cl,2),ontheway(cl,4)).queuek2=[int32(LENGTH32(ontheway(cl,2
),ontheway(cl,4)).queuek2(1)+1);LENGTH32(ontheway(cl,2),ontheway(cl,4)).queue
k2];

LENGTH32(ontheway(cl,2),ontheway(cl,4)).timek2=[time;LENGTH32(ontheway(cl,2),
ontheway(cl,4)).timek2];
```

```
Q_LENGTH32(ontheway(cl,2)).k2=[int32(Q_LENGTH32(ontheway(cl,2)).k2(1)-
1);Q_LENGTH32(ontheway(cl,2)).k2];

Q_LENGTH32(ontheway(cl,2)).time2=[time;Q_LENGTH32(ontheway(cl,2)).time2];
end%if otheway(cl,8)==1
end
ifontheway(cl,3)==4
ifontheway(cl,8)==1

NODE34(ontheway(cl,2),ontheway(cl,4)).queuek1=[int32(NODE34(ontheway(cl,2),on
theway(cl,4)).queuek1(1)+1);NODE34(ontheway(cl,2),ontheway(cl,4)).queuek1];

NODE34(ontheway(cl,2),ontheway(cl,4)).timek1=[time;NODE34(ontheway(cl,2),onth
eway(cl,4)).timek1];


LENGTH34(ontheway(cl,2),ontheway(cl,4)).queuek1=[int32(LENGTH34(ontheway(cl,2
),ontheway(cl,4)).queuek1(1)+1);LENGTH34(ontheway(cl,2),ontheway(cl,4)).queue
k1];

LENGTH34(ontheway(cl,2),ontheway(cl,4)).timek1=[time;LENGTH34(ontheway(cl,2),
ontheway(cl,4)).timek1];


Q_LENGTH34(ontheway(cl,2)).k1=[int32(Q_LENGTH34(ontheway(cl,2)).k1(1)-
1);Q_LENGTH34(ontheway(cl,2)).k1];

Q_LENGTH34(ontheway(cl,2)).time1=[time;Q_LENGTH34(ontheway(cl,2)).time1];
else

NODE34(ontheway(cl,2),ontheway(cl,4)).queuek2=[int32(NODE34(ontheway(cl,2),on
theway(cl,4)).queuek2(1)+1);NODE34(ontheway(cl,2),ontheway(cl,4)).queuek2];

NODE34(ontheway(cl,2),ontheway(cl,4)).timek2=[time;NODE34(ontheway(cl,2),onth
eway(cl,4)).timek2];


LENGTH34(ontheway(cl,2),ontheway(cl,4)).queuek2=[int32(LENGTH34(ontheway(cl,2
),ontheway(cl,4)).queuek2(1)+1);LENGTH34(ontheway(cl,2),ontheway(cl,4)).queue
k2];

LENGTH34(ontheway(cl,2),ontheway(cl,4)).timek2=[time;LENGTH34(ontheway(cl,2),
ontheway(cl,4)).timek2];


Q_LENGTH34(ontheway(cl,2)).k2=[int32(Q_LENGTH34(ontheway(cl,2)).k2(1)-
1);Q_LENGTH34(ontheway(cl,2)).k2];

Q_LENGTH34(ontheway(cl,2)).time2=[time;Q_LENGTH34(ontheway(cl,2)).time2];
end%if otheway(cl,8)==1
end
end%if ontheway(cl,1)==3

else
warning('A client is out of the supply net!');
disp(['current time: ',num2str(time)]);
disp('current client:');
disp(ontheway(cl,:));
disp('');
ontheway(cl,5)=SIMEND;
disp('clients processing time has been changed to ''SIMEND''.');
```

```
end%if ontheway(1:2)==ontheway(3:4)

otherwise
error('The time does not match to any event! The loop was broken to avoid
endless loops.');

end%switch time

%search the next event:
ti-
me=min([min(min(prodtime14k1)),min(min(prodtime41k1)),min(min(prodtime14k2)),
min(min(prodtime41k2)),min(ontheway(:,5)),min(min(abs(trans12.arr))),min(min(
abs(trans23.arr))),min(min(abs(trans34.arr)))]);

end%while time

disp('Simulation has finished.');
%%---------------------------------------------------------------------------
%%functions for standard tasks
%%---------------------------------------------------------------------------
function[val]=expval(para)
%This function returns exponentially distributed values, where the mean
%value is (1/para).

val=-para*log(rand(1));
%%---------------------------------------------------------------------------
function[val]=unival(paramin,paramax)
%This function returns uniformly distributed values of the intervall
%(paramin,paramax).

val=paramin+rand(1)*(paramax-paramin);
%%---------------------------------------------------------------------------
function[ind1,ind2]=get_the_index(val,matrix,dim1,dim2)
for ind1=1:dim1
for ind2=1:dim2
ifval==matrix(ind1,ind2)
break;% the ind2
%The loops are broken to return the indices.
end%if
end%for ind2
ifval==matrix(ind1,ind2)
break;% the ind1
end%if
end%for ind1
%%---------------------------------------------------------------------------
function[Next]=best_route(cur_col,cur_row,dest_col,dest_row)
%This function estimates the fastest route from
%(current_column,current_row) to (dest_column,dest_row).

Next=0;

global N2 N3;

globalontheway;
global time;
globalqueue;

global mu21 mu23 mu32 mu34;

global trans12 trans23 trans34;
```

```
global shipmin12 shipmin23 shipmin34;
global shipmax12 shipmax23 shipmax34;
global shipment12 shipment23 shipment34

ifdest_col==4
switchcur_col

case 3 %In this case you have no choice
            Next=dest_row;

case 2 %In this case you can choose the row of column 3

min_dur=inf;

for three=1:N3
%duration=time_to_3 + processing_duration_at_3 +
%           estimated_time_to_4
if trans23.arr(cur_row,three)<0 %i.e. the transport is on the way to 2
                    trans_dur=-trans23.arr(cur_row,three)-
time+shipment23(cur_row,three).time(1);
else%i.e. the transport is on the way to 3
                    trans_dur=trans23.arr(cur_row,three)-
time+sum(shipment23(cur_row,three).time(1:2));
end

%the client does not know how much clients will arrive, so he
%just looks at the clients at the harbour.
duration=trans_dur+queue.p3d4(three,2)-time+1/mu34(three,2);

%Now, the client knows hows it takes to get ready at the
%next harbour. He now has to find out, when the next ship
%arrives:

%expected duration until the transport arrives at the next harbour:
                trans_dur=(time-
trans34.dep(three,dest_row))/(abs(trans34.arr(three,dest_row))-
trans34.dep(three,dest_row))*((shipmax34(three,dest_row)+shipmin34(three,dest
_row))/2);
if  trans34.arr(three,dest_row)>=0  %this  harbour  is  of  column  4  and  the
transport has to come back:

trans_dur=trans_dur+(shipmax34(three,dest_row)+shipmin34(three,dest_row))/2;
end

%It could be that the client arrives after the transport has
%left. To use this knowledge, the client takes the
%estimated time for sure and estimates what happens if he
%misses a transport in that case:
while duration>trans_dur

trans_dur=trans_dur+shipmax34(three,dest_row)+shipmin34(three,dest_row);  %The
division with 2 cancels out, because the ship has to take the way 2 times.
end

%Thus it he needs
duration=trans_dur;
%time to leave the next harbour, and estimately
duration=duration+(shipmax34(three,dest_row)+shipmin34(three,dest_row))/2;
%as the time to get to its destination.
```

```
%See if this duration is smaller than the others
if duration<min_dur
min_dur=duration;
                    Next=three;
end
end%for three=1:N3

case 1

min_dur=inf;

for two=1:N2
%dur_two=time_to_2 + processing_duration_at_2 +
%           + rest_w.r.t._3
if trans12.arr(cur_row,two)<0 %i.e. the transport is on the way to 1
                    trans_dur=-trans12.arr(cur_row,two)-
time+shipment12(cur_row,two).time(1);
else%i.e. the transport is on the way to 2
                    trans_dur=trans12.arr(cur_row,two)-
time+sum(shipment12(cur_row,two).time(1:2));
end

%the client does not know how much clients will arrive, so he
%just looks at the clients at the harbour.
dur_two=trans_dur+queue.p2d3(two,2)-time+1/mu23(two,2);

for three=1:N3
%duration=dur_two + time_to_3 + processing_duration_at_3 +
%           estimated_time_to_4

duration=dur_two;
%Now, the client knows hows it takes to get ready at the
%next harbour. He now has to find out, when the next ship
%arrives:

%expected duration until the transport arrives at the next harbour:
                    trans_dur=(time-
trans23.dep(two,three))/(abs(trans23.arr(two,three))-
trans23.dep(two,three))*((shipmax23(two,three)+shipmin23(two,three))/2);
if trans23.arr(two,three)>=0 %this harbour is of column 3 and the transport
has to come back:

trans_dur=trans_dur+(shipmax23(two,three)+shipmin23(two,three))/2;
end

%It could be that the client arrives after the transport has
%left. To use this knowledge, the client takes the
%estimated time for sure and estimates what happens if he
%misses a transport in that case:
while duration>trans_dur

trans_dur=trans_dur+shipmax23(two,three)+shipmin23(two,three);%The    division
with 2 cancels out, because the ship has to take the way 2 times.
end

%Thus it he needs
duration=trans_dur;
%time to leave the next harbour, and estimately
duration=duration+(shipmax23(two,three)+shipmin23(two,three))/2;
%as the time to get to its next aimed harbour.
```

```
%Add the queue time to know when the client is again
%ready to leave the harbour:
duration=duration+queue.p3d4(three,2)-time+1/mu34(three,2);

%expected duration until the transport arrives at the next harbour:
                    trans_dur=(time-
trans34.dep(three,dest_row))/(abs(trans34.arr(three,dest_row))-
trans34.dep(three,dest_row))*((shipmax34(three,dest_row)+shipmin34(three,dest
_row))/2);
if  trans34.arr(three,dest_row)>=0  %this  harbour  is  of  column  4  and  the
transport has to come back:

trans_dur=trans_dur+(shipmax34(three,dest_row)+shipmin34(three,dest_row))/2;
end

%It could be that the client arrives after the transport has
%left. To use this knowledge, the client takes the
%estimated time for sure and estimates what happens if he
%misses a transport in that case:
while duration>trans_dur

trans_dur=trans_dur+shipmax34(three,dest_row)+shipmin34(three,dest_row);%The
division with 2 cancels out, because the ship has to take the way 2 times.
end

%Thus it he needs
duration=trans_dur;
%time to leave the next harbour, and estimately
duration=duration+(shipmax34(three,dest_row)+shipmin34(three,dest_row))/2;
%as the time to get to its destination.

%See if this duration is smaller than the others
if duration<min_dur
min_dur=duration;
                        Next=two;
end
end%for three=1:N3
end%for two=1:N2
end%switch cur_col

else%i.e. dest_col==1

switchcur_col
case 2 %In this case you have no choice
            Next=dest_row;

case 3

min_dur=inf;

for two=1:N2
%duration=time_to_2 + processing_duration_at_2 +
%           estimated_time_to_1
if trans23.arr(two,cur_row)>0 %i.e. the transport is on the way to 3
                    trans_dur=trans23.arr(two,cur_row)-
time+shipment23(two,cur_row).time(1);
else%i.e. the transport is on the way to 2
                    trans_dur=-trans23.arr(two,cur_row)-
time+sum(shipment23(two,cur_row).time(1:2));
end
```

```
%the client does not know how much clients will arrive, so he
%just looks at the clients at the harbour.
duration=trans_dur+queue.p2d1(two,2)-time+1/mu21(two,2);

%Now, the client knows hows it takes to get ready at the
%next harbour. He now has to find out, when the next ship
%arrives:

%expected duration until the transport arrives at the next harbour:
                trans_dur=(time-
trans12.dep(dest_row,two))/(abs(trans12.arr(dest_row,two))-
trans12.dep(dest_row,two))*((shipmax12(dest_row,two)+shipmin12(dest_row,two))
/2);
if trans12.arr(dest_row,two)<=0 %the next harbour is of column 1 and the
transport has to come back:

trans_dur=trans_dur+(shipmax12(dest_row,two)+shipmin12(dest_row,two))/2;
end

%It could be that the client arrives after the transport has
%left. To use this knowledge, the client takes the
%estimated time for sure and estimates what happens if he
%misses a transport in that case:
while duration>trans_dur

trans_dur=trans_dur+shipmax12(dest_row,two)+shipmin12(dest_row,two);
end
%Thus it he needs
duration=trans_dur;
%time to leave the next harbour, and estimately
duration=duration+(shipmax12(dest_row,two)+shipmin12(dest_row,two))/2;
%as the time to get to its destination.

%See if this duration is smaller than the others
if duration<min_dur
min_dur=duration;
                    Next=two;
end
end%for two=1:N2

case 4

min_dur=inf;

for three=1:N3
%dur_three=time_to_3 + processing_duration_at_3 +
%           + rest_w.r.t._2
if trans34.arr(three,cur_row)>0 %i.e. the transport is on the way to 4
                    trans_dur=trans34.arr(three,cur_row)-
time+shipment34(three,cur_row).time(1);
else%i.e. the transport is on the way to 3
                    trans_dur=-trans34.arr(three,cur_row)-
time+sum(shipment34(three,cur_row).time(1:2));
end

%the client does not know how much clients will arrive, so he
%just looks at the clients at the harbour.
dur_three=trans_dur+queue.p3d2(three,2)-time+1/mu34(three,2);

for two=1:N2
%duration=dur_three + estimated_time_to_2 +
```

```
%           processing_duration_at_2 + estimated_time_to_1
duration=dur_three;
%Now, the client knows hows it takes to get ready at the
%next harbour. He now has to find out, when the next ship
%arrives:

%expected duration until the transport arrives at the next harbour:
                    trans_dur=(time-
trans23.dep(two,three))/(abs(trans23.arr(two,three))-
trans23.dep(two,three))*((shipmax23(two,three)+shipmin23(two,three))/2);
if trans23.arr(two,three)<=0 %this harbour is of column 2 and the transport
has to come back:

trans_dur=trans_dur+(shipmax23(two,three)+shipmin23(two,three))/2;
end

%It could be that the client arrives after the transport has
%left. To use this knowledge, the client takes the
%estimated time for sure and estimates what happens if he
%misses a transport in that case:
while duration>trans_dur
trans_dur=trans_dur+shipmax23(two,three)+shipmin23(two,three);
end
%Thus it he needs
duration=trans_dur;
%time to leave the next harbour, and estimately
duration=duration+(shipmax23(two,three)+shipmin23(two,three))/2;
%as the time to get to its next aimed harbour.

%Add the queue time:
duration=duration+queue.p2d1(two,2)-time+1/mu21(two,2);

%expected duration until the transport arrives at the next harbour:
                    trans_dur=(time-
trans12.dep(dest_row,two))/(abs(trans12.arr(dest_row,two))-
trans12.dep(dest_row,two))*((shipmax12(dest_row,two)+shipmin12(dest_row,two))
/2);
if  trans12.arr(dest_row,two)<=0  %this  harbour  is  of  column  1  and  the
transport has to come back:

trans_dur=trans_dur+(shipmax12(dest_row,two)+shipmin12(dest_row,two))/2;
end

%It could be that the client arrives after the transport has
%left. To use this knowledge, the client takes the
%estimated time for sure and estimates what happens if he
%misses a transport in that case:
while duration>trans_dur

trans_dur=trans_dur+shipmax12(dest_row,two)+shipmin12(dest_row,two);
end

%Thus it he needs
duration=trans_dur;
%time to leave the next harbour, and estimately
duration=duration+(shipmax12(dest_row,two)+shipmin12(dest_row,two))/2;
%as the time to get to its destination.

%See if this duration is smaller than the others
if duration<min_dur
min_dur=duration;
```

```
                        Next=three;
end
end%for two=1:N2
end%for three=1:N3

end% switch cur_col
end%if dest_col==4

if Next==0
error('The route search had no result!');
end
%%----------------------------------------------------------------------------

%%----------------------------------------------------------------------------
%%functions for the simulation start
%%----------------------------------------------------------------------------
function[val_struct]=makeinput(lambdak1,lambdak2,simend)
%This function calculates all the input times for both classes for the
%whole simulation duration.

val_struct=struct('k1',0,'k2',0);

dim=size(lambdak1);

for ind1=1:dim(1)
for ind2=1:dim(2)

%First values:
val_struct(ind1,ind2).k1(1)=single(expval(lambdak1(ind1,ind2)));
val_struct(ind1,ind2).k2(1)=single(expval(lambdak2(ind1,ind2)));

k_ind=1;
whileval_struct(ind1,ind2).k1(k_ind)<=simend
k_ind=k_ind+1;
%To know when the input is sufficient, each entry is a sum of
%its precessor random inputtime and the own random inputtime.

val_struct(ind1,ind2).k1(k_ind)=single(val_struct(ind1,ind2).k1(k_ind-
1)+expval(lambdak1(ind1,ind2)));
end%while k1

%to be sure that the simualtion does not run out of input events:
k_ind=k_ind+1;

val_struct(ind1,ind2).k1(k_ind)=single(val_struct(ind1,ind2).k1(k_ind-
1)+expval(lambdak1(ind1,ind2)));

k_ind=1;
whileval_struct(ind1,ind2).k2(k_ind)<=simend
k_ind=k_ind+1;

val_struct(ind1,ind2).k2(k_ind)=single(val_struct(ind1,ind2).k2(k_ind-
1)+expval(lambdak2(ind1,ind2)));
end%while k2

%to be sure that the simualtion does not run out of input events:
k_ind=k_ind+1;

val_struct(ind1,ind2).k2(k_ind)=single(val_struct(ind1,ind2).k2(k_ind-
1)+expval(lambdak2(ind1,ind2)));
```

```
end%for ind2
end%for ind1
%%---------------------------------------------------------------------------
function[val_struct]=makeprocess(MU21,MU23,MU32,MU34)
%This function calculates all the processing times for all nodes and
%classes in a sufficient number w.r.t SIMEND.

%val_struct.currentposition_destination
val_struct=struct('p2d1',0,'p2d3',0,'p3d2',0,'p3d4',0);

dim2=size(MU21);
dim3=size(MU32);

for k=1:dim2(2)
forind=1:dim2(1)
val_struct(ind,k).p2d1(1)=single(expval(MU21(ind,k)));
val_struct(ind,k).p2d3(1)=single(expval(MU23(ind,k)));

%         time_ind=1;
%           while sum(val_struct(ind,k).p2d1)<=10*simend %there are 10% extra
times to be sure that the simluation will not run out of processingtimes
%             time_ind=time_ind+1;
%             val_struct(ind,k).p2d1(time_ind)=single(expval(MU21(ind,k)));
%         end %while p2d1
%
%         time_ind=1;
%         while sum(val_struct(ind,k).p2d3)<=10*simend
%             time_ind=time_ind+1;
%             val_struct(ind,k).p2d3(time_ind)=single(expval(MU23(ind,k)));
%         end %while p2d3
end%for ind=1:dim2(1)
%
forind=1:dim3(1)
val_struct(ind,k).p3d2(1)=single(expval(MU32(ind,k)));
val_struct(ind,k).p3d4(1)=single(expval(MU34(ind,k)));
%
%         time_ind=1;
%         while sum(val_struct(ind,k).p3d2)<=10*simend
%             time_ind=time_ind+1;
%             val_struct(ind,k).p3d2(time_ind)=single(expval(MU32(ind,k)));
%         end %while p3d2
%
%         time_ind=1;
%         while sum(val_struct(ind,k).p3d4)<=10*simend
%             time_ind=time_ind+1;
%             val_struct(ind,k).p3d4(time_ind)=single(expval(MU34(ind,k)));
%         end %while p3d4
end%for ind=1:dim3(1)
end%for k
%%---------------------------------------------------------------------------
function[val_struct]=makeshiptime(shipmin,shipmax,simend)
%This function calculates all the shiptment times for the whole simulation
%duration.

val_struct=struct('time',0);

dim=size(shipmin);

for ind1=1:dim(1)
for ind2=1:dim(2)
```

```
time_ind=1;

val_struct(ind1,ind2).time(time_ind)=single(unival(shipmin(ind1,ind2),shipmax
(ind1,ind2)));

while sum(val_struct(ind1,ind2).time)<=simend%while the times are not suffi-
cient for the simulation duration
time_ind=time_ind+1;

val_struct(ind1,ind2).time(time_ind)=single(unival(shipmin(ind1,ind2),shipmax
(ind1,ind2)));
end

%The shipment times are used to choose a route, even if there is no
%time left to pass it. In this case extra shipment times are
%required, because the estimations go beyond SIMEND.

val_struct(ind1,ind2).time(time_ind+1)=single(unival(shipmin(ind1,ind2),shipm
ax(ind1,ind2)));

val_struct(ind1,ind2).time(time_ind+2)=single(unival(shipmin(ind1,ind2),shipm
ax(ind1,ind2)));
end
end
%%--------------------------------------------------------------------------
function[val_struct]=makenode(n1,n2)
%This function defines the variables callesNODExy which contain all data
%about the client behaviour.
val_struct=struct('queuek1',0,'timek1',0,'queuek2',0,'timek2',0);
for ind1=1:n1
for ind2=1:n2
val_struct(ind1,ind2).queuek1=int32(0);
val_struct(ind1,ind2).queuek2=int32(0);
val_struct(ind1,ind2).timek1=single(0);
val_struct(ind1,ind2).timek2=single(0);
end
end
%%--------------------------------------------------------------------------
function[]=errorcheck(n1,n2,n3,n4);
%This function exists to shorten the main function. Its use should be
%obvious. ;-)

global lambda14k1 lambda41k1 lambda14k2 lambda41k2;
global mu23 mu34 mu21 mu32;
global shipmin12 shipmin23 shipmin34;
global shipmax12 shipmax23 shipmax34;

if size(lambda14k1)~=[n1,n4]
error('inputrates lambda for N_1 k_1 are not correctly defined!');
end
if size(lambda14k2)~=[n1,n4]
error('inputrates lambda for N_1 k_2 are not correctly defined!');
end
if size(lambda41k1)~=[n4,n1]
error('inputrates lambda for N_4 k_1 are not correctly defined!');
end
if size(lambda41k2)~=[n4,n1]
error('inputrates lambda for N_4 k_2 are not correctly defined!');
end
if size(mu23)~=[n2,2]
error('processing times for column 2 to 3 are not defined correctly!');
```

```
end
if size(mu34)~=[n3,2]
error('processing times for column 3 to 4 are not defined correctly!');
end
if size(mu21)~=[n2,2]
error('processing times for column 2 to 1 are not defined correctly!');
end
if size(mu32)~=[n3,2]
error('processing times for column 3 to 2 are not defined correctly!');
end
if size(shipmin12)~=[n1,n2]
error('shipment minimum times between N1 and N2 are not correctly defined!');
end
if size(shipmin23)~=[n2,n3]
error('shipment minimum times between N2 and N3 are not correctly defined!');
end
if size(shipmin34)~=[n3,n4]
error('shipment minimum times between N3 and N4 are not correctly defined!');
end
if size(shipmax12)~=[n1,n2]
error('shipment maximum times between N1 and N2 are not correctly defined!');
end
if size(shipmax23)~=[n2,n3]
error('shipment maximum times between N2 and N3 are not correctly defined!');
end
if size(shipmax34)~=[n3,n4]
error('shipment maximum times between N3 and N4 are not correctly defined!');
end
```