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Design of Screening System for Transatlantic Container Transport

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DESIGN OF SCREENING SYSTEM FOR TRANSATLANTIC CONTAINER TRANSPORT

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Dedication

I would like to dedicate this thesis to a special memory of doc. Ing. Ladislav Bína, CSc, whose hard work on the Transatlantic Dual Masters Degree Program gave me the opportunity to fulfill my dream of studying at a university in the United States.

In addition, I would also like to dedicate this thesis to my family, who have always provided me with unyielding support and encouraged me to pursue a degree abroad.

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by

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This thesis is jointly supervised by the following faculty members:

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Abstract

Maritime container transport plays a major role in international trade. As such, it can be an attractive target of acts of unlawful interference, e.g., smuggling, piracy or terrorism. One major issue of maritime security is the container screening at ports, which is the main focus of this thesis. The goal of this thesis is to study the efficiency of different designs of screening systems using simulation. The literature review covers contemporary laws and requirements, container screening equipment and processes related to screening that take place in seaports. Next, operation of three screening checkpoints models, which symbolize predominant approaches to container screening, is simulated in Arena Simulation Software. The simulated cases are a representation of shipping containers through the transatlantic route from the European Union to the United States. The results are subsequently analyzed in order to gain insight into various aspects of checkpoint operation. Furthermore, recommendations on implementation of container screening at maritime terminals are provided to both policy makers and terminal designers.

Keywords: container screening, maritime security, container terminal operations, Arena Simulation Software, security checkpoint

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Chapter 1: Introduction

Since the tragic events of the 9/11 terrorist attacks, the perception of transportation security has changed significantly. The last decade saw the introduction of new security measures in both passenger and freight transport. This trend is still ongoing and most likely will continue in the future, since the nature of threats against transportation is continuously changing.

In June 2014 the Council of the European Union (2014) has identified risks and threats in the maritime domain that can pose a potential risk to European citizens and European Union (EU) Member States. Most notably, the list includes terrorism, proliferation of weapons of mass destruction or cross-border crime, such as smuggling, human trafficking, and etc. It is safe to say that the same threats exist all around the world, including the United States (U.S.). To prevent such acts of unlawful interference against maritime freight transport, complex proactive security systems must be implemented.

1.1 Background

1.1.1 Multi-layered Approach to Transportation Security

One of the most prominent approaches to ensure proactive transportation security is to implement the so-called multi-layered approach. Initially introduced in passenger air transportation by Transportation Security Administration (TSA), this concept relies on introducing multiple security measures (layers) throughout the whole transportation process. The combination of all layers provides increased probability of threat detection, more robust security system and generally enhances the level of transport infrastructure security (TSA 2014). Figure

1.1 depicts the application of the multi-layered approach to maritime container transport. However, this figure does not include all the available security measures.

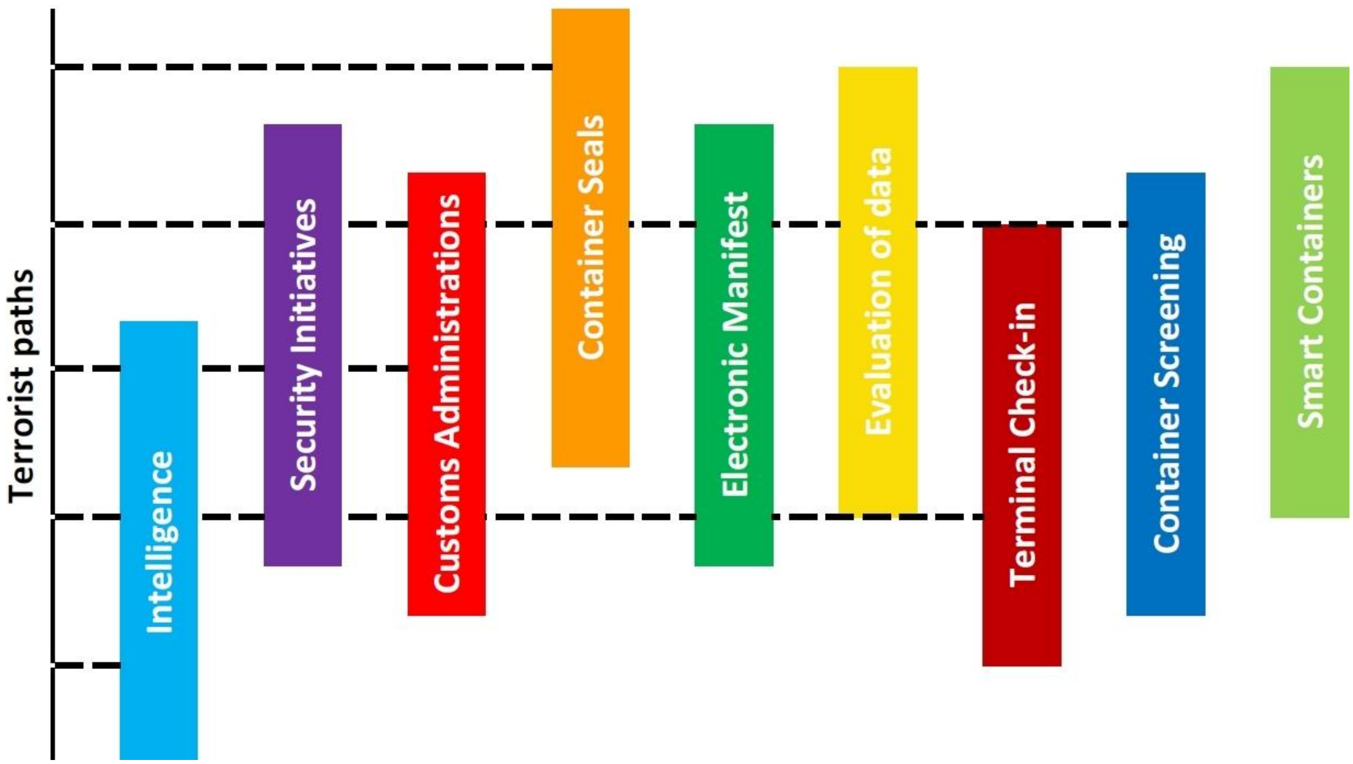

Figure 1.1: Layers of Maritime Container Security

The key information for preventing crimes such as weapons smuggling through a port of entry is information about the content of the container. Therefore, based on the customs requirements, every container must be accompanied by a cargo manifest, which generally specifies its contents, consigner (sender), consignee (recipient), shipper, ports of departure and destination, and etc. Nowadays, the cargo manifest is mostly electronic. However, there is no guarantee that the information contained in the manifest is genuine or has not been tampered

with. If there is such uncertainty, the actual contents of the container shall be verified by container inspections.

The inspections can either be done physically by trained personnel or using special automated equipment, in which case it is described as screening or scanning. The screening requirements and procedures are established by both international and national legislations, which will be reviewed in the next section of this chapter.

1.1.2 International Screening-Related Legislation

At the international level, the most influential international organization dealing with custom inspection in global trade is the World Customs Organization (WCO). Its main goal is to set international customs standards that shall lead to harmonization and simplification of the global trade, improving the efficiency of customs administrations of its member states. These standards also include SAFE Framework of Standards to Secure and Facilitate the Global Trade (SAFE Framework) that focuses on the Supply Chain Security (SCS). This document sets the minimal requirements for security of logistic chains, including maritime cargo screening. It states that at the request of the state of destination, the custom administration of state of departure shall perform an outbound inspection of high-risk containers and cargo, preferably using non-intrusive detection equipment (WCO 2012). In addition, it defines basic rules for Authorized Economic Operator (AEO) programs, which strengthen SCS through customs-to-business partnership.

The maritime and port security is the subject of the International Ship and Port Facility Security (ISPS) Code. Developed by United Nation (UN) agency International Maritime Organization (IMO), it came into effect in July 2004 as a response to the 9/11 event. It contains guidelines for maritime vessels and facilities of international ports, which ensure that risk management techniques are used for the determination of security measures (IMO 2014).

1.1.3 Related Legislations in U.S.

To protect its borders against possible threats related to transported cargo, the U.S. have adopted the principles of risk assessment to conduct cargo inspections. Based on the rule called Importer Security Filing and Additional Carrier Requirements (also known as 10+2 rule), the cargo information carried by all U.S. bound vessels must be transmitted electronically to U.S. Customs and Border Protection (CBP) at least 24 hours before loading the cargo in the port of departure. Importers must provide 10 data elements (such as name and address of buyer, seller, country of origin etc.) and carriers two additional data elements (vessel stow plan, container status message) (CBP 2009). This and additional information is used for the purposes of high-risk shipment identification, which is carried out by the Automated Targeting System (ATS). Based on the output of ATS, containers are selected for screening.

To enhance the efficiency of the risk-based approach to screening, the Customs-Trade Partnership against Terrorism (C-TPAT) program was established based on the framework given by WCO SAFE Framework. The C-TPAT member operators are obliged to implement a certain level of security measures and co-operate with CBP to protect the supply chain. Both parties benefit from the C-TPAT - the members can enjoy competitive advantages (such as expedited processing etc.) and the CBP can utilize its resources for better risk assessment and target higher-risk cargo shipments (CBP n.d.).

In addition, one of the first measures after 9/11 was the establishment of the Container Screening Initiative (CSI) under the jurisdiction of CBP. Its core elements are:

- Identifying and targeting of containers that pose a threat by using intelligence and automated advance targeting information systems;

- Prescreening of containers that pose a risk at the port of departure before their arrival at a port of entry;
- Using state-of-the-art detection technology to scan high-risk containers.

The CSI is based on cooperation with foreign ports, where a team of both CBP and Immigration and Customs Enforcement (ICE) officers are deployed to conduct container screening before containers are loaded onto vessels heading for U.S. As of 2014, CSI has been implemented in 58 ports worldwide (CBP n.d.).

However, there are legal exceptions to the risk-based approach to screening. In 2006, the Security and Accountability for Every Port Act of 2006 (SAFE Port Act) has been enacted. One of its sections defines the obligation to screen all import containers in the 22 busiest seaports using radiation detection equipment (U.S. Government Printing Office, 2006). This measure was expanded by the Implementing Recommendations of the 9/11 Commission Act of 2007 – it states that containers shall not enter the U.S. unless they have been screened using Non-Intrusive Imaging (NII) and radiation detection equipment at the port of departure before being loaded onto the vessel (U.S. Government Printing Office, 2007).

The deadline for screening of 100% US-bound containers was originally set to the 1st of July 2012. However, due to the high costs and technical problems, the deadline was postponed twice, currently being 2016 (Homeland Security News Wire, 2014). Moreover, the industry community is concerned with delays and extra cost this measure could bring. According to GAO (2012), the future of 100 % screening of U.S. bound containers is uncertain and further research on its feasibility should be carried out.

1.1.4 Related Legislation in the EU

The EU has adopted the risk-based approach to screening as the main method of ensuring supply chain security, i.e., only containers that are targeted for inspection are screened (EC 2005). Carriers are required to electronically transmit the Entry Summary Declaration (ENS) data to the Customs authorities of EU member states. The measure applies to all imported goods to the EU, goods to be transshipped through the EU, goods to be reloaded in an EU port for transit and freight remaining on board. The data is used for risk assessment of cargo, based on which NII inspections are carried out. The ENS data include information about consignor and consignee, goods specification, and etc. (EC 2006).

The EU has implemented its version of customs-to-business partnership program, simply called the Authorised Economic Operator (AEO). Unlike import-focused C-TPAT, it is focused on both import and export. Based on an agreement between U.S. and EU, both programs are mutually recognized (EC 2014).

Besides the mutual recognition of AEO and C-TPAT programs, the EU is cooperating closely with U.S. in the matter of customs based on Agreement on Customs Cooperation and Mutual Assistance in Customs Matters from 1997. This agreement was expanded in 2004 to include cooperation related to supply chain security, particularly the CSI. Lastly, a Joint statement on supply-chain security was signed by EU and US officials in 2011, outlining a joint agenda between European Commission and DHS on future approach to customs, aviation security, maritime security, research and development (EC 2014).

1.2 Thesis objectives

The thesis has several objectives, the first of which is to provide a detailed review of the topic of container screening at seaports. It should cover all related legislations, equipment and methods, as well as different approaches to implement screening.

The second objective is to review the proposed concept of 100% container screening and its potential impact on container terminal operation and supply chain.

The third objective is to create simulation models in the Arena Simulation Software and simulate the operations of screening checkpoints. Three configurations of screening checkpoint are modelled, each of which corresponds to a different approach to screening containers.

The fourth objective is to analyze the output of the simulation and provide insight into the behavior of simulated checkpoints under different operational conditions.

Finally, the fifth objective of the thesis is to provide recommendations for policy makers and terminal designers on how to implement screening at seaports, using the findings of the simulations.

1.3 Thesis outline

Chapter 1 serves as an introduction to maritime shipping security and provides reviews of the related legislation at international level, in the U.S. and in the EU.

Chapter 2 is devoted to overview of equipment and technology that is currently used for screening of containers in seaports.

Chapter 3 focuses on security processes all maritime containers undergo when they are being shipped from the EU to the U.S. In addition, currently used methods for container screening and checkpoint configurations are described.

Chapter 4 introduces the 100% container screening concept that in the future should be implemented when importing maritime containers to the U.S.. As it is a highly controversial concept among the industry experts, a literature review of its possible impact and issues is conducted as part of the chapter.

Chapter 5 describes the experiments that were conducted in the Arena Simulation Software. It defines the models that were used for the simulation of container screening checkpoints, as well as the settings that were used for running of the simulations.

Chapter 6 analyzes the first part of the simulation results that were conducted for low container traffic. It provides insight on how the checkpoint could behave during operation at a container terminal with low rates of container arrivals.

Chapter 7 continues the analysis of results which correspond to high container traffic that can be expected at container terminals with high throughput.

Chapter 8 provides recommendations for both policy makers and terminal designers on the topic of container screening implementation.

Chapter 9 concludes this work and suggests potential and future research directions.

Chapter 2: Container Screening Equipment

The aim of this chapter is to review the equipment currently used for container screening at seaports. Equipment for radiation detection and NII will be covered.

2.1 Radiation detection equipment

Radiation detection screening serves to detect radioactive material concealed in containers. The inspection can be divided into primary and secondary. Currently, the most widely used equipment are the Radiation Portal Monitor (RPM) for primary inspection and Radiation Isotope Identification Device (RIID) for secondary inspection.

2.1.1 Radiation Portal Monitor

The RPM (Figure 2.1) is a passive, non-intrusive screening system used to screen containers and vehicles for radiation. The system is composed of two panels, each located on opposite site of a truck lane, through which a vehicle with a container shall pass, to detect radiation. The radiation sensors can be based upon several principles. According to OIG DHS (2013), the majority of RPMs used in U.S. use sensors that compose of tubes filled with polyvinyl toluene plastic and helium-3, which serves as neutron moderator. In addition to the sensor panels, the RPM system includes control unit to relay alert messages or system status and various accessories, such as traffic lights, booths, and etc.

The RPM performance parameters vary according to its vendor. For instance, the false alarm rate of RPM systems by TSA Systems (today's Rapiscan Systems), which were used during the Secure Freight Initiative (SFI) pilot project in 2008, is quoted to be less than 1 in 1000 containers. The optimal speed of truck passing through the same RPM system was quoted to be 5 mph (8 km/h) (Bennett and Chin 2008).

Figure 2.1: Radiation Portal Monitor (RPM)

(Gowadia and Koeppel 2014)

According to OIG DHS (2013), as of August 2012, there were 444 RPMs installed in U.S. seaports, originally installed by Domestic Nuclear Detection Office (DNDO) and operated by CBP. The GAO (2007) estimates the average cost of an RPM unit itself to be $55,000, with additional $200,000 required for its installation.

The RPM systems are reported to have two significant disadvantages. Firstly, they cannot detect shielded radioactive material. Secondly, they cannot distinguish between Naturally Occurring Radioactive Material (NORM) and threat objects. This can lead to higher false alarm

rate as well as the need to conduct secondary detection to identify the nature of the detected radiation source (Qi et al. 2011).

These limitations encouraged the development of the next generation radiation detection equipment, called Advanced Spectroscopic Portal (ASP). Developed by DNDO from 2005, it was supposed to distinguish between NORM and threat objects, provide very high detection rates and relatively low inspection times (Qi et al. 2013). However, the project was abandoned in 2011 because of operational and technical challenges (OIG DHS 2013).

2.1.2 Radiation Isotope Identification Device

To determine the nature of radiological alarm at RPM, secondary inspection must be carried out. If the alarm is confirmed by another RPM, the alarm must be resolved by trained personnel using handheld RIID. The most commonly used types of RIID are either sodium-iodide (NaI) based, or high-purity Germanium (HPGe) based. The former provides lightweight equipment solution (5.5 lbs), while the latter offers high resolution, but also weighs more (40 lbs) (Bennett and Chin 2008). In addition to RIID, the personnel conducting the secondary radiation inspection must use personal radiation pagers for health and safety reasons.

According to Qi et al. (2013), the process of secondary radiation detection inspection with RIID can create a delay between 5 and 15 minutes (or more) per container. The result of RIID inspection determines if further security measures shall be taken, for example the isolation of the container or intervention of specialized action team.

As a part of their research, Bennett and Chin (2008) conducted a market survey of secondary radiation inspection equipment. The overview of costs states the average price of RIID to be $10,300 per unit and price of a personal radiation pager to be approximately $1,000 per unit.

2.2 Non-Intrusive Inspection

A NII system serves to identify the container contents without the need to open the container and physically inspect it. It can help to identify various kind of contraband, including weapons and drugs. Generally, a NII system provides an image of container contents, which is reviewed for the presence of undesirable objects.

Current NII systems are usually based on Gamma ray or X-ray imaging technology (CBP 2013). X-ray-based systems use X-ray generator to emit X-rays to penetrate the inspected containers. The objects inside the container absorb a certain amount of X-ray radiation and thus alter the original emitted radiation. The altered X-rays are consequently detected by radiation detectors. Since different materials differ in radiation absorption, an image representation of container contents is created. To penetrate the container casing, X-ray systems use high energy radiation, ranging from 2.5 to 9 MeV. Gamma ray systems function on a similar basis, only use a radioactive source, e.g. Cobalt-60 or Cesium-137, as the source of radiation (Bennett and Chin 2008). Naturally, appropriate health and safety procedures are implemented when operating NII equipment.

NII equipment can be divided into several groups according to their properties. The NII systems can be stationary (whole facility, gantries etc.), semi-stationary (trailers) or mobile (truck-based). Screening procedures may also vary. The majority of NII systems require the vehicle with the container to pass through the equipment. However, some NII systems require the driver to operate the vehicle with the container during the actual screening, while other require the driver to exit the vehicle beforehand, using conveyor systems to pull the vehicle through the equipment.

Figure 2.2: Stationary NII Equipment – Smith Detection HCVS

(Poverello 2012)

In addition, high capacity NII systems and low capacity NII systems can be distinguished. The former offer high throughput of screening, processing up to 150-200 containers per hour. However, their accuracy is limited due to low level of radiation used. Because of that, additional inspections might be required. The other type, low capacity NII systems, utilizes a high level radiation to produce container images. This leads to higher accuracy, but also lower throughput (approximately 20 containers per hour) and more advanced safety measures, such as encasing the NII equipment in a layer of concrete (Policy Research Corporation 2009).

As Bennett and Chin (2008) noted, since the NII systems generally do not provide any automatic alarm notification, the NII images must be analyzed visually by trained personnel. This can lead to longer inspection times since the duration of NII inspection depends on the image review time or higher alarm rates, because of involvement of the human factor. However, some vendors offer software-based tools for NII image analysis that can assist the NII operators, improving system throughput and reliability of detection. Qi et al. (2011) reported the reliability of NII detection to be higher than 98% on average.

Figure 2.3: Mobile NII Equipment – Rapiscan Eagle M60

(Rapiscan Systems 2014)

The wide variety of systems available in the market is reflected in the price range of the NII equipment. It depends on the detection technology (Gamma or X-ray) and type of NII system (stationary, semi-stationary, mobile) or other NII configuration. In the market review conducted by Bennett and Chin (2008) the cost of NII system varied from about $1 million to $4 million. In addition, their research revealed that the annual maintenance of NII equipment is roughly equal to 10 % of the original price of purchase.

2.3 Summary

The container screening equipment forms a crucial part of the container terminal security infrastructure. Currently, there is a wide variety of different equipment compliant with security

measures available in the market. With new technologies, the market may become even more diverse in the future.

The Table 2.1 sums up the general information about all the types of equipment currently being used for radiation detection and NII container inspections. The container throughput and inspection time for RPM systems were estimated based on the previously quoted truck operation speed, length of the truck carrying one 40 ft. container and 10-second headways between arriving trucks. In addition, container throughput is not given for RIID system, since only small percentage of selected containers undergo RIID inspection.

Table 2.1: Overview of Container Screening Equipment

<table>
<tr><th></th><th>Type</th><th>Screen for</th><th>Container Throughput [cont./hour]</th><th>Inspection Time</th><th>Detection reliability</th><th>Approximate costs</th></tr>
<tr><td rowspan="2">Radiation detection</td><td>Radiation Portal Monitor (RPM)</td><td>Presence of radioactive material</td><td>~ 240</td><td>~ 10 seconds</td><td>98 %</td><td>$55,000</td></tr>
<tr><td>Radiation Isotope Identification Device (RIID)</td><td>Nature of radioactive material</td><td>-</td><td>5 – 15 minutes</td><td>99.9 %</td><td>$10,300</td></tr>
<tr><td rowspan="2">Non-Intrusive Inspection</td><td>Low capacity system</td><td>Contraband, threat objects</td><td>~ 20</td><td rowspan="2">2 – 5 minutes (depending on image review time)</td><td rowspan="2">> 98 %</td><td rowspan="2">$1-4 million</td></tr>
<tr><td>High Capacity System</td><td>Contraband, threat objects</td><td>up to 150 -200</td></tr>
</table>

Chapter 3: Transatlantic Container Screening Processes

Chapter 3 provides a thorough review of security processes containers go through during its handling in the port. The focuses are the current practice of screening of export containers in EU ports and import containers at U.S. ports. The Port of Hamburg in Germany and the Port of Houston, Texas are used as examples.

3.1 Transatlantic Container Shipping Process

To understand how container security processes influence the whole shipping process, this section describes the process of shipping containers between EU and U.S. The process is depicted in the Figure 3.1 where the solid line symbolizes the physical container flow and the dotted line information flows.

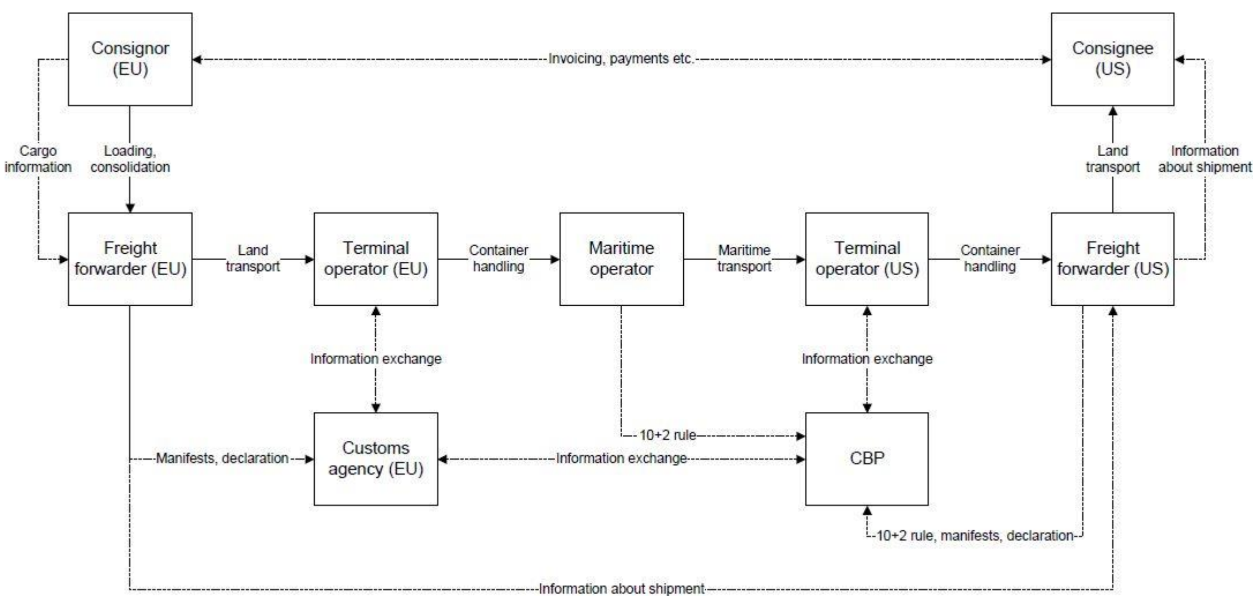

Figure 3.1: Container Supply Chain between the EU and U.S.

The shipping process starts in an EU member state when a container is loaded and sealed with a container seal (with a unique number) in the location of the consignor (sender), e.g. a factory (EC 2002). The information about the cargo is shared with the freight forwarder, a company that handles the land transportation to the port. The cargo information is used to create cargo and container manifests, documents that accompany the container during the whole process of shipping. The manifests are shared with the customs administration in both the EU and U.S. for evaluation. If there is a justifiable security concern, container inspection can be conducted once the container arrives at the EU port. If the container poses no threat, it is cleared for loading onto a vessel, after which the actual transport across the Atlantic Ocean is conducted by a maritime operator.

When transporting containers to the U.S., freight forwarders and maritime operators are required to transfer extra information to CBP based on the Importer Security Filing and Additional Carrier Requirements (10+2 rule) prior to loading of the vessel (CBP 2009). The CBP uses this information for the purposes of targeting containers for inspection in the U.S. ports. In addition, according to the WCO (2012), the WCO members can request the customs administration of the port of departure state to conduct additional inspection. This means the CBP can contact the customs agency at the EU port of departure and request the latter to conduct additional screening. Moreover, if the port participates in the CSI program, it must fulfill additional requirements for container inspection.

Once the container is unloaded and inspected in the U.S. port, a freight forwarder provides transport to the location of the consignee (recipient) of the goods. If goods for multiple consignees are present in the container, the container is deconsolidated first by the freight forwarder.

3.2 Container Inspections at the Port of Departure

3.2.1 Outbound Container Inspection Processes

The process of container handling starts when the container arrives at the port area. In general, the freight forwarder must report the arrival to the container terminal operator either in advance or during terminal gate check-in. If the container is targeted for inspection, screening is conducted either at the terminal gate or at a detached screening location, depending on the port layout. Screening in the EU ports is usually conducted using NII. Radiation detection equipment might also be used, although in a very small scale (Representative of Main Customs Office Port of Hamburg 2014). According to European Commission working paper (2010), the percentage of containers that are selected for screening ranges from 0.1% in larger ports to 3% in smaller ports. If the NII equipment detects a threat or contraband, the container is detained, opened and physically inspected. Further investigation might also ensue, depending on the nature of security violation.

If the container is cleared from the inspections or had not been selected for screening previously, it is cleared to enter the container terminal. At the check-in gate, all documents are checked before allowing the vehicle with the container to enter the terminal. The container seal (including its engraved seal number) is checked against any sign of tampering (EC 2002). In addition, if the container is reported to be empty, it is opened to verify whether it is actually empty (Representative of Main Customs Office Port of Hamburg 2014). If any issue is discovered, the container may be subjected to additional inspections. The next step in the process is the actual container handling at the terminal. The container is unloaded from the vehicle and put in a stack at the container yard. There it may dwell for a certain period of time before being loaded onto a vessel. The inspection process is depicted in Figure 3.2.

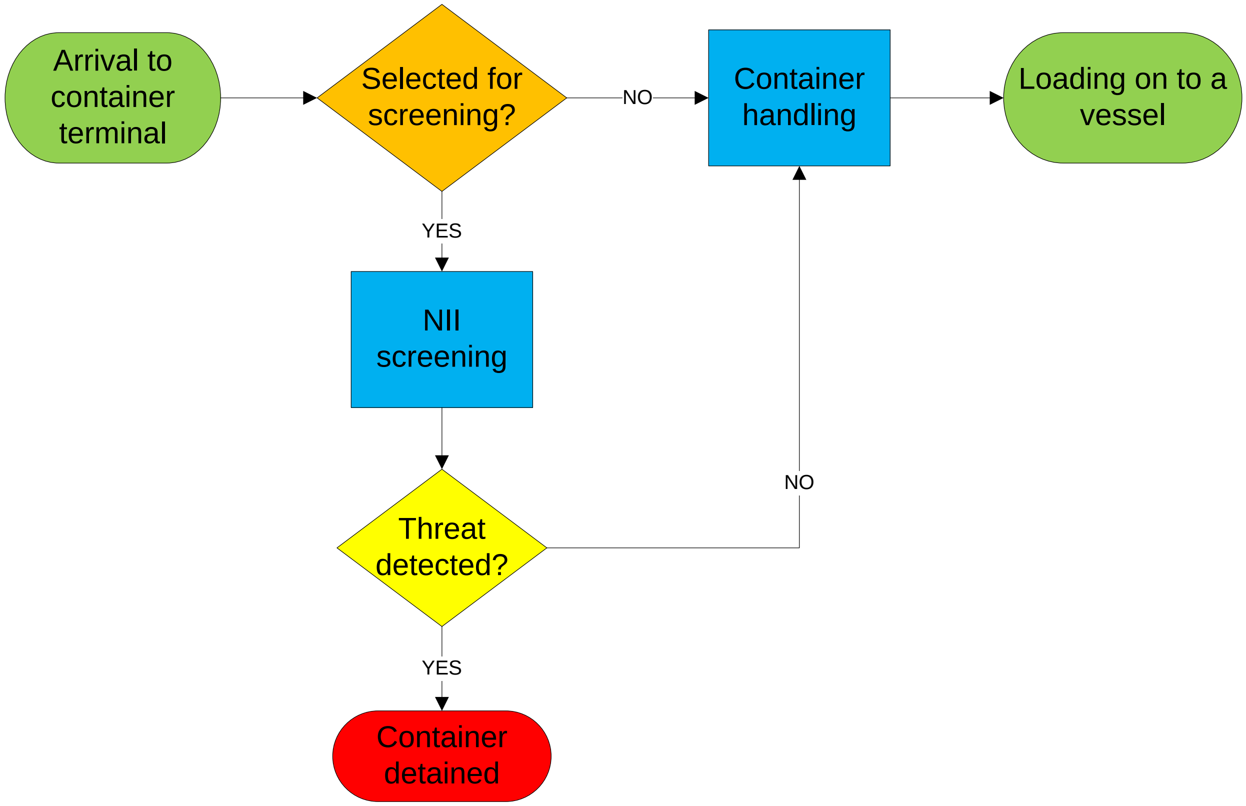

Figure 3.2: Container Inspection Flow Chart at Port of Departure in the EU

3.2.2– Container Inspection Process at Port of Hamburg, Germany

To discover the current state of container inspections in the EU ports, an email interview with a representative of Main Customs Office Port of Hamburg was conducted in June 2014. The Port of Hamburg was selected because it is one of the most important ports in Europe, especially for the region of Central Europe.

The Port of Hamburg is the largest container port in Germany and second largest in Europe. In 2013, 9.3 million Twenty-Foot Equivalent Units (TEU) were handled in its container terminals. It is located in the north of Germany on the river Elbe, approximately 130 kilometers

from the North Sea. The location of the Port of Hamburg makes it a major transportation hub, offering connection to the inland Europe via highway, rail or inland waterways (Hafen Hamburg Marketing 2014).

The screening of containers in the Port of Hamburg is conducted at a detached facility designated as Containersprüfunganlage (CPA) (Container Inspection Facility in German) under the jurisdiction of the Customs Office Waltershof. There is only one screening facility (see Figure 3.3) that serves all container terminals in the port. If a container is targeted for inspection, it must be transported from the terminal to the screening site by a truck.

Figure 3.3: Port of Hamburg Screening Site Satellite Image

(Google 2014)

The equipment available for screening is X-ray-based NII system. Its average throughput was quoted to be 6 containers (trucks) per hour. The average delay caused by the screening procedure is reported to be 20 minutes per container or vehicle. The hit rate (ratio of threats detected to containers screened) of the NII inspection is estimated to be approximately 50%. In case of an alarm, the container is inspected physically. Only the containers targeted for inspections are screened, regardless whether they are import or export container The decision to screen a container is done based on available information or upon request of the WCO member state.

3.3 Container Inspections at the Port of Arrival

3.3.1 Inbound Container Inspection Processes

The whole handling process starts with the arrival of the vessel at the container terminal. The placement of screening site may depend on the terminal layout. For example, at the Port of Long Beach, containers that are selected for screening are gathered on the wharf and screened using mobile NII equipment (Pulse of the Port: New Scanning Technology 2012). However, other ports (especially small ports) may place NII screening equipment at a designated site where the containers are brought for screening. After passing the screening process, the container is handled in the port and loaded onto a truck that will provide land transport to its destination. The RPM screening of containers is usually conducted at the terminal exit gate prior to leaving the terminal. According to OIG DHS (2013), if a RPM indicates the presence of radioactive material, the alarm must be confirmed using a different RPM to eliminate unnecessary secondary inspections caused by equipment errors. If the alarm is confirmed, secondary inspection with usage of RIID devices is conducted. This inspection serves to determine the nature of detected

radiation and to distinguish between natural radiation and possible threats. If the latter is detected, further actions such as isolation of container or intervention of special radiological teams are taken.

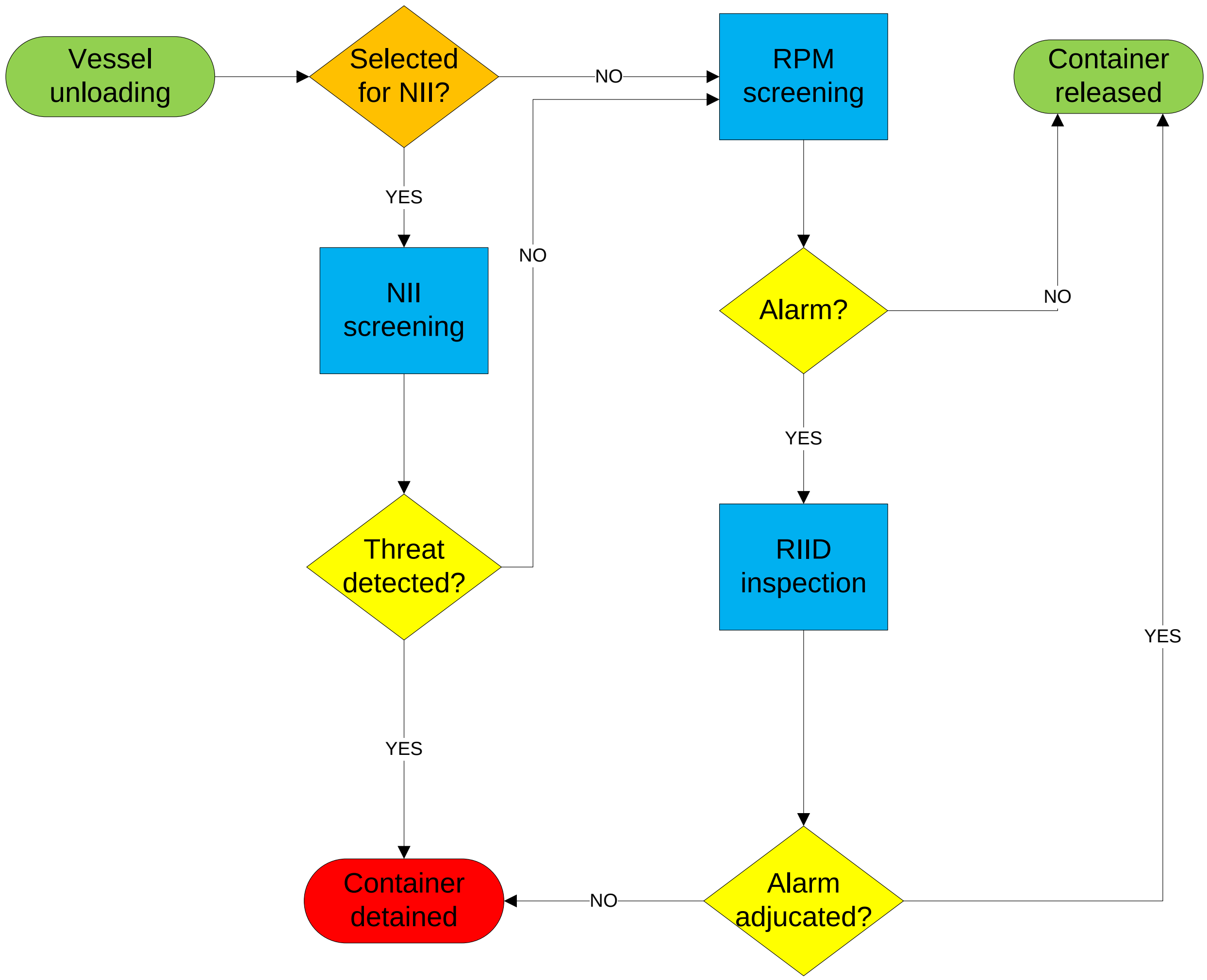

Figure 3.4: Container Inspection Flow Chart at U.S. Port of Arrival

3.3.2 Container Inspection Process at Port of Houston

To gain information for their research, Qi et al. (2011) conducted an interview with Port of Houston CBP Officers in November 2010. Their findings provide an insight on how legislation requirements are implemented and show examples of the best practices in the container screening implementation.

Port of Houston is located Houston, Texas, on the shore of Gulf of Mexico. It is one of the most important U.S. ports, being the busiest port in terms of foreign tonnage and 2nd busiest in the terms of overall tonnage (Collier 2013).

The Port of Houston implements both approaches to screening of imported containers, e.g. risk-based approach for NII inspection and 100% screening for RPM inspection. According to the interview, less than 5% of containers is selected for NII screening. In addition, a few containers are physically inspected either based on screening alarms or CBP officer's discretion. For that purpose, all CBP officers are trained to supervise incoming cargo. The delay time of screening process (including RPM, RIID and NII) per container is estimated to take approximately 30 – 35 minutes (Qi et al. 2013). Figure 3.5 show the satellite image of check-in and check-out gate for the Bayport Container Terminal and a detail of RPM checkpoint.

The targeting of containers for inspection is based on the cargo manifests. The information in the manifest is reviewed for red flags (warning signals) or incomplete items. If any ambiguities are found, further information can be requested from the shippers, thus delaying the shipment. In addition, first time shippers and previous violators are checked more thoroughly. The study of Qi et al. (2013) estimates that 10% of all cargo comes from suspicious importers and 80% of all contraband is carried by suspicious importers. These percentages were based on interviews with CBP officers and their experience.

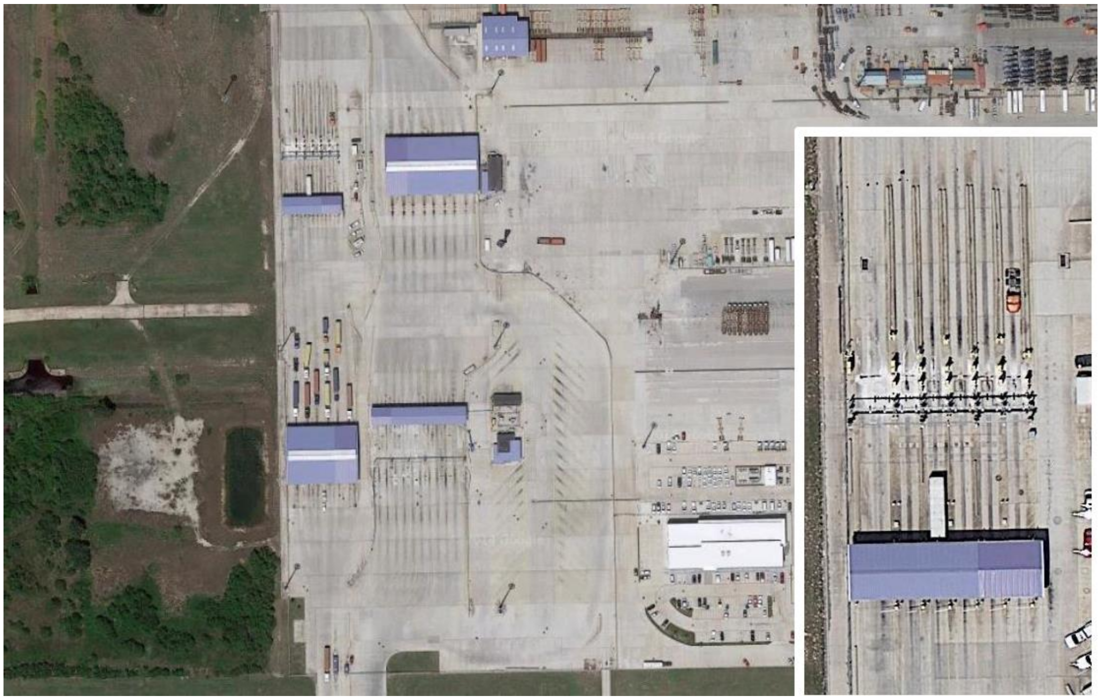

Figure 3.5: Bayport Container Terminal, Port of Houston – Check-in/out Gate For Trucks and

RPM Screening Site Detail

(Google 2014)

Chapter 4: One Hundred Percent Container Screening Concept

As mentioned in the introduction, the Implementing Recommendations of the 9/11 Commission Act of 2007 extends the screening of containers in the U.S., mandating that all U.S. bound containers are screened in the port of origin by RPM and NII equipment. This requirement is highly controversial amongst the industry and its experts. This chapter introduces the concept of 100% screening, with the first part describing the processes involved and the second part being literature review of its possible impact.

4.1 One Hundred Percent Container Screening Processes

The Implementing Recommendations of the 9/11 Commission Act of 2007 (further referred to as the 9/11 Act) does not specify any details about the 100% container inspection except that it must be performed using NII and radiation detection equipment prior to loading onto U.S.-bound vessel (U.S. Government Printing Office 2007). Nevertheless, the inspection flow chart can be created by modifying the inspection flow charts from the previous chapter.

The inspection is performed in the port of departure. Firstly, after checking the documents and container seal integrity, the container undergoes primary radiation detection inspection by a RPM. If there is an alarm, radiation detection inspection is performed using a RIID. If the RIID identifies that the radiation is not NORM, the container is detained and further actions to resolve the situation ensue.

After the radiation detection inspections, all containers that have no alarm proceed to the site of NII inspection. To accommodate for a large volume of containers, high capacity NII systems should be used. If threat objects or contraband is detected in the image provided by the NII equipment, the container is detained and physically inspected. Otherwise, containers that

pass the inspection are cleared and continue to the terminal, where they are eventually loaded onto the vessel.

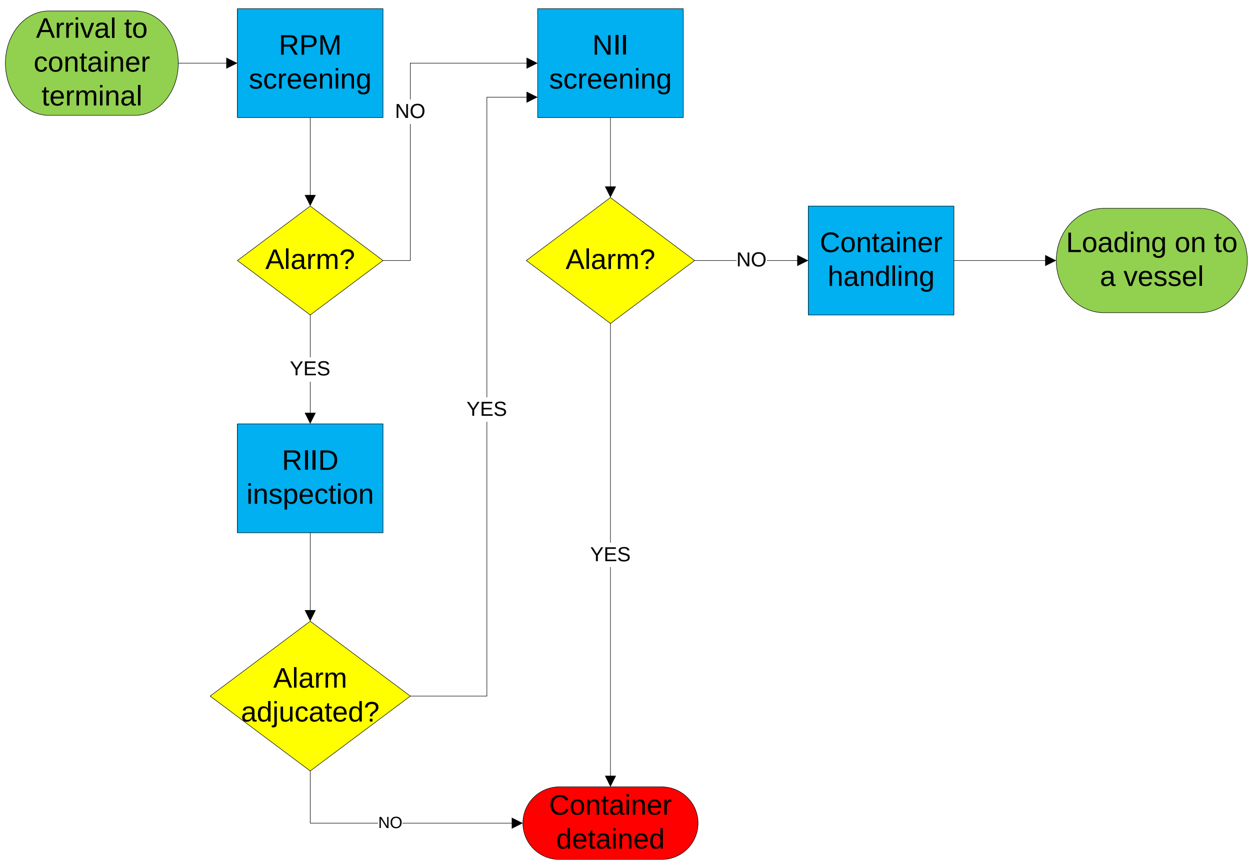

Figure 4.1: 100% Container Screening Inspection Flow Chart

4.2 Issues with One Hundred Percent Container Screening

Unfortunately, the transition to 100% screening of U.S.-bound containers is not without difficulties. Even eight years after enacting the 9/11 Act in 2007, these issues are not fully

resolved, leading to discussions about abandoning the concept completely (Homeland Security News Wire 2014).

The feasibility of full deployment of 100% container screening was tested in a series of pilot projects from 2006 to 2007. The selected ports for full deployment were Southampton in United Kingdom, Port Qasim in Pakistan and Puerto Cortéz in Honduras. Several other ports (e.g. Singapore and Hong Kong) participated only in limited deployment test. In the following sections, observations on these pilot projects shall be used to support and justify concerns of the industry related to 100% screening.

4.2.1 Port Layout Issues

Since substantial area is required for placement of the screening site and truck waiting area, a question arises on how to implement the new screening site to the current port layout. There are several options for locating the 100% container screening site:

- Outside the port area at specifically devoted site;
- At the port gates, in which case the site will serve all container terminals at the port;
- Inside the port area, but outside container terminals;
- At container terminal gates;
- Inside the terminal (Policy Research Corporation 2009).

The main factor for choice of screening site location would be the land availability. Many ports face area constraints. Devoting valuable space inside the terminal as screening site may hinder future terminal expansion. However, acquiring land for screening checkpoint outside the terminal or port may require additional significant cost. This issue cannot be generalized, each port or terminal authority must make a decision based on their situation.

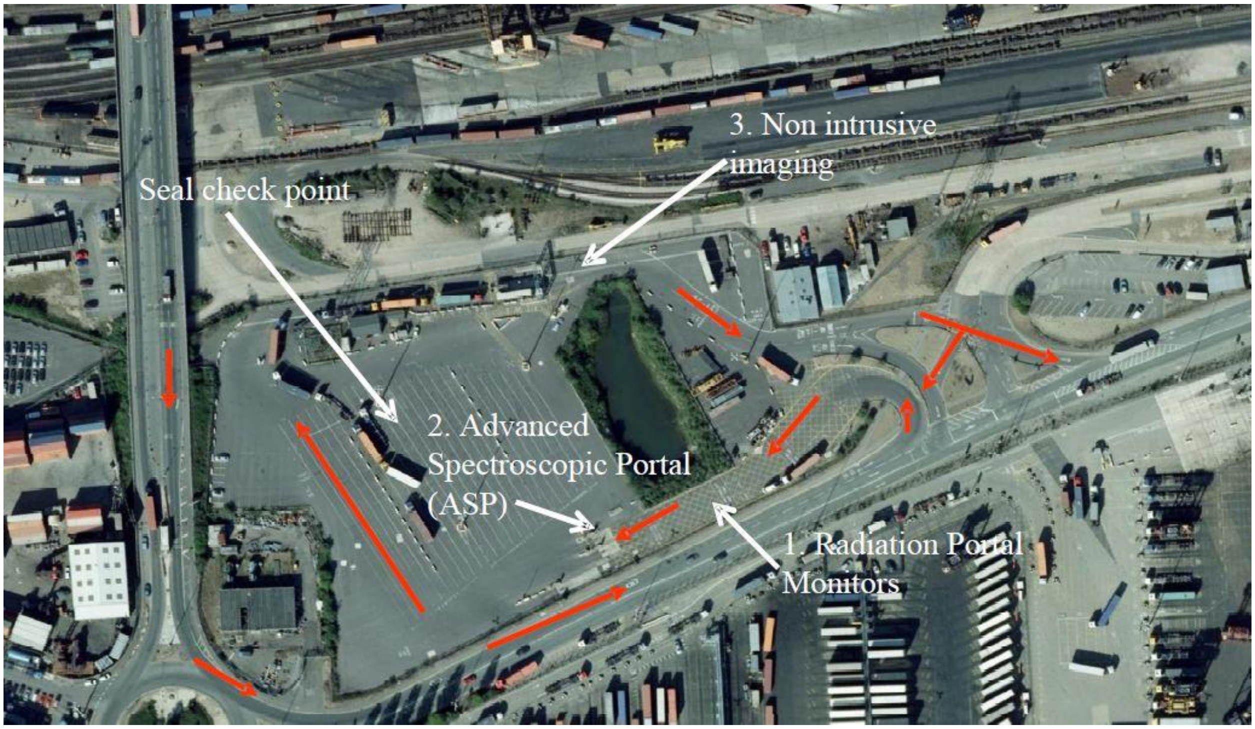

Figure 4.2: Pilot Project Site in Port of Southampton

(Policy Research Corporation 2009)

The placement of the site also influences operation procedures in the port. For example, during the pilot project in the Port of Southampton, the screening site was placed outside the terminal (Figure 4.2). Being equipped with three RPMs, one Advanced Spectroscopic Portal (ASP) and one NII machine, it covered area of 30 000 m^2. An issue arose when handling containers delivered to the terminal by rail, which form 27% of the container traffic (compared to truck accounting for 70% and feeder ships for 3%). Those containers had to be brought to the inspection area, creating extra 1124 container moves during the 10-week test period. According to the Policy Research Corporation (2009), this extra drayage would cost approximately €159.374 per year (€54.5 per container), effectively increasing price of handling of rail

transported containers by 20%. In addition, it created extra workload for the rail terminal personnel. If this is implemented permanently, additional workforce would be needed. The extra costs lead to the concern that 100% screening may divert cargo from rail to road, thus contributing to road congestion.

4.2.2 Truck Congestion

One of the major concerns of 100% container screening is that the new checkpoint will generate truck congestion, further worsening the situation in some container terminals, gates or port entrances.

The truck operators would be directly affected by increased congestion. Their trucks would have to spend more time queueing for container inspection, which would increase their turnaround time. This would lead to increased prices of land transport (Bennett and Chin 2008). Furthermore, due to increased waiting time of trucks, unless consignors dispatch the containers earlier, the shipment may miss its vessel. The whole land transport of the supply chain may need to be adjusted to new conditions introduced by 100% screening.

In addition, there other indirect impacts of new checkpoint implementation. Firstly, increased truck congestion brings environmental issues such as increased emissions due to increased truck idling time. Secondly, the truck waiting areas at the container terminals, gates and port entrances may not be able to sustain increased number of trucks in queues. Some ports may have an issue with expanding the truck areas due to the terminal layout, which may move the congestion to public roads, influencing passenger traffic.

4.2.3 Relocation of Container Traffic

Implementation of 100% screening concept may bring significant changes on the current shipping market, changing the current container shipping routes. The concern is that small ports could become less competitive in handling U.S.-bound container traffic. Although ports with small volume of U.S.-bound cargo should generally expect lower investment costs and operational issues, the costs related to 100% container screening would be divided among smaller volume of containers. This may lead to higher increase in handling fees such that the small port would no longer be competitive and could lose their U.S.-bound container traffic to larger ports in the area. For example, this scenario may happen in Netherlands, where ports of Amsterdam and Vlissingen could be threatened by Port of Rotterdam (Policy Research Corporation 2009).

On the other hand, this trend may be beneficial for some ports. As the report on EU perspective of 100% container screening by Policy Research Corporation (2009) illustrates, implementing new screening system may bring the port a competitive advantage and new customers. This happened during the pilot project in Port of Qasim, Pakistan, when the container traffic of the port increased by 3% (Policy Research Corporation 2009). According to the report, the traffic increase occurred because the implementation of pilot project theoretically reduced the time to get through all the formalities at U.S. ports, which the local exporters welcomed.

4.2.4 Checkpoint Performance and Reduction of Container Output

As has been previously mentioned, several major container ports, such as Singapore, participated in the partial deployment pilot project of the 100% container screening system. Their experiences revealed significant issues related to the 100% screening checkpoint performance.

For instance, Port of Singapore agreed to participate in the trial, allowing screening of containers shipped by American President Lines (APL) in the Pulau Brani container terminal. The implementation of the project was scheduled for second half of 2008. However, Port of Singapore withdrew from the trial in August 2008. The Ministry of Transport of Singapore provided several reasons for abandoning the project, among which is the concern of checkpoint congestion (Policy Research Corporation 2009).

The Port of Singapore is heavily focused towards transshipment containers (which makes up 85–90% of all its traffic), that are brought to the port by feeder vessels. These containers would have to be brought to the screening site (at the terminal gates), prolonging the trips of the prime movers (terminal tractors). It was estimated that without the screening, if one feeder vessel carrying 300 containers is served by 3 quay gantry cranes and 5 prime movers are assigned for each quay gantry crane, it is possible to handle 31 containers per quay gantry crane per hour. However, if screening of all containers is implemented, the handling rate is reduced to 18.35-20.8 containers per quay gantry crane per hour due to longer trips of the prime movers. Unloading a single feeder vessel with 300 containers would be prolonged from 3.2 hours to 4.8 hours. The terminal would thus experience significant drop in container handling output and would not be able to sustain the previous level of service. Furthermore, the financial loss created by the output drop in the port of Singapore would be as high as $575,800 per annum (Policy Research Corporation 2009).

4.2.5 Cost Concerns

As already illustrated by several examples in this chapter, the concept of 100% container screening can potentially have very high implementation and operation costs. Bennett and Chin

(2008) attempted to estimate these cost for a generic small container port and for a generic large container port.

The small port estimate was based on Puerto Cortes in Honduras, which in 2006 had total throughput of 507,946 TEUs, of which 162,741 TEUs were shipped directly to U.S. Similarly, the large port estimate was based on the Port of Antwerp, Belgium. Its total throughput in 2006 reached 7 million TEUs, whereas 347,848 TEUs were shipped directly to U.S. Costs for terminal level installation (each terminal has its own screening checkpoint) and port authority level installation (screening checkpoints are shared by multiple terminals) were determined. The following types of costs were calculated: initialization costs, annual operation costs and annual operation costs, including the annualized life cycle cost of the equipment. In addition, screening fees per container were determined, the first one showing the fee if only U.S. bound containers are screened, whereas the second one is related to screening of all export containers regardless of their destinations. The estimates are shown in Table 4.1.

As can be observed, the cost are quite substantial, especially for the terminal level deployment. On the other hand, it should provide much larger screening capacity and dissipate queue. The screening cost per container depends largely on the amount of container traffic in the port. If screening is applied to all exports, the unit cost drops significantly. Unfortunately, the estimates do not contain indirect costs of screening, such as the cost of extra drayage within the terminal. Therefore, it can be expected that the overall cost would be higher than the estimates provided.

Table 4.1: One Hundred Container Screening Cost Estimates

(Bennett and Chin 2008)

	Small port		Large port	
Installation level	Port authority	Terminal	Port authority	Terminal
Initialization costs	$7,432,734	$14,865,468	$14,865,468	$74,447,340
Annual operational cost	$4,689,730	$8,979,460	$8,979,460	$43,338,099
Annual operational cost (10 year life cycle)	$5,433,003	$10,466,007	$10,466,007	$50,782,833
Screening fee (U.S.-bound export only)	$63	$122	$45	$219
Screening fee (all export)	$39	$74	$4	$21

The EU quite strongly opposes the concept of 100% container screening because of several reasons, one of which is the high implementation cost. Currently, majority of European ports have screening systems at their disposal. The European Commission (2010) estimates that the share of containers screened at EU ranges from 0.1% in larger ports to 3% in smaller ports. The transition to 100% container screening would therefore be a significant step with major consequences, for example re-designing of current ports. Such adjustments would have very high economical costs. European Commission (2010) assumes that the total cost of transition to 100% screening would be between €280 million as of 2012. Taking into account investment for additional terminal operation, the number would increase to €430 million by 2020. In addition, the operational cost would be affected, requiring additional staff (1750 new staff in 2012 and 2220 persons by 2020) to perform the screening and related port operations. Besides, other expenses, such as depreciation, maintenance or energy consumption, would further increase the

operation cost, that were estimated at €180 million annually in 2012 and €225 million annually in 2020. Needless to say, such amounts would present a significant burden for EU ports, and the cost will eventually be passed down to shippers and then consumers.

4.2.6 Operational and Technical Issues

During the pilot projects, several operational and technical issues appeared. For instance, during the pilot project in Port Qasim in Pakistan, the Integrated Cargo Container Control (IC3) system, that performed screening through a live video link inspected by CBP and Pakistani customs officers, was tested. However, the system experienced problems with data connection to CBP National Targeting Centre that resulted in system outage. The issue led to delays in clearing of containers through the inspection and subsequently through the terminal (Policy Research Corporation 2009).

Other technical issues arose during the partial deployment pilot project in the Port of Hong Kong in 2007. The participating terminal operator Modern Terminals Ltd. experienced multiple equipment malfunctions. Between November 19th 2007 and January 10th 2008 the checkpoint equipment was out of order for 450 hours over 29 days in a 52-day trial period, reaching a breakdown rate of 35.6% (Policy Research Corporation). The issues were mitigated by strengthening the technical support of the equipment manufacturer.

One of the most prominent operational issues was related to availability of container data that are collected under the 10+2 rule 24 hours before loading of the container onto the vessel. For instance, in the Port of Southampton, a large number of containers arrives at the port more than 24 hours prior to vessel departure. Therefore, the CBP did not have the electronic manifest information at the time of screening, which brought several complications, for example for resolving radiation alarms on shipments that contained NORM. A similar issue was observed

during the pilot project in Puerto Cortes, Honduras. Virtually all containers arrived to the screening site before the electronic manifest data was submitted to CBP. Therefore, all the arriving containers were screened regardless of their destinations. Later into the pilot project, the Honduran customs officers divided the containers into U.S.-bound and non-U.S.-bound on the basis of documentation review, which was later validated by CBP once it received the electronic manifest (Policy Research Corporation 2009). However, this method would not be applicable in busier ports, as screening at such scale may not be feasible.

4.3 SUMMARY

The implementation of 100% screening is by no means a trivial tasks. There is a large variety of factors that have to be considered for every port. Otherwise, issues may arise, whether they may be related to terminal operation, its layout or checkpoint performance. All of the issues mentioned in this chapter eventually lead to unnecessary financial losses and extra expenses that can be utilized in a more efficient manner. In the highly competitive global trade market this could bring undesirable consequences for ports, shippers, truck operators and even indirectly end customers.

Experts argue that risk based screening is sufficient for providing port security. Since it is mandatory to provide advanced information about the cargo electronically, targeting of containers for inspection has become quite efficient. However, Elsayed et al. (2009) provided some interesting notions on container inspection. They assumed that the number of container inspections is dependent on the budget. When they increased the hypothetical budget for screening by 11%, the probability of missing suspicious cargo decreased from 0.03 to 0.0002. Therefore, it can be argued that screening of all containers may bring very high level of security, but also at a very high cost.

Nevertheless, the goal of this thesis is not to justify the policy, but to provide new insight into its impact and introduce recommendations for its implementation. Thus the issues mentioned in this chapter may be mitigated or approached in a proper way, based on the findings in Chapters 6 and 7 of this thesis.

Chapter 5: Screening Checkpoint Simulation

This chapter is devoted to the description of simulations that were conducted in order to assess the operational impact of 100% screening legislation.

From the wide range of simulation tools, Arena Simulation Software, or Arena in short, was selected to be used in this research. It is a discrete event simulation software developed by Rockwell Automation that is widely used in various engineering and business applications (Rockwell Automation 2005). The version that was used in the thesis was 14.70.03, run in Training/Evaluation Mode (Student version).

5.1. Review of Arena

Rountree and Demetsky (2004) were among the first to make experiments related to transportation security in Arena. Their research focused on screening of cargo at airports. They compared several different approaches to screening air cargo, each of which utilized a different combination of screening equipment. Their research proved that Arena is suitable for modelling of transportation security processes, whether they take place at an airport or seaport.

Qi et al. (2013) used Arena to compare different screening equipment used for container inspections. Using the Arena model, the usage and operation of new screening technologies were explored.

Jenkins et al. (2014) used Arena to assess procedures at a U.S. land port of entry. They modelled various security processes at a border checkpoint, such as queuing at lanes before the border check, checking of documents by an officer or backscatter screening. Their research provided insight into possible outputs of the simulation, which included waiting times per each vehicle, queue properties, number of vehicles processed etc.

5.2 SIMULATION IN ARENA

As mentioned in the above review, Arena is well suited for modelling the flows of entities such as containers. A container inspection simulation model was constructed with flow-chart logic using various Arena modules that perform specific functions in the model. The following paragraphs introduce the modules that were used to model the processes in the container screening checkpoint, their properties and parameters used in the simulation. In addition, simulation settings under the Run Setup menu is explained.

Since available information about certain container screening parameters and their distributions are unfortunately limited, assumptions were made in the model. The assumptions were based on the available information, recommendations from Arena User's Guide (Rockwell Automation 2005) and by Kelton et al. (2007) or previous research.

5.2.1 Create Module – Time between Container Arrivals

The Create module is used to generate containers and enter them into the screening system. For representing the system input of container arrival rate, exponential distribution was used. The Arena User's Guide (Rockwell Automation 2005) recommends this distribution to be used to model inter-event times in random arrivals of entities. In this case, it generates time between arrivals of containers, i.e., their time headways, into the screening system. The exponential distribution has only one parameter - its mean that corresponds to the average time between container arrivals. During the simulation, the value of this parameter was changed multiple times in order to examine the behavior of the checkpoint under different arrival rates in order to determine the system' screening capacity.

5.2.2 Decide Module – Selection for Screening, Screening Alarms

The Decide module is used for modeling decision-making processes in the simulated system. It separates the flow of entities based on various conditions, such as probability, attribute values, variable values, entity type or defined expression (Rockwell Automation 2005).

In the case of simulating container screening checkpoint, the Decide module was used for modeling the selection of containers for screening and setting screening alarms. The decision was based on probabilities of the different outcomes that are estimated from the available information. During the different simulation runs, the values of those probabilities were changed to determine the behavior of the checkpoint under different operational conditions.

5.2.3 Process Module – NII Screening, RPM Screening and RIID Inspection

The Process module serves as the main processing method in the simulation. It simulates resources (such as screening equipment) that are occupied to perform certain process or tasks. The arriving entity "seizes" the available resource for a user defined process time, during which simulated process or task takes place. This time can be specified using a suitable distribution. After the process time has elapsed, the entity releases the resource and let it continue to the next module. The resource is than seized by another arriving entity and the whole process is repeated.

As mentioned, the process time can be defined using various distributions. In this case, different distributions were selected for each method of screening, i.e. RPM, RIID and NII.

The RPM screening time was modelled using a uniform distribution. As mentioned in Chapter 2, the optimal operating speed of trucks going through the RPM system is quoted to be 5 – 8 mph (Bennett and Chin 2008). Assuming that the length of the truck carrying one 40-foot container to be 65 feet, the time of screening will be 5.54 – 8.86 seconds. However, if the time

reserve for entering and clearing the inspection site is added, the screening time may be extended to an interval from 15 to 30 seconds.

For RIID, a uniform distribution was used to represent the duration of the inspection as well. The available sources (Qi et al. 2013) provide the duration of the inspection to be between 5 and 15 minutes. These values will be used as parameters for the uniform distribution in the simulation.

The NII screening time was modelled using a triangular distribution with minimum value of 1 minute, mode of 1.5 minutes and maximum of 5 minutes. As mentioned in Chapter 2, the NII screening times was quoted to have a range from 2 to 5 minutes (Bennett and Chin 2008), depending on the image review time. However, as Bennett and Chin (2008) observed, the average inspection time per container is approximately 1 minute, since majority of the images are not expected to contain any strikingly suspicious anomalies and there is no need for thorough and time-consuming image analysis. Therefore, the triangular distribution was selected to reflect this fact. In addition, the specified values of the distribution parameters have already accounted for possible delays caused by preparing the inspection (driver leaving the truck) or moving of the truck into position.

5.2.4 Record Module – Recording Various Statistics of the Container Flow

The Record module serves to collect statistics in the simulation model. In our case, statistics were collected on the number of containers that will be subjected to inspections and number of containers that are detained or cleared through the inspection. Other statistics, such as queue length, delay, and etc., are provided through the automatically generated report at the end of the simulation.

5.2.5 Dispose Module – Clearance and Detention of Containers

The Dispose module is used as an ending point for entities in the simulation model. In the model of screening checkpoint, there are two Disposed modules, one for containers that are detained (did not pass the inspection) and the other for containers that are cleared through the inspection.

5.2.6 Simulation Inputs and Outputs

The objective of the simulations is to determine the capacities and performances of different screening checkpoint designs under various operational conditions. These conditions will be created using the different values of input parameters, such as:

- Arrival rates of containers (headways between container arrivals);
- Percentage of containers targeted for screening;
- Number of inspection lanes for trucks carrying containers.

The Arena model provides a number of simulation outputs that were used for the evaluation and comparison of the screening systems. In the analysis, the dependency between the inputs and outputs will be analyzed for better understanding of the checkpoint behavior. In addition, several parameters that are critical for security checkpoint performance will be determined. The main outputs provided by simulation are:

- Delays per container (include total time spent in the system, waiting time, screening time);
- Queue length (at each screening station or equipment);
- Screening stations utilization (necessary to determine the checkpoint capacity).

5.2.7 Simulation Settings

In order for the model to function properly and provide useful data, the simulation procedure must be properly set up. This section therefore goes through the simulation settings under the Arena menu Run Setup.

Table 5.1: Simulation Modules Parameters

Module	Distribution
Create module – container arrival headway	Exponential (avg. varies)
Process module - RPM screening	Uniform (minimum 15 sec, maximum 30 sec)
Process module - RIID screening	Uniform (minimum 5 min, maximum 15 min)
Process module – NII screening	Triangular (minimum 1 minute, most probable value 1.5 minutes, maximum 5 minutes)
Decide module – Containers screening selection (NII Case 1 and 3)	5 %
Decide module – RPM alarms	5 %
Decide module – RIID alarms	10 %
Decide module – NII alarms	5 %

To gain more variability that reflect the randomness of the container arrivals, screening times etc., 100 replications were performed for each run. The lengths of simulation run for 100 replications vary according to the simulated experiment (4 or 12 hours), depending on the number of containers in the system. In addition, one hour of warm-up period was added at the beginning to the simulation length to avoid potential inaccuracy of the results caused by initial conditions of the model. The base time unit of the model is minutes (hence the results provided

in the software are in minutes). Statistics were collected on entities (e.g. total delay per container), resources (e.g. utilization of screening checkpoint), queues (e.g. average number of trucks) and processes (e.g. waiting times at individual screening stations). Table 5.1 sums up all the input parameters of individual modules in the models.

5.3 Simulation Limitations

Several test runs were performed to verify the behavior of the model and gain feedback about the model parameters. They were run with different values of container headway (from one to 10 minutes between container arrivals). In each run 100 replications were performed. The test run revealed one limitation of Arena Training & Evaluation Mode (student version).

When experimenting with low headways between containers (three minutes and less), the simulations was unexpectedly terminated by an error. This happened because the academic version of Arena is limited to 150 entities in the system at any time. In case of low container headways, the model was not able to service all generated entities and queue grows until it reached its maximum entity limit and the simulation was terminated. This can be bypassed by lowering the simulation length to 5 hours or less, which does not allow the queue to grow to the 150 entity limit before the end of the simulation. Therefore, when conducting experiments where the checkpoint runs at its capacity, the simulation length will be shortened.

Another limitation of the model is that its parameters were not based on real-life operation and measurements. Unfortunately, such data are very hard to obtain due to their sensitive nature. Nevertheless, even with the parameters estimated on available sources, general conclusions regarding 100% screening can be drawn. If in the future the methodology introduced in this thesis should be used, the use of parameters based on real-life measurements is recommended.

5.4 SIMULATED CASES

This section describes the cases of screening checkpoints that will be simulated. The case studies were selected to reflect the changes introduced by the new legislation. The modeled cases correspond to three approaches to screening:

- **Risk-based approach** – only containers that are targeted for inspection based on their risk are screened. This method is currently used in majority of the ports around the world, including EU ports (detailed description has been provided in section 3.2).
- **100% screening approach** – all containers arriving to the terminal are screened using both NII and RPM. This approach is required to be implemented in terminals handling U.S.-bound cargo by the 9/11 Act (for detailed information see section 4.1).
- **Hybrid approach** – all arriving containers are screened using RPM, whereas only targeted containers are screened using NII. This type of screening is currently implemented in the 22 busiest ports in U.S. according to the SAFE Port Act (description appears in section 3.3).

5.4.1 Case 1: Risk-Based Approach

Case 1 corresponds to the current method of screening in EU ports. The inspection is based on risk-based screening principle, where only the selected containers undergo NII inspection. Based on the interview with representative of Main Customs Office Port of Hamburg (2014), radiation detection equipment is available as well; however it is used only when necessary. Therefore it is not included in the model. This type of screening procedure is fully compliant with EU and international legislation. This case served as the benchmark for comparison with 100% screening checkpoint. The screenshot of the Arena model for Case 1 is shown in the Figure 5.1. The inspection process is the same as in Figure 3.2.

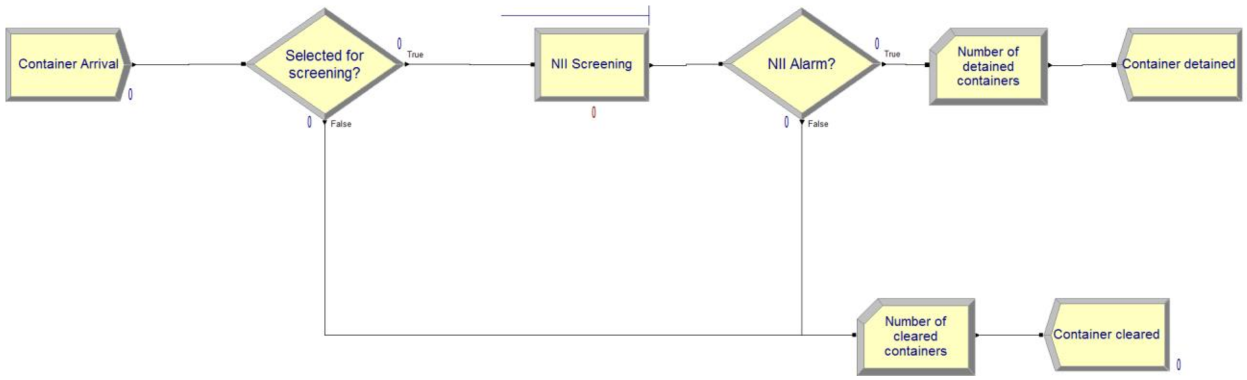

Figure 5.1: Case 1 Arena Model Screenshot

5.4.2. Case 2: 100% Screening

Case 2 corresponds to the method of screening that will be in the near future mandatory for container terminals handling U.S.-bound cargo as required by the 9/11 Act. All containers without exception go through both methods of screening, i.e. RPM and NII. The Arena model for this case is depicted in Figure 5.2. The inspection process is the same as in Figure 4.1.

This model provides the main focus of this thesis and majority of conclusions drawn depend on the results of this particular model. This model can be used to test the design of a screening system compliant with the latest U.S. legislation.

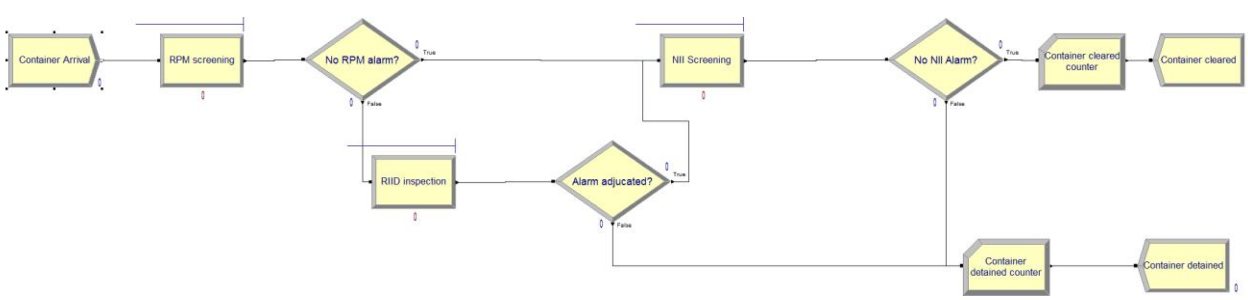

Figure 5.2: Case 2 Arena Model Screenshot

5.4.3 Case 3: Hybrid Approach

Case 3 is an interpretation of currently used checkpoint in the U.S. In this case, hybrid inspection is implemented, i.e., all containers are screened using RPM and those selected for more thorough inspection undergo NII screening. This method is required in U.S. according to the SAFE Port Act of 2006. The Arena model for this case can be found in Figure 5.3. The inspection process corresponds to flow chart in Figure 3.4.

The idea behind this model is to compare the hybrid screening operation (Case 3) with 100% screening operation (Case 2). Since NII screening is the most problematic part from the capacity point of view (NII has a longer screening time than RPM), the overall checkpoint performance of Case 3 should be much better than Case 2.

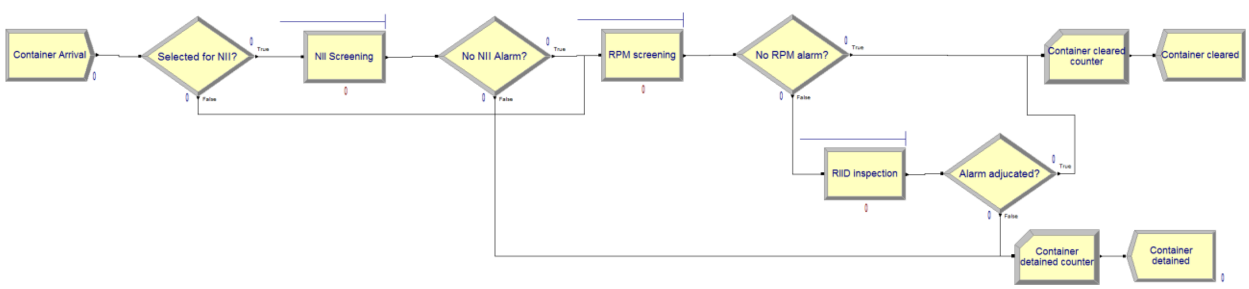

Figure 5.3: Case 3 Arena Model Screenshot

5.5 Simulated Experiments

The following paragraphs describe the experiments that were conducted to evaluate the three cases of checkpoint operations. The experiments have been divided into 2 groups based on the simulated container arrival rates.

Firstly, to evaluate the system performance under low traffic operations, simulations were run for container headway ranging from three minutes to 10 minutes (which corresponds to six – 20 containers per hour) with a step size of 0.5 minute (total of 15 simulation runs per each case). This experiment used only one lane per each screening station. For each value of container headway, there were 100 replications, each of which will be 13 hours long including the warm-up period. Simulations shall be conducted for Cases 1, 2 and 3 under the same settings to have comparable results.

Secondly, high container arrival rate operations were simulated in a similar fashion. Container headway input ranged from one minute to 5 minutes (corresponding to 12-60 containers per hour) with a step size of 0.25 minute (total of 17 simulation runs for each case). In this experiment one lane will be used for RPM and RIID stations, but there will be 2 lanes for NII screening. In addition, to avoid the limitation of academic version of Arena, the replication length was reduced to 5 hours including the warm-up period. The number of replications for each run remained at 100. Simulations shall be conducted for each case under the same settings to have comparable results. The summary of simulation settings can be seen in the table below.

The results were evaluated for various indicators of the checkpoint performance, such as the total delay created by the inspection, waiting time in the queue, number of containers waiting in the queue, station utilization, and etc.

Table 5.2: Simulation Settings

	Low container traffic	**High container traffic**
Container headway input	3 – 10 min (0.5 min step)	1 – 5 min (0.25 min step)
Container arrival rates	6-20 containers per hour	12-60 containers per hour
Replication length (including warm-up period)	13 hours	5 hours
Warm-up period	1 hour	
Number of replications	100	
Number of inspection lanes	1 for RPM 1 for RIID 1 for NII	1 for RPM 1 for RIID 2 for NII

Chapter 6: Results with Low Container Traffic

Chapter 6 presents and analyzes the first half of the results obtained from Arena simulation software in order to gain insight into various aspects of checkpoint operation. Firstly, the performance indicators of the screening checkpoint are explained for better understanding of the text. Next, the results for low container arrival rates are evaluated.

6.1 Checkpoint Performance Indicators

Since the screening checkpoint can be described as a queuing system, several terms used in queuing theory can be applied in the analysis. Firstly, the majority of plots uses the quantity **average arrival rate** as an X-axis. Based on the queueing theory, the arrival rate describes the rate at which containers arrive at the checkpoint. Since the model in Arena uses the **average headway** (time between container arrival) as an input parameter, the average arrival rate has be calculated using the following equation (Taha 1997):

$$\lambda = \frac{1}{h}$$

where the average arrival rate is denoted as λ and the headway as h. The unit of measurement used in this thesis is minutes for the headway and containers per hour (or minute) for the arrival rate. It should be noted that if the arrival rate is mentioned in the text or the plots, it is exclusively the arrival rate for the whole checkpoint, not the individual stations.

As mentioned in Chapter 4, one of the major screening related concerns of terminal operators is the possible reduction of handling capacity. This is closely linked to the output of the screening system – if the new system interferes with the feeding of containers to the terminals, the handling equipment (such as cranes) may become underutilized. Therefore, the **checkpoint**

output will be analyzed, showing the total number of containers that were processed during the simulations.

The output of Arena contains data on the duration of the inspection, such as screening time, waiting time and total delay. The screening time is the duration of the screening process itself. It is denoted as **service time** (μ) in the terminology of queuing theory. The waiting time is the time period a container (a truck) spends waiting in a queue, i.e. **waiting time in the queue** (W_Q). Finally, the total delay in Arena denotes the total time a container spends at the inspection checkpoint. This simulation output corresponds to the **time spent in the system** (W_S). Since we assume the transfer time between individual stations to be zero (the truck does not need to move long distances between stations), the time spent in the system is the sum of the 2 previous quantities (service time and waiting time). All the previously mentioned terms can either have a global value for the whole checkpoint or values for individual stations.

If both average arrival rate λ and average service rate μ are known, the **utilization factor** (ρ) can be calculated using the equation

$$\rho = \frac{\lambda}{\mu}.$$

If the utilization factor is greater than 1, the queue length will grow to infinity, meaning that the checkpoint does not manage to screen all incoming containers (Taha 1997). Otherwise, if the utilization factor is less than 1, the system is in a recurrent state, meaning the queue will grow and dissipate alternately. The utilization factor is useful for illustration the screening capacity of the checkpoint.

The number of trucks in a queue (queue length) is a crucial indicator for design of screening station, namely the waiting area for trucks. The maximal value of the queue length is especially important, since the waiting area has to sustain the maximal expected queue. In the

terminology of queuing theory, the queue length is denoted as **number of items (containers) in the queue** (L_Q).

Finally, the Arena output called utilization shows the usage of the screening equipment. It can be calculated as a percentage of time the screening equipment is in use. The utilization corresponds to detector occupancy in traffic engineering. Therefore, a term **occupancy of a screening station** will be used to avoid confusion with the utilization factor ρ.

6.2 Checkpoint Output

The Table 6.1 compares the checkpoint output in all simulated cases. It is quite surprising that there is little difference between the three simulated cases. This can be explained by the fact that the during low container traffic the checkpoint does not operate at its capacity.

Table 6.1: Checkpoint Output

Input Headway [min]	Arrival rate [cont./h]	Case 1 [cont./h]	Case 2 [cont./h]	Case 3 [cont./h]
3.00	20.0	20.2	20.1	20.0
3.50	17.1	17.3	17.0	17.1
4.00	15.0	15.1	15.2	15.0
4.50	13.3	13.4	13.4	13.3
5.00	12.0	12.0	12.0	12.1
5.50	10.9	10.9	10.8	10.9
6.00	10.0	10.0	10.0	10.1
6.50	9.2	9.3	9.3	9.3
7.00	8.6	8.5	8.6	8.7
7.50	8.0	7.9	8.1	8.1
8.00	7.5	7.4	7.5	7.7
8.50	7.1	7.0	7.1	7.2
9.00	6.7	6.6	6.6	6.8
9.50	6.3	6.3	6.3	6.4
10.00	6.0	5.9	5.9	6.1

However, there are bigger differences between the three cases if we focus on the number of containers that were detained during the screening operations. The average detention rates and their standard deviations are listed in the Table 6.2. It can be observed that the Case 2 has the highest detention rate, while Case 1 and Case 3 are roughly equal. If we assume that the detention rate corresponds to the level of security, it can be concluded that screening of all containers would improve security at container terminals. However, in our simulation, targeting of the containers for inspection in Cases 1 and 3 was random. In reality, sophisticated algorithms are used, so the level of security should be much higher.

Table 6.2: Average Checkpoint Detention Rates

	Case 1	Case 2	Case 3
Average Detention Rate [containers]	0.24%	5.40%	0.27%
Standard Deviation [containers]	0.02%	0.25%	0.03%

6.3 Service Time

6.3.1 Average Station Service Times

Since the model uses the same distributions for duration of the screening in all simulated cases, the average service time for individual screening stations is roughly constant all the time. The Table 6.2 contains the average values for individual stations across all simulations, as well as averages calculated using the assumed distribution. Although the RIID inspection has the highest service time, it should be noted that only a small volume of containers undergo this type of inspection.

Table 6.3: Screening Stations Service Times

Screening Station	Distribution Average [min]	Average Service Time [min]	Standard Deviation [min]
Radiation Portal Monitor (RPM)	0.3750	0.3748	0.0005
Radiation Isotope Identification Devices (RIID)	10.0000	9.9803	0.1269
Non-Intrusive Equipment (NII)	2.5000	2.5235	0.0318

6.3.2 Average Checkpoint Service Time

Similarly, the values of average service time for the whole checkpoint have been calculated. Once again, the distributions of service time remain the same, as well as approximate number of containers that undergo screening. The Table 6.3 contains the summary of the results. It should be noted, that the values in the table are averaged across all incoming containers, even the ones that are not selected for screening (Case 1 and 3), which leads to a significant decrease in the service time per container. As expected, the 100% screening (Case 2) has the largest average service time, reaching the value of 3.3609 minutes with a standard deviation of 0.0114 minutes. The service time between simulations did not fluctuate significantly, as its standard deviations are low.

Table 6.4: Checkpoint Service Times

Simulated Case	Average Service Time [min]	Standard Deviation [min]
Case 1	0.1299	0.0016
Case 2	3.3609	0.0114
Case 3	1.0012	0.0074

6.4 Waiting Time

The waiting time in the queue is an important indicator for truck operators. While the truck with a container waits in a queue, it is usually idling. That leads to wasting of fuel and economic loss for the operators, not to mention unnecessary engine emissions.

6.4.1 Average Checkpoint Waiting Time

Let us consider the total waiting time in the queues for the whole checkpoint. According to the simulation output, there is typically negligible waiting time for Case 1 (not even reaching 1 second) and Case 3 (range 1.76 – 5.08 seconds). However, for the case of 100% container screening (Case 2), the average waiting time increases rapidly with increasing arrival rate, ranging from 0.5 minute to 6.76 minutes (Figure 6.1).

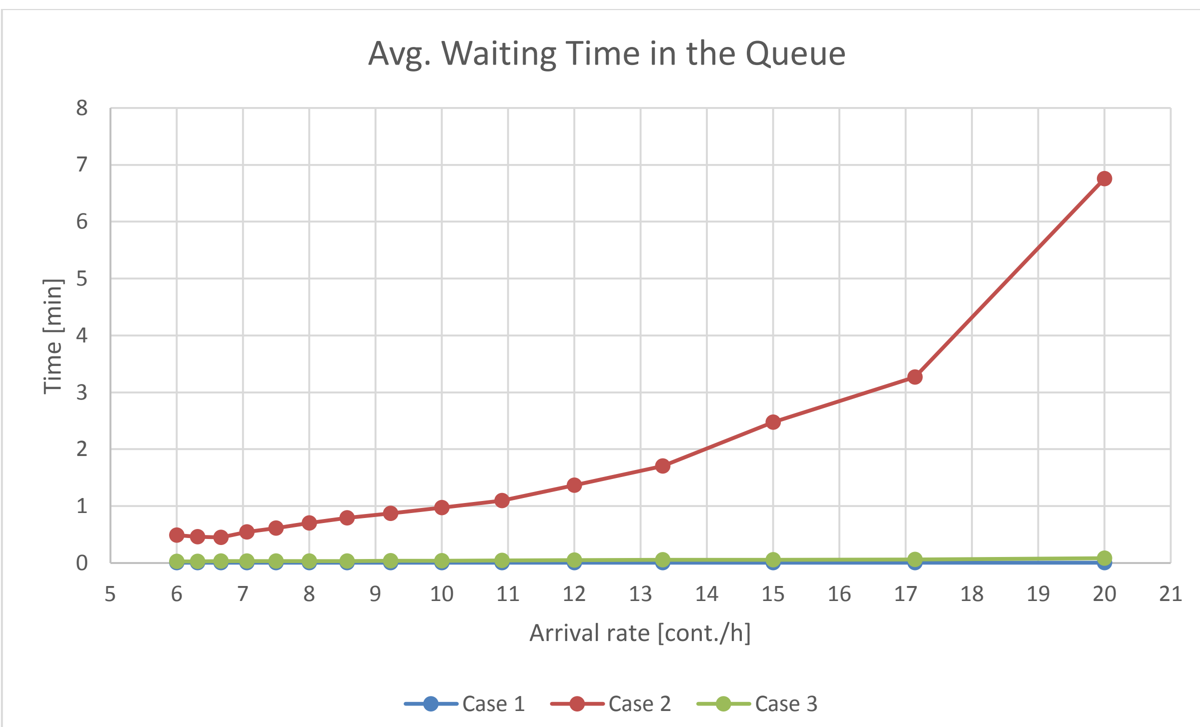

Figure 6.1: Average Waiting Time in the Queue

The biggest share of average waiting time in Case 2 can be accounted to NII screening station (on average 96.62%, compared to 1.29% for RPM and 2.09% for RIID). This leads to a conclusion that the NII station is the biggest bottleneck in the case of 100% container screening. Nevertheless, if the container terminal's traffic corresponds to the simulated range, on a typical day of operation there should be no congestion severe enough to disrupt the operation of the truck operators.

6.4.2 Maximum Average Checkpoint Waiting Time

However, we should also focus on the values of maximal average waiting time in the queue. In Arena, this was the highest average waiting time among the 100 replications in a simulation run, for a certain container arrival rate. As can be seen from the plot at Figure 6.2, the maximum average waiting time in Case 2 starts increasing rapidly at the arrival rate of 12 containers per hour (2.4 minutes), eventually reaching 25.28 minutes. This is already quite significant. Should such case apply, the container terminal operators ought to analyze their traffic statistics to determine whether such arrival rate is occurring frequently or not. If the answer is yes, adding a checkpoint lane for NII station should be considered. For comparison, a simulation with the same setting for 20 containers per hour but with 2 NII lanes was conducted, which led to decrease of maximum waiting time to 0.7061 seconds, effectively eliminating the queue (reduction by 97.21%). Other measured parameters showed a similar trend.

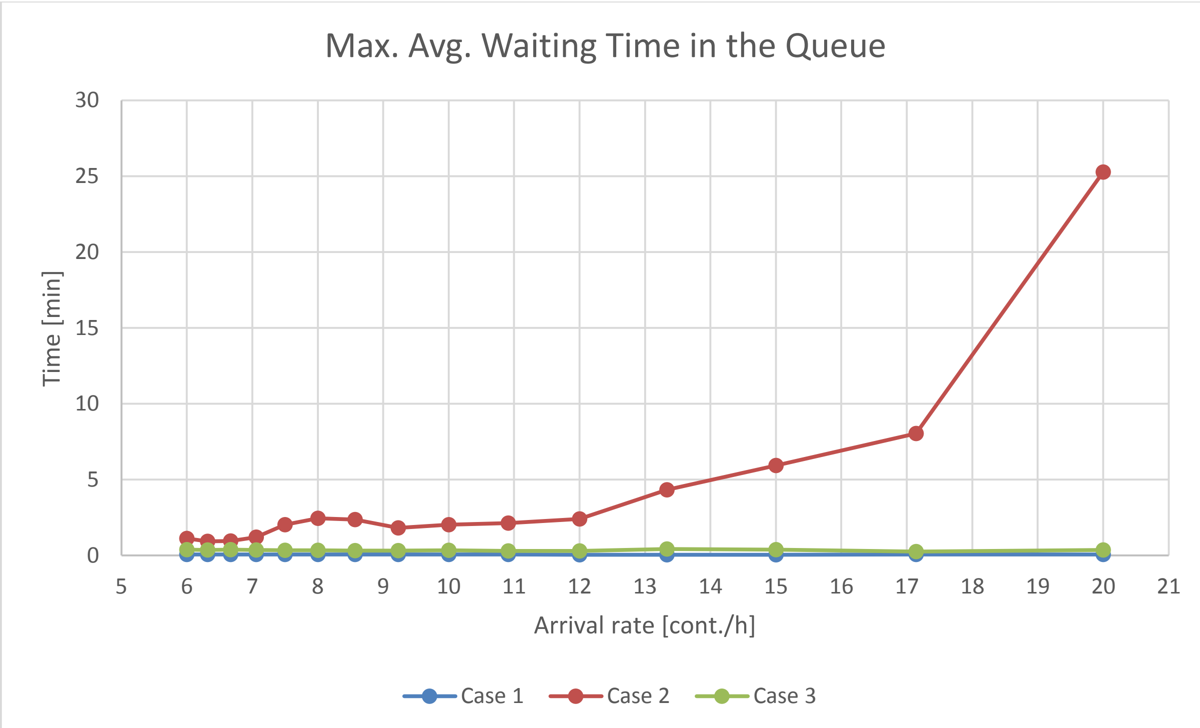

Figure 6.2: Maximal Average Waiting Time in the Queue

6.5 Time Spent in the System

The time spent in the system is a parameter of concern for truck operators. If it is significantly high, truck turnaround time at the port would be increased significantly. In addition, the total time spent at the screening checkpoint tells how long in advance trucks should come to the container terminal.

6.5.1 Average Time Spent in the System

Figure 6.3 is a plot of the average time spent in the system. In Cases 1 and 3, it is virtually constant regardless of the arrival rate. The values for Case 3 are higher than Case 1 (by approximately 1 minute), since the container is subject to all the three methods of screening,

whereas there is just NII inspection at Case 1 (8 seconds per container on average). As was the case for waiting time in the queue, the average time spent in the checkpoint is highest for Case 2. During low arrival rates, screening time forms a majority of the total time spent in the system, whereas as the arrival rate rises, the waiting time in queue becomes the major contributor to the time spent in the system.

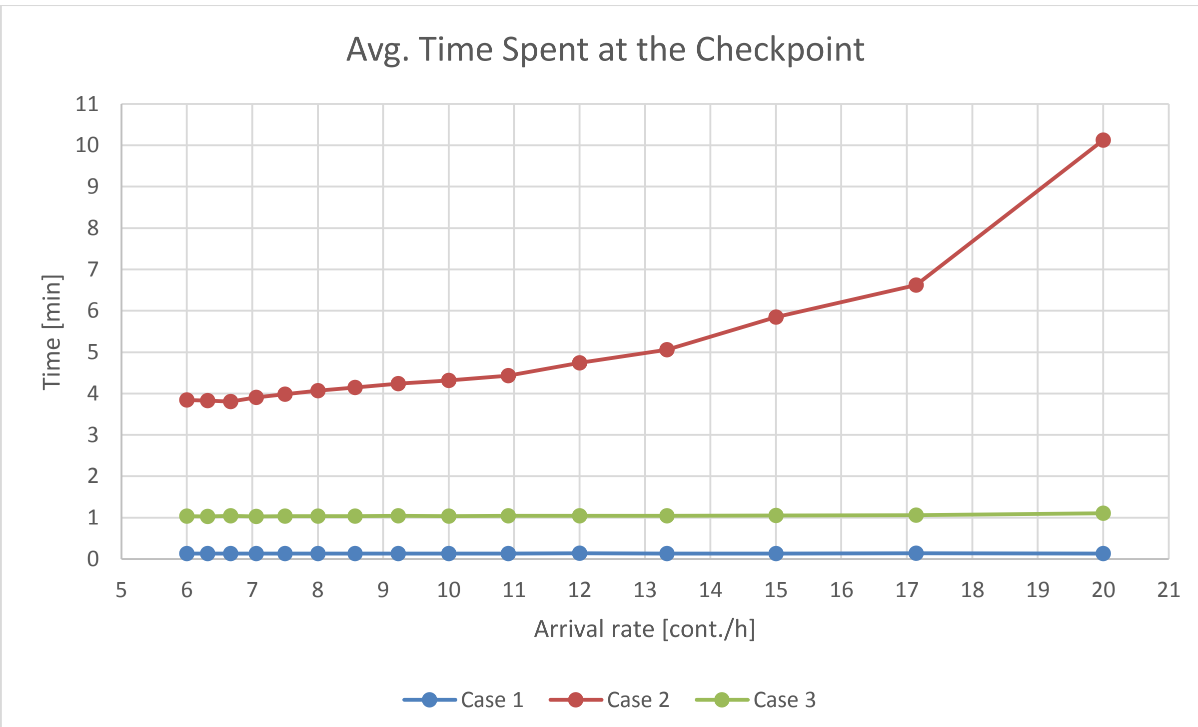

Figure 6.3: Average Time Spent at the Checkpoint

In addition, according to the data, the NII station is the main contributor to the time spent in the system, since it typically has the largest service time per container and waiting time in a queue.

6.5.2 Maximum Average Time Spent in the System

The results of maximum average time spent in the system (Figure 6.4) is quite similar to the results for maximum average waiting time (Figure 6.2), since the former is created by adding values of the service time (which is more or less constant) to the latter. Therefore, the same conclusion as in section 6.2.3 can be made.

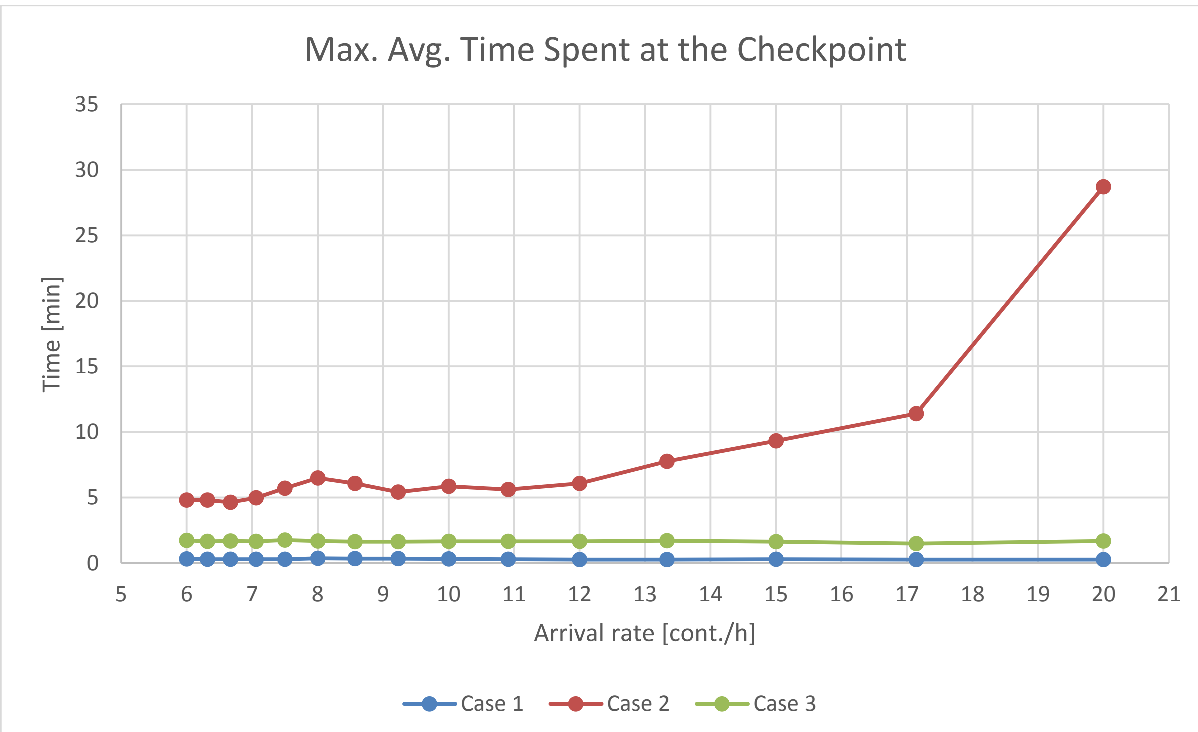

Figure 6.4: Maximum Average Time Spent at the Checkpoint

6.6 Number of Containers in the Queues

In the model, queues are formed at each screening station. First, there is the RPM station (Case 2 and Case 3). Since its service time is quite low compared to RIID and NII, the number of containers in the queue for RPM is generally low. The average number of containers in the queue

ranges from 0.001 to 0.009. There was only a negligible difference between Case 2 and Case 3. The fact that there is no significant queuing at the RPM station is confirmed by the maximum value of containers waiting. On average, there were at most 2 or 3 trucks with containers waiting in a queue at a time in both simulated cases.

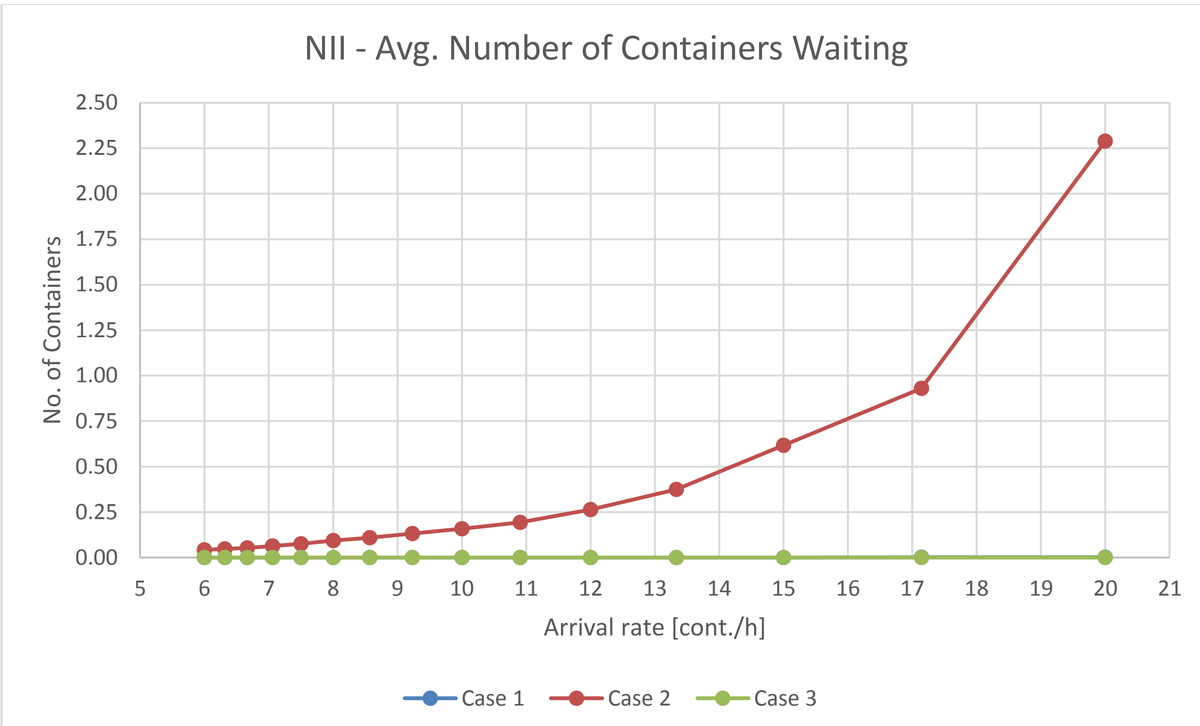

Figure 6.5: Average Number of Containers in the NII Queue

Secondly, there is the RIID station (Case 2 and Case 3). Although its service time is significantly larger (9.98 minutes) when compared to a RPM station, only a small number of containers that is chosen for secondary radiation detection inspection is screened by RIID. Therefore, the average number of containers waiting in the RIID queue is low as well, acquiring values from 0.0015 to 0.0185. The maximum average number of containers waiting in the queue reached values between 1 to 3 containers (typically 2). As was the case for RPM station, there is

no significant difference between Case 2 and Case 3. This means that for the simulated arrival rates, no high capacity waiting area is needed in case of RPM and RIID station.

However, this is not the case for the NII station especially for the case of 100% screening of containers. As can be observed at the Figure 6.5, the average number of containers in the queue significantly larger in Case 2 when compared to Case 1 and 3 (which are practically identical). With increasing arrival rate the average number of containers in the queue increases rapidly.

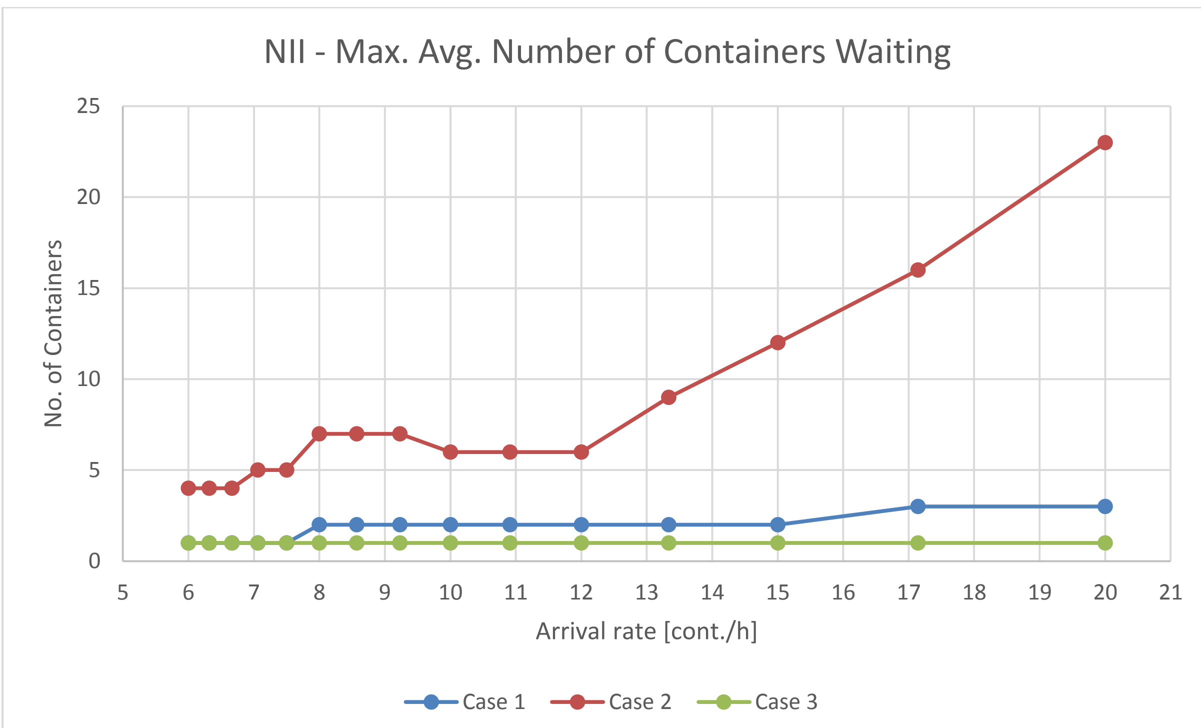

Figure 6.6: Maximal Average Number of Containers Waiting in the NII Queue

The fact that there can be significant congestion when screening all containers using NII equipment is further confirmed by the plot of maximal average number of containers in the queue (Figure 6.6). In Case 2, the maximum number of containers in the queue can reach up to

23 containers, compared to 1 in Case 3 and 3 in Case 1. If the queue reaches the length such as in Case 2, the waiting area at the station should be properly designed to accommodate such number of trucks carrying containers.

6.7 Screening Station Occupancy

6.7.1 RPM and RIID Occupancy

Since in both related cases (Case 2 and 3), 100% of incoming containers is screened using the RPMs, there is no significant difference in the RPM station occupancy. This was confirmed by the simulation results. The maximum value of occupancy reached 12.61% (at arrival rate 20 cont./h), while the lowest reached approximately 5% (at arrival rate 6 cont./h). The simulation output is plotted in Figure 6.7.

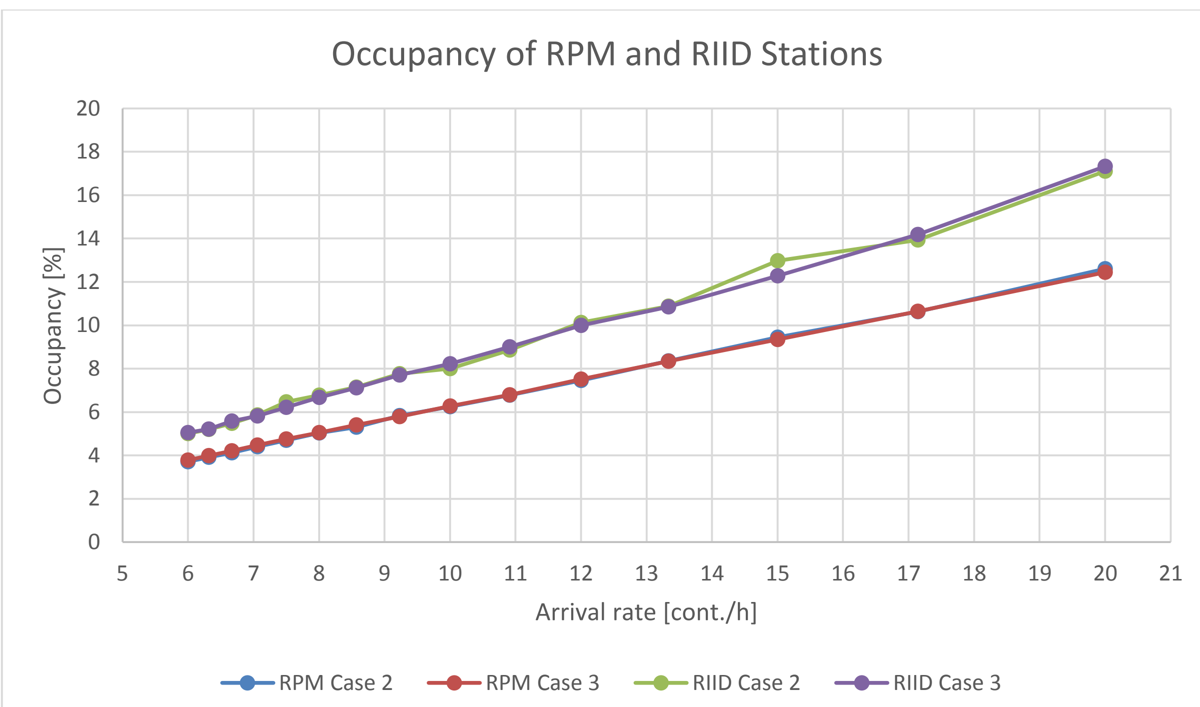

Figure 6.7: Occupancy of RPM and RIID Stations

The occupancy of RIID station does not differ significantly between the two applicable cases (Case 2 and 3), since number of containers that are screened using RIID is roughly the same (5% of the traffic according to the Decide module in Arena). The occupancy ranges from 5% to 17.33%. The plot of RPM and RIID occupancy can be observed in Figure 6.7.

6.7.2 NII Occupancy

The most interesting results can probably be observed for NII screening (Figure 6.8). Since in Case 2 all incoming containers are screened, the occupancy of NII equipment is quite high – it ranges from 24.69% to 83.33%. On the other hand, in Cases 1 and 3 the occupancy was once again roughly equal, reaching values in the range of 1.31% - 4.37%.

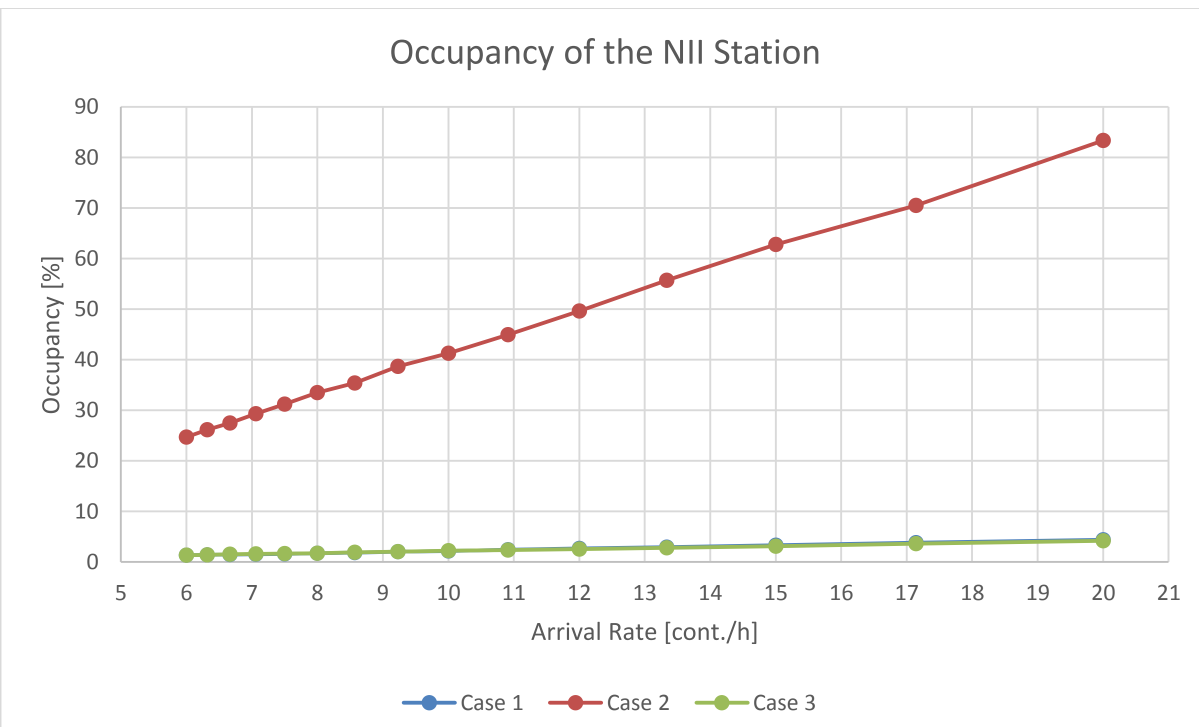

Figure 6.8: Occupation of the NII Station

6.7.3 Maximum Occupancy of the Screening Stations

Based on the best fitting trend line functions of the occupancy data (plotted in Figures 6.7 and 6.8), the arrival rates at which the screening stations are 100% occupied were calculated. This can be regarded as the maximal value of arrival rate that one lane of a station is able to service. Beyond that value the queue will grow to infinity. Please note, that the arrival rate does not correspond to the output of the screening station, which depends on the number of containers that are actually screened. The calculated values can be observed at the Table 6.5.

The calculations showed that the maximum screening output (that corresponds to 100% occupancy) is approximately 160 containers per hour for a RPM station, 6 for RIID station and 24 for NII station. All stations have one lane available. The calculated values in the table fluctuate since, they are calculated from an output that varies with every simulation.

Table 6.5: Occupancy Trend Lines and Maximal Arrival Rates for Screening Stations

	Simulated Case	Trend Line Function	R^2	Max. Arrival Rate [cont./h]	Max. Output [cont./h]
RPM	Case 2	$y = 0.6299x - 0.058$	0.9996	158.85	158.85
	Case 3	$y = 0.6154x + 0.1153$	1.0000	162.31	162.31
RIID	Case 2	$y = 0.8211x^{1.0063}$	0.9963	118.18	5.91
	Case 3	$y = 0.8196x^{1.0059}$	0.9986	118.62	5.93
NII	Case 1	$y = 0.2034x^{1.0274}$	0.9988	416.74	20.84
	Case 2	$y = 4.1626x - 0.1525$	0.9997	24.06	24.06
	Case 3	$y = 0.1997x + 0.1516$	0.9983	499.99	25.00

6.9 Low Traffic Simulation Results Summary

The data from the simulation output brought many intriguing notions. Firstly, it can be concluded that 100% screening of containers has the largest potential for queuing of containers. Secondly, when screening 100% of incoming containers, the NII station poses the bottleneck in the system. The simulation results will be further evaluated in Chapter 7.

Chapter 7: Results with High Container Traffic

Chapter 7 continues the presentation and analysis of the simulation results. The behavior of the checkpoints and their stations will be analyzed under the conditions of high container traffic that are described in Chapter 5.

7.1 CHECKPOINT OUTPUT

The Table 7.1 lists the simulated output rates for all the three simulated cases. It can be observed that in Case 2 there is a noticeable drop in the output rate at the arrival rate of 60 containers per hour. The checkpoint would most probably not able to service all incoming containers at this arrival rate, hence the drop in output.

Table 7.1: Checkpoint Output Rates

Input Headway [min]	Arrival rate [cont./h]	Case 1 [cont./h]	Case 2 [cont./h]	Case 3 [cont./h]
1.00	60.0	60.3	48.3	59.3
1.25	48.0	48.5	46.3	47.5
1.50	40.0	40.0	40.3	40.3
1.75	34.3	34.5	34.3	34.5
2.00	30.0	30.0	30.3	30.5
2.25	26.7	26.8	26.5	26.8
2.50	24.0	24.0	24.5	24.3
2.75	21.8	21.5	21.8	22.0
3.00	20.0	19.8	20.3	20.0
3.25	18.5	18.3	18.3	18.5
3.50	17.1	17.0	17.3	17.3
3.75	16.0	15.8	16.3	16.0
4.00	15.0	14.8	15.0	15.3
4.25	14.1	14.0	14.0	14.3
4.50	13.3	13.3	13.5	13.5
4.75	12.6	12.5	12.5	12.8
5.00	12.0	12.0	12.0	12.3

Since the same model logic as in the low container traffic was used, the average detention rates and their standard deviations for high container traffic are not significantly different. Their values are shown in Table 7.2.

Table 7.2: Average Checkpoint Detention Rates

	Case 1	Case 2	Case 3
Average Detention Rate [containers]	0.24%	5.56%	0.23%
Standard Deviation [containers]	0.02%	0.16%	0.03%

7.2 SERVICE TIME

7.3.1 Average Station Service Times

As expected, the screening times do not differ significantly from the values in the previous chapter, since the same distributions are used. In addition, the values are very close to the averages of the screening time distributions. The RIID has the longest duration, while RPM the shortest.

Table 7.3: Screening Stations Service Times

Screening Station	Distribution Average [min]	Average Service Time [min]	Standard Deviation [min]
Radiation Portal Monitor (RPM)	0.3750	0.3747	0.0005
Radiation Isotope Identification Device (RIID)	10.0000	9.7605	0.3344
Non-Intrusive Equipment (NII)	2.5000	2.4711	0.0821

7.2.2 Average Checkpoint Service Time

Since the distributions of service times are identical as in low container traffic, the average service times and their standard deviations are approximately identical in the case of high container traffic. Therefore, the same conclusion can be drawn. The 100% screening checkpoint (Case 2) has the highest average service time per container, because the screening time is averaged across all incoming containers.

Table 7.4: Checkpoint Service Times

Simulated Case	Average Service Time [min]	Standard Deviation [min]
Case 1	0.1308	0.0033
Case 2	3.3594	0.0207
Case 3	1.0019	0.0091

7.3 WAITING TIME

7.3.1 Average Checkpoint Waiting Time

According to the simulation, the average waiting time for the checkpoint is practically negligible in Case 1 (between 0.00 and 0.18 seconds) and Case 3 (between 2.78 and 23.00 seconds). In Case 2, the queue length depends on the arrival rate. At arrival rate of less than 20 containers per hour the waiting time is less than 30 seconds. If we compare this waiting time value to low container traffic with similar arrival rate, it has been reduced since two NII lanes are used. However, if the arrival rate is increased above 35 container per hour, the average waiting time rises significantly, reaching its maximum of 36.06 minutes for 60 containers per hour (Figure 7.1).

Despite the fact that the NII station uses 2 lanes, it has once again proven to be the dominant source of the waiting time in Case 2. For example, at arrival rate 60 containers per hour it accounted for waiting time 35.89 minutes. At the same arrival rate the average waiting time at the RPM station was 7.03 minutes and at RIID station 4.8 minutes.

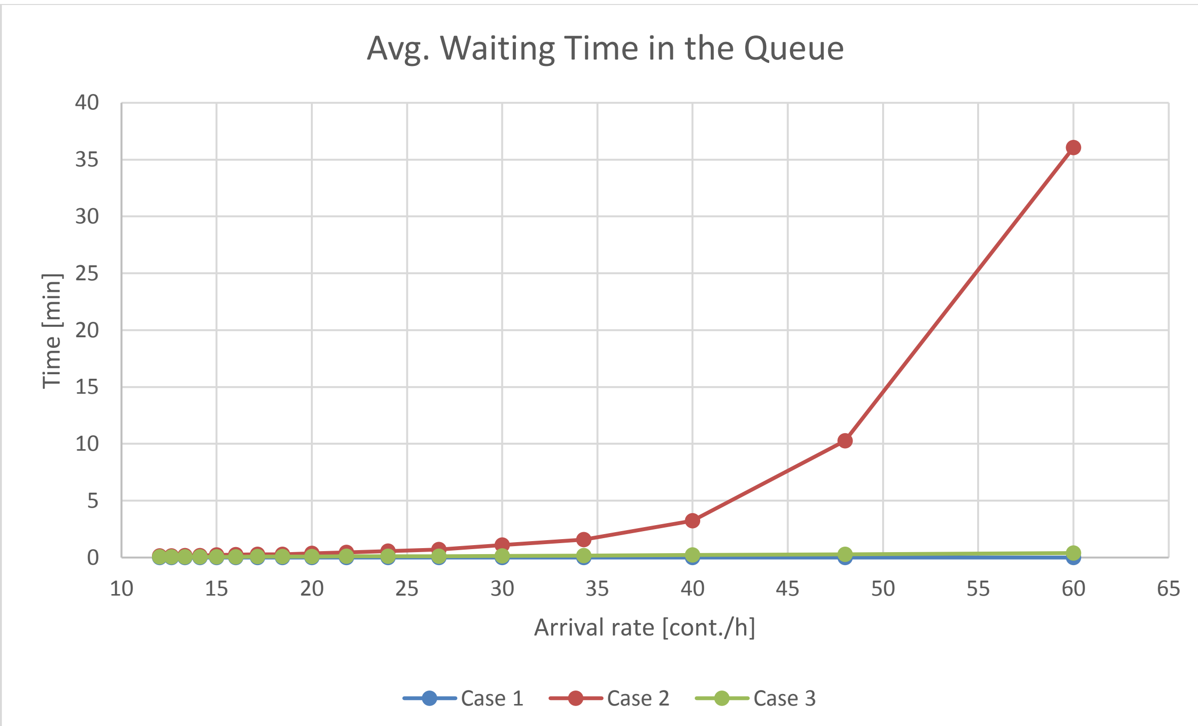

Figure 7.1: Average Waiting Time in the Queue

7.3.2 Maximum Average Checkpoint Waiting Time

Let us consider the maximum average waiting time for the whole checkpoint (Figure 7.2). While there is a similar trend as in the average waiting time, the values of maximum average waiting time have increased. If the arrival rate rises beyond 40 containers per hour, the time spent in the queue surpasses 10 minutes, ultimately reaching its peak of 68.57 minutes at 60

containers per hour. Therefore, if the terminal expects the typical arrival rate higher than 40 containers per hour, adding additional NII inspection lanes should be considered.

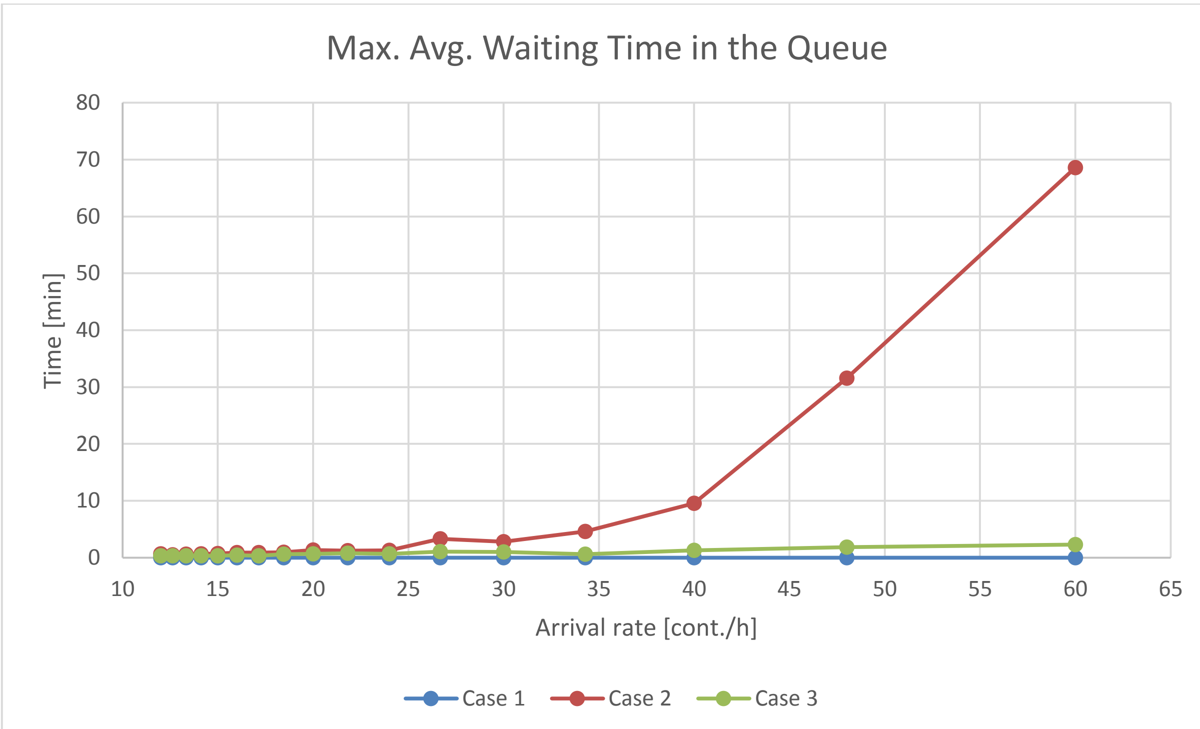

Figure 7.2: Maximal Average Waiting Time in the Queue

7.4 Time Spent in the System

7.4.1 Average Time Spent in the System

In Case 1, the time spent in the system is nearly constant, oscillating around its average of 7.85 seconds. Naturally, this is only a theoretical value, in real operation the time spent at the inspection would be higher, e.g. due to checking of documentation, and etc. The same conclusion can be made for Case 3 (average time of 1.12 minutes in the system). As expected, based on the

previous results, Case 2 checkpoint is very dependent on the value of the arrival rate. It works relatively efficiently up to the arrival rate of 40 container per hour, beyond this value significant delays can be observed.

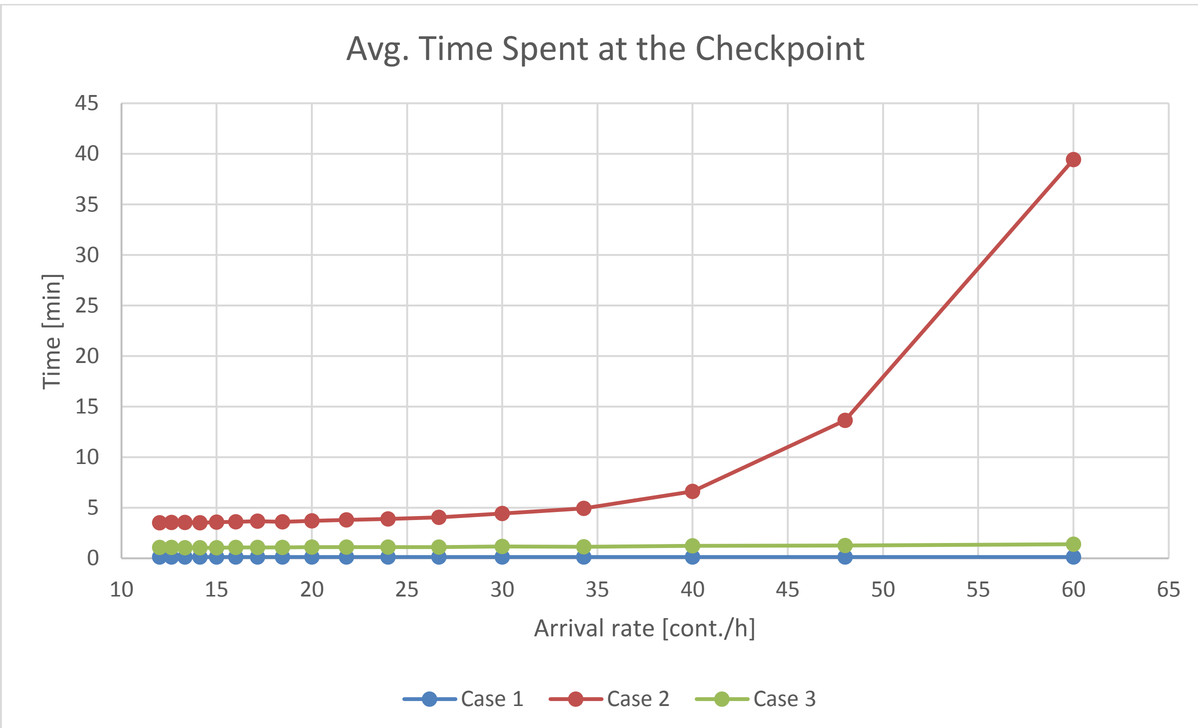

Figure 7.3: Average Time Spent at the Checkpoint

7.4.2 Maximum Average Time Spent in the System

As the maximum average time spent in the checkpoint corresponds to the sum of service time of the whole checkpoint and the maximum waiting time in the queue. Its plot in Figure 7.4 follows the same pattern that has been observed in Figure 7.2. Once again, it can be observed that if the arrival rate in Case 2 is less than 40 containers per hour, the checkpoint provides acceptable level of delay. Case 1 and Case 3 checkpoints once again generate little or no delay.

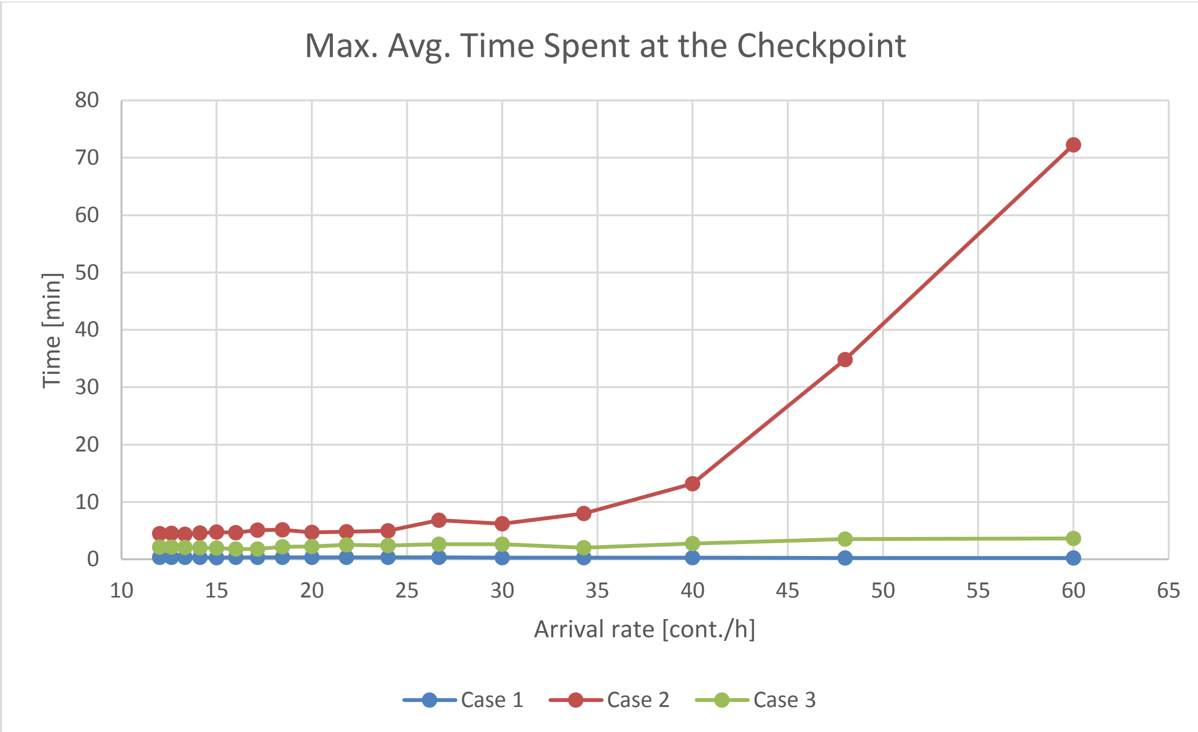

Figure 7.4: Maximum Average Time Spent at the Checkpoint

7.5 Number of Containers in the Queues

As has been established in the previous chapter, there is a queue at each screening station. Firstly, let us analyze the queue at the RPM station (Case 2 and Case 3). The number of trucks in the queue is on average between 0.0032 and 0.1196. These values are low since most of the time there is no queue. According to the results, the maximum average number of trucks in the queue is between 2 and 7 containers. From the point of view of terminal infrastructure, queue of this length would not require a large waiting area at the checkpoint.

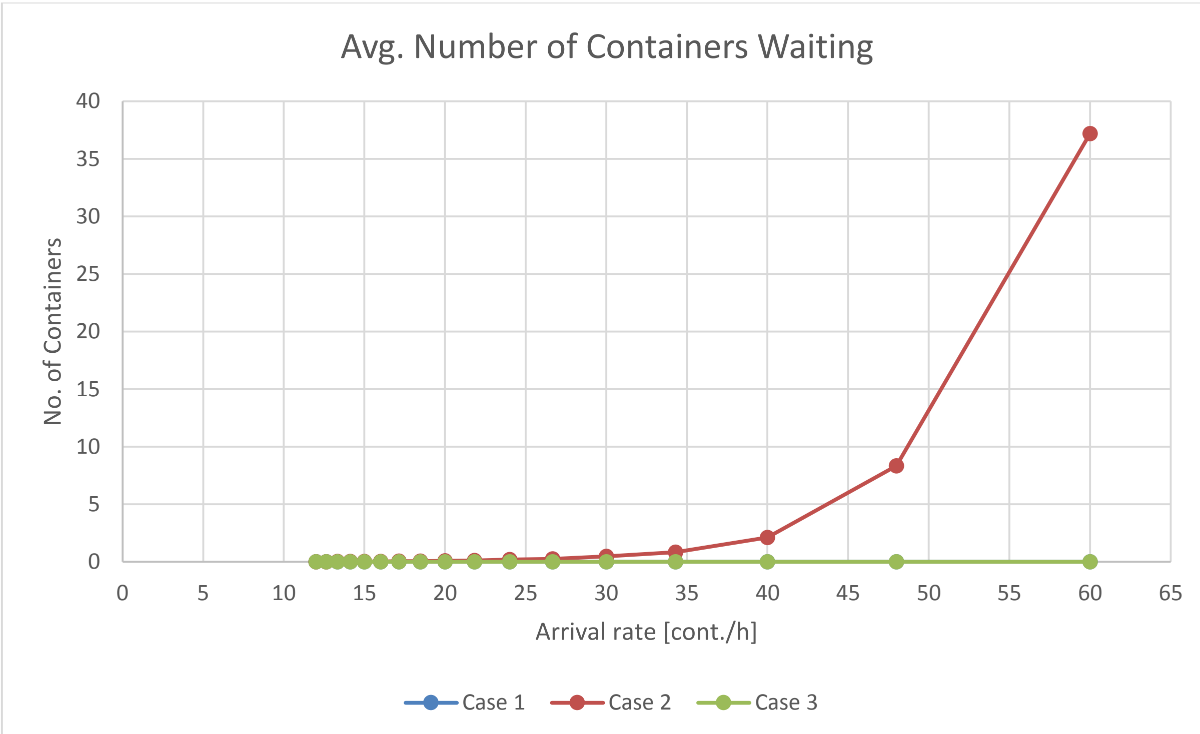

Figure 7.5: Average Number of Containers in the NII Queue

Let us continue the analysis with RIID station (Cases 2 and 3). Since only 5% of containers is selected for RIID screening in both applicable cases, there typically should not be significant queue. This can be supported by the values of the average number of trucks in the queue that ranges from 0.0048 to 0.2997. On the other hand, the maximum average queue length can reach up to 7 trucks. This value is still acceptable in terms of capacity of truck waiting area.

Similar to the low container traffic simulation, the NII equipment provides the most diverse results. Since two NII inspection lanes are used, the queue lengths in Cases 1 and 3 are practically negligible. Interestingly, if the arrival rate is lower than 30 containers per hour in Case 3 (20 containers per hour in Case 1), the output specifies that there is typically no queue at the station whatsoever. Case 2 result shows a different trend. Under approximately 35 containers

per hour the average number of trucks in the queue does not even reach 1. However, after this value is exceeded, the queue builds up fast, reaching its peak of 37.2 containers at 60 containers per hour. As has already been speculated, using two lanes at this arrival rate is probably not sufficient.

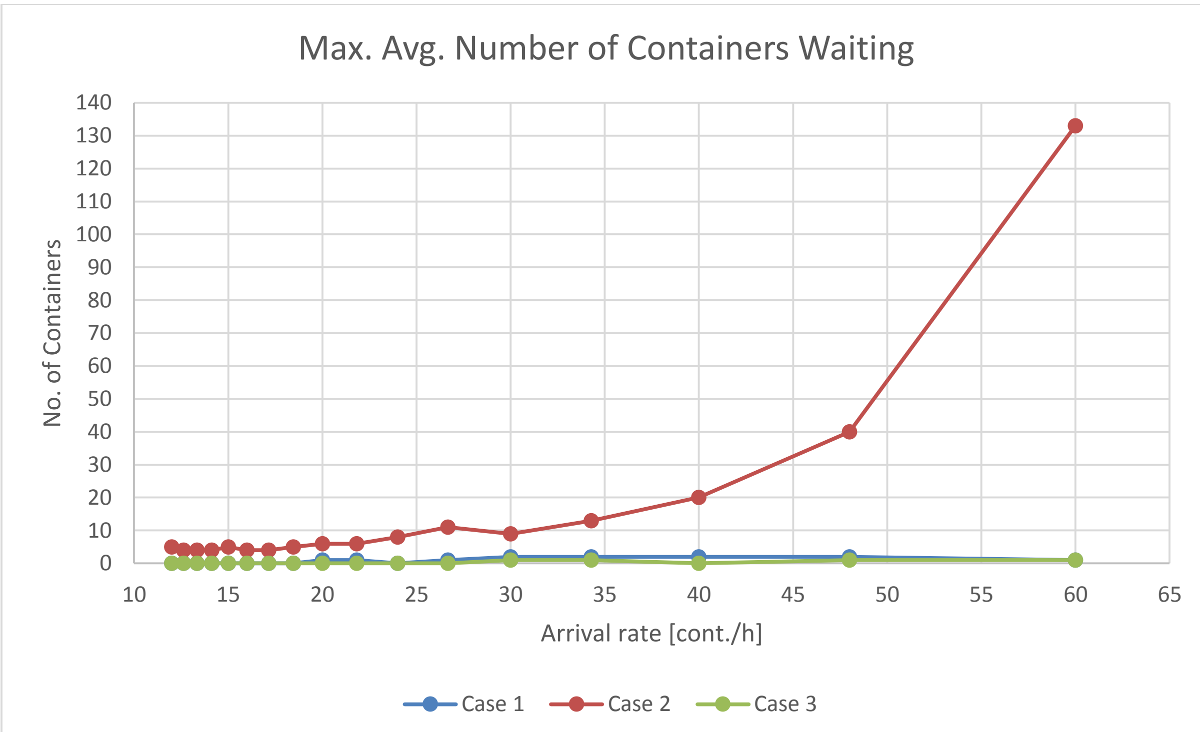

Figure 7.6: Maximal Average Number of Containers Waiting in the NII Queue

This claim is supported by the results of maximum average number of trucks in the queue. While there is approximately 13 containers in the queue at the arrival rate of 35 containers per hour, there are 133 containers at arrival rate 60 container per hour. This level of congestion is practically impossible to manage in terms of the size of the waiting area. Therefore, installation of additional NII lane would be required.

7.6 SCREENING STATION OCCUPANCY

7.6.1 Stations Occupancy

The increased value of arrival rate in high container traffic simulation resulted in higher occupancy of both RPM and RIID stations. The number of inspection lanes remained the same, each station has only one lane available. Once again, no significant difference between Case 2 and 3 occupancies has been observed. The minimum value of occupancy for RPM was 7.5% at arrival rate 12 cont./h and for RIID 10.28% at the identical arrival rate. The maximum values of occupancy reached as high as 51.3% for RIID and 37.94% for RPM, both at the maximum simulated arrival rate of 60 containers per hour. The output of the simulation is plotted in Figure 7.7. To conclude, both RPM and RIID station, even though equipped with just one inspection lane, are still able to provide satisfactory performance despite the increased arrival rates.

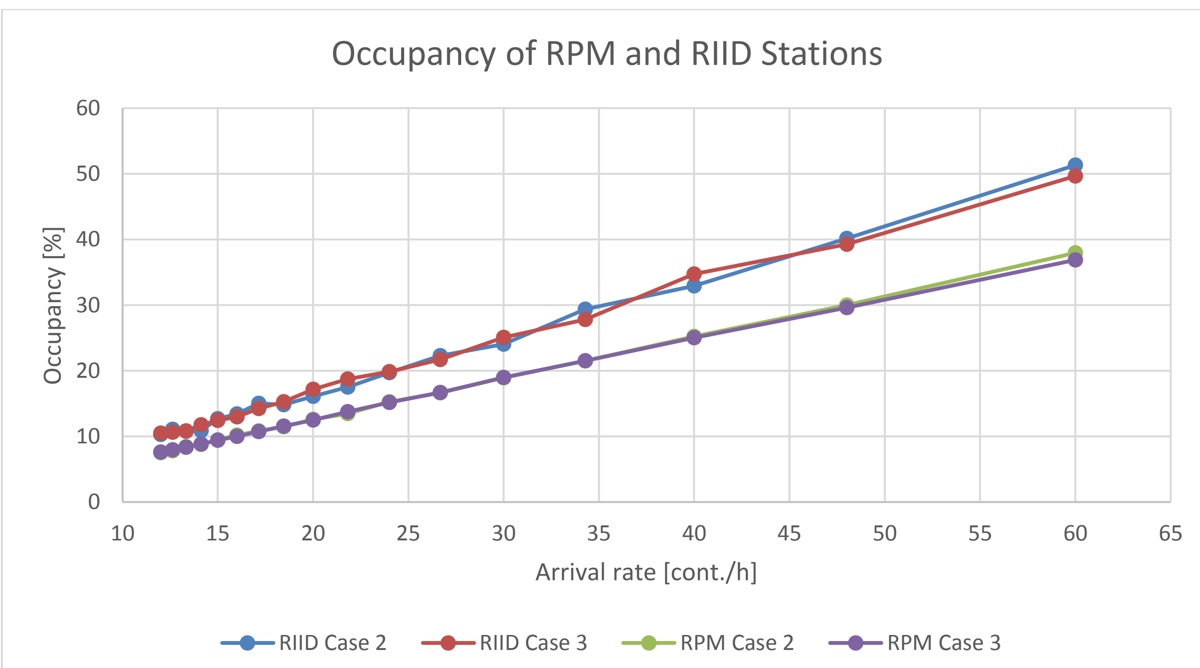

Figure 7.7: Occupancy of RPM and RIID Stations

7.6.2 NII Station Occupancy

Since NII station has two lanes available, the results are substantially different from the previous simulation, mostly in Case 2. Utilizing two lanes significantly reduced the occupancy for lower arrival rates, while enabling screening of higher arrival rates (Figure 7.8). An interesting observation how the station behaves at peak occupancy can be made. Although at the arrival rate of approximately 48 containers per hour the station is still not fully utilized (occupancy of 96%), the queues and waiting times grow rapidly. Had arrival been increased beyond 60 containers per hour, which corresponds to maximal utilization (99.97%), the queueing would even intensify. On the other hand, at the minimum simulated arrival rate (10 cont./h) only one inspection lane would suffice, since the two lanes were underutilized (24.83%).

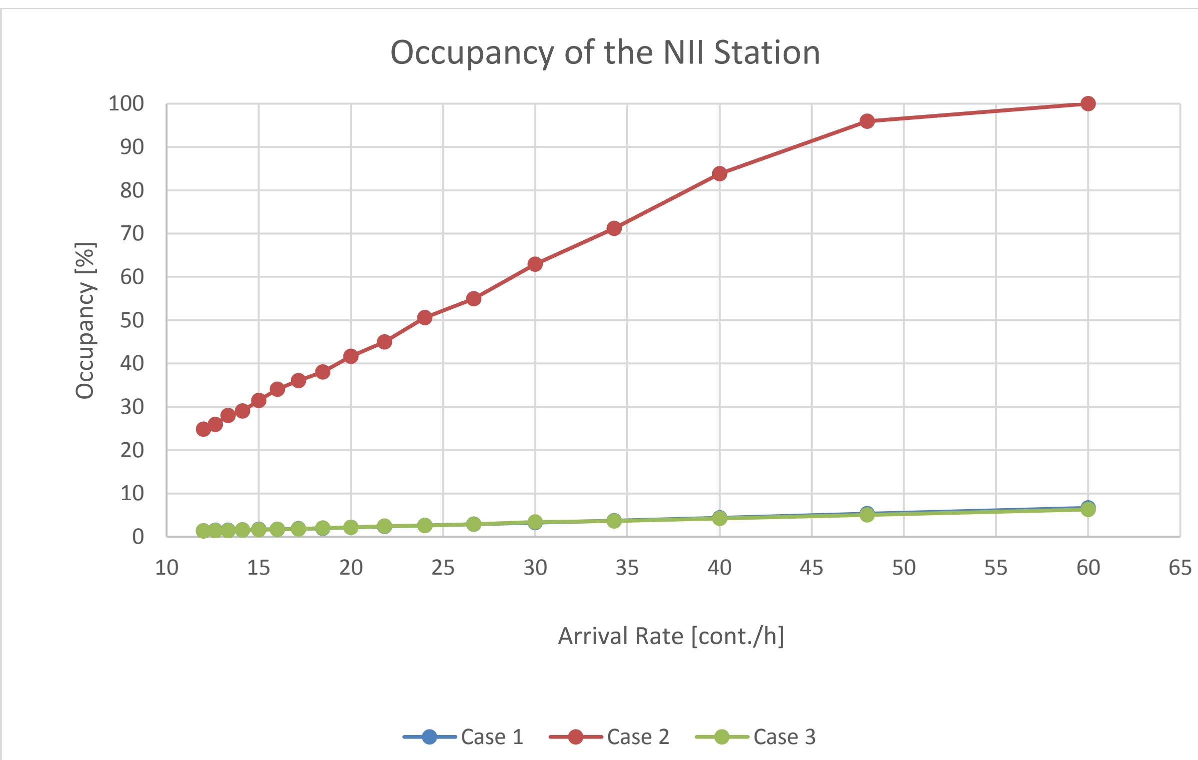

Figure 7.8: Occupation of the NII Station

7.6.2 Maximum Occupancy of the Screening Stations

In the same fashion as in Sub-section 6.7.3, maximal arrival rates for each stations were calculated using trend line functions of the occupancy data plot. The obtained results (Table 7.4) differ from the previous chapter, since the simulation had different settings and therefore the data does not fit the same functional forms. Nevertheless, the maximum calculated screening output was 160 containers per hour for RPM, approximately 6 containers per hour for RIID and about 50 containers per hour for NII.

Table 7.5: Occupancy Trend Lines and Maximal Arrival Rates for Screening Stations

	Simulated Case	Trend Line Function	R^2	Max. Arrival Rate [cont./h]	Max. Output [cont./h]
RPM	Case 2	$y = 0.6312x - 0.0761$	0.9998	158.55	158.55
	Case 3	$y = 0.6142x + 0.2647$	0.9997	162.38	162.38
RIID	Case 2	$y = 0.0015x^2 + 0.747x + 0.9025$	0.998	108.86	5.44
	Case 3	$y = -0.0003x^2 + 0.8461 - 0.1063$	0.9979	123.74	6.187
NII	Case 1	$y = 0.1101x - 0.035$	0.9987	908.58	45.43
	Case 2	$y = -0.0197x^2 + 3.0781 - 10.755$	0.994	56.185	56.19
	Case 3	$y = 3.10^{-6}x^3 - 0.0005x^2 + 0.1253x - 0.164$	0.9981	336.88	46.84

7.7 HIGH TRAFFIC SIMULATION RESULTS SUMMARY

The conclusions from this chapter are similar to ones in the previous chapter. The model representing 100% screening checkpoint (Case 2) once again generates the highest queue length and waiting time out of the three simulated cases. The main culprit is NII as well, although in the case of high container traffic simulation two lanes were used for NII.

Chapter 8: Recommendations on Design of Container Screening Systems

Chapter 8 proposes recommendations on screening of containers for both policy makers and container terminal designers. Firstly, results from the previous chapters and information from literature review will be used to make proposals on possible changes to current legislation. Secondly, recommendations on how to implement 100% screening checkpoint at seaports will be given.

8.1 Recommendations for Policy Makers

As has been mentioned in the introduction, there is an ongoing debate on the topic of 100% screening among the industry experts. The feasibility of the concept has been questioned numerous times, because of astronomical costs, technical issues and operational constraints. Indeed, as has been confirmed by the simulation in Arena in Chapters 6 and 7 of this thesis, if the 100% screening checkpoint (Case 2) is not designed properly, it does not provide satisfactory performance. For instance, if insufficient number of inspection lanes at NII screening station is used, there can be heavy congestion at the checkpoint, resulting in a drop of quality of service of the terminal. As a consequence, the supply chain and trade between the EU and U.S. can be disturbed to an unexpected degree. Is there an alternative for screening all incoming containers?

If we consider the current arrangement at the EU ports (Case 1), we come to the conclusion that although it does not generate significant congestion and delays, it lack one crucial component – radiation screening. Therefore, it does not meet the demand on the increased security of the supply chain.

However, even among the current methods of screening, there is an alternative to the 100% screening concept. Currently, in U.S. ports, the hybrid approach to screening (Case 3) is

implemented. While all containers undergo the radiation inspection like in case of 100% screening, only containers targeted for inspection are screened using NII equipment. This significantly reduces values of all negative performance indicators, such as queue length or delay as has been proven by the simulation.

Besides the delay, truck congestion at container terminals has to be considered. The current trend in development of container terminals is to provide environment friendly operation. For instance, to meet this goal, renewable sources of energy are used to power the handling equipment. The congestions at terminals created by 100% screening would go against the "green" effort of terminal operators, since it would bring increased levels of emissions caused by idling of trucks in the queue.

To support this claim, the results of the simulation were analyzed to determine possible levels of engine emission caused by queuing at the checkpoint. The values were calculated by multiplying the truck waiting time by idling emission rates provided by U.S. Environmental Protection Agency (2008). Trucks incoming to the terminal are assumed to be classified as heavy-duty diesel vehicles (HDDV), gross vehicle weight class VIIIb. The resulting rates of emissions per hour of checkpoint operation for volatile organic compounds (VOC), hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_X) and particulate matter ($PM_{2.5}$ and PM_{10}) are provided in the Table 8.1. It compares the rates for Case 2 and 3 and for arrival rates 20 container per hour (low traffic simulation) and 48 container per hour (high traffic simulation).

Table 8.1: Emission Rates (Grams per Hour of Checkpoint Operation)

		VOC [g/h]	HC [g/h]	CO [g/h]	NO_X [g/h]	$PM_{2.5}$ [g/h]	PM_{10} [g/h]
20 cont./h	Case 2	9.66	9.80	79.34	97.41	2.62	2.76
	Case 3	0.12	0.12	0.98	1.20	0.03	0.03
48 cont./h	Case 2	33.79	34.27	277.55	340.79	9.17	9.65
	Case 3	0.90	0.92	7.43	9.12	0.25	0.26

Although trucks in the EU have a different engine specification and therefore the absolute values of emissions may vary, the percentage by which the emissions are reduced by transition to hybrid approach to screening remains constant. In the case of arrival rate 20 containers per hour, the emissions were reduced by 98.77% just by transition from 100% screening to hybrid approach. Similarly, the rates for 48 containers per hour dropped by 97.32%. That is a significant difference in a long term, especially for CO and NO_X emissions, which are both highly harmful for the environment.

Table 8.2 Effect of Transition from 100% Screening to Hybrid Approach

	20 cont./h	48 cont./h
Waiting Time in the Queue	-98.75%	-97.36%
Time Spent at the Checkpoint	-89.10%	-90.67%
No. of Trucks in RPM Queue	0.00%	-3.94%
No. of Trucks in RIID Queue	1.08%	4.99%
No. of Trucks in NII Queue	-99.97%	-99.99%
Truck Emissions	-98.77%	-97.32%

To conclude, it is recommended that the 100% screening approach would be abandoned in favor of the hybrid approach, which would provide comparable level of number of containers screened by radiation while having lower cost, better operational performance and as

substantially negative impact on the environment. Table 8.2 provides percentages, by which the average values of the observed parameters are reduced by the transition.

8.2 Recommendations for Terminal Designers

Implementing of screening checkpoint to existing infrastructure can be a great challenge, especially in the case of 100% screening checkpoint. The following section therefore provides several recommendations for the terminal designers that may help them with the design.

8.2.1 Usage of Simulation

As has been discovered during the visit of Port of Hamburg, the terminal designers currently do not utilize any simulation software to simulate and verify the design of terminal checkpoints (Representative of Main Customs Office Port of Hamburg 2014). Instead, they rely on experience and expert opinion. As valuable as it may be, the screening of containers on a mass level is relatively new concept. Therefore simulation software should be used to help with the design, at least for the validation of the expert's design.

As has been demonstrated by the thesis, one possible choice of simulation software is the Arena Simulation Software. It is relatively intuitive and user-friendly, while providing functions that are necessary for simulation of the checkpoint operation. The biggest issue with Arena discovered during this research was the limitation of the academic edition, which is limited to 150 entities in the system at any time during the simulation. However, if a designer uses a standard license of Arena, this issue does not apply.

If a terminal designer should decide to use Arena Simulation Software for the purpose of design of screening checkpoint, the models defined in the thesis may be used as a template. However, it is recommended that the distributions for screening time are revisited and adjusted

to specifications given by the screening equipment manufacturer. Similar recommendation applies to the simulated input, which should correspond to the expected container traffic in the terminal.

8.2.2 Implementation of Simulation Output

The simulation of the checkpoint behavior provides useful information on the checkpoint operation and design. However, the terminal designer must make several important decisions when implementing the output of the simulation in reality.

The crucial decision is which the type of checkpoint is to be implemented. The choice will probably very often be made based on the minimum legislative requirement. However, a terminal designer may choose to go beyond the minimum requirement and implement more advanced security methods in order to gain competitive advantage over other terminals.

Next, the number of inspection lanes should be determined. This should not be done just by dividing the expected container arrival rates by the theoretical capacity of each lane. It is preferable to set an acceptable level of delay or queue length first and subsequently estimate the necessary number of lanes based on simulation.

For instance, if a terminal operator decides to have a screening checkpoint based on 100% screening with the expected arrival rate is 48 containers per hour, and he has a choice of how many lanes of NII station to implement (as one lane for RPM and one lane for RIID are sufficient according to the earlier reported simulation results). A quick simulation has been conducted based on the high container traffic for the Case 2 model, the results are summed up in Table 8.3. Should the terminal designer set the average acceptable level of delay (time spent in the system) per container to 10 minutes, it is clear that two NII lanes will not be sufficient and three lanes must be used instead. Similarly, if there is a demand to eliminate the queues entirely,

one additional lane (total of four lanes) must be added. However, this is assuming that the quality of operation has a priority over the cost of screening implementation.

Table 8.3: Influence of No. of NII Lanes on Operation at Arrival Rate 48 cont. per hour

No. of NII Lanes	Avg. Time in the System [min]	Max. Avg. Time in the System [min]	Avg. No. of Containers in the NII Queue	Max. Avg. No. of Containers in the NII Queue
2	13.6379	34.8416	8.3421	27.5145
3	4.1980	5.4300	0.4630	1.3644
4	3.7117	5.5267	0.0913	0.2704

Although in the case of RPM station, one lane was able to provide an acceptable output at all simulated arrival rates, it might be prudent to implement at least 2 lanes if the budget allows. As mentioned in Chapter 3, it is a good practice to implement 2 or more lanes, so that an alarm at one RPM may be verify with the second RPM.

Finally, the checkpoint placement and layout should be decided (the possible options are listed in in Section 4.2.1). The decision should be based on land availability inside the port and the terminal traffic circulation pattern. For instance, if the seaport in the EU consist of multiple terminals each serving a shipping line which has a small share of U.S. bound traffic, it is recommended to create a dedicated screening site for all terminals. On the other hand, if there is a terminal with a major share of U.S. bound traffic, a more suitable solution would be to build a screening site dedicated to the terminal in question.

To conclude, it should be noted that the recommendations for terminal designers in this chapter should not be regarded as a universal rule. Every seaport is different in layout, budget, traffic or other operational constraints. Therefore, the terminal designers should decide what kind of checkpoint configuration suits their situations the best.

Chapter 9: Conclusion

9.1 Summary of Research

The research in this thesis was devoted to the topic of container screening in seaports. Although this area does not often receive spotlight on the transportation and logistics research scene, it is important for ensuring the safety and security of the global supply chain. In order to provide background necessary to understand the issue, the first four chapters of the thesis introduced the most important concepts, legislation and technical means of screening of containers at seaports with a focus on shipping containers from EU to U.S. Subsequently, models representing three major approaches to screening were formulated and created in the Arena Simulation Software. Using the models, the operations of the screening checkpoints were simulated and evaluated. The experience and results gained by performing the simulation served as a basis for recommendations on container screening at seaports for both policy makers and terminal designers.

9.2 Contributions

The thesis compared various operation aspects of three screening approaches by simulation. There are two parties that can benefit from the information provided in the thesis. Firstly, the policy makers can learn from the analysis of the three approaches to screening in order to support more efficient solutions in future legislation. Secondly, terminal designers can use the simulation method described in the thesis during the process of screening checkpoint design. This way, more efficient checkpoint design might be achieved.

9.3 LIMITATIONS

There are several limitations in the research that should be addressed if using the models described in the thesis for a design of a checkpoint. Firstly, the distributions used for screening time at the screening stations are based on estimates from available resources. Despite best efforts, real data from seaports were not obtained. Therefore, when using the simulation method, new distributions should be devised for the simulated case. Secondly, there has been an issue with the limitations of the academic edition of Arena simulation software, which limited the scope of the simulation. It is thus recommended to get a standard industry license which should not have this issue.

9.4 FUTURE RESEARCH

There are several aspects of container screening, which can be used for future research. For instance, a research devoted to risk-based screening can be suggested, focusing on data analysis used for targeting containers for screening. Alternatively, on a more technology-oriented note, emerging screening technologies and their impact can be researched. Finally, the simulation method used in this thesis can be revisited in order to perform a sensitivity analysis, if the number of container that are screened changes.

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Glossary

Container inspection – a process of security check of an intermodal freight container. It can include checking of all documentation, container screening (radiation detection or non-intrusive imaging) or physical inspection of the container.

Container screening – a method that utilizes detection equipment to inspect and identify contents of an intermodal freight container without opening it. A term “container scanning” is a synonym.

Inspection lane – a road lane for one truck at a screening station.

Naturally Occurring Radioactive Material (NORM) – a material that has detectable level of naturally occurring radiation, but poses no security threat.

Non-Intrusive Imaging (NII) – a method of screening, which generates the image of container contents without opening it in order to detect illicit objects inside.

Radiation detection – a part of the screening process that serves for detecting radioactive material inside the container. It can be either primary (using RPM) or secondary (using RIID), which ensues when there is an alarm at the primary detection.

Radiation Isotope Identification Device (RIID) – handheld device that is used for secondary radiation detection.

Radiation Portal Monitor (RPM) – a stationary device that is used for primary radiation detection.

Screening checkpoint – a designated area at a seaport or terminal, where screening of containers is conducted.

Screening station – an area inside the screening checkpoint, where particular screening equipment is placed (e.g. RPM, RIID, NII) and used.

Supply Chain Security (SCS) – protection of supply chain against malevolent acts of unlawful interference that could disrupt the supply chain or in any way endanger general population.

Vita

Michal Jizba was born in Kolin, Czech Republic on February 15, 1991. He received his Bachelor Degree in Technology in Transportation and Telecommunications – Air Transport from the Czech Technical University in Prague (CTU) in 2013 after successfully defending his bachelor thesis “Modern Technologies in Passenger Security Control”. Afterwards, he enrolled in the Transatlantic Dual Master Degree Program in Transportation and Logistic Systems, which is jointly offered by the Czech Technical University in Prague (CTU), University of Zilina (UNIZA) and The University of Texas at El Paso (UTEP) and funded through the EU-US Atlantis Program.

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