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16. Abstract

The quantity of cargo handled by United States ports has increased significantly in recent years. Based on 2004 data, almost 2.7 billion tons of cargo passed through the ports in one year. To protect the U.S., all of this cargo must be inspected by U.S. Customs Border Protection (CBP) officials in the most effective manner possible. Existing non-intrusive inspection (NII) technologies have significant strengths, but they also have some weaknesses, such as a low detection rate and a long inspection time. Fortunately, there are newer and more advanced technologies that can be used to inspect cargo with higher accuracy and less delay. The goal of this research was to identify the most effective and efficient combination of NII technologies for inspecting cargo arriving at U.S. ports. For this purpose, a discrete-event simulation model was developed to simulate the cargo inspection procedure. By simulating the operations of different combinations of NII technologies, the effectiveness and efficiency of the various combinations were evaluated. This information was used to provide recommendations about the most effective and efficient combinations of NII technologies for detecting a wide range of contraband. The results of this research are helpful in making decisions concerning the appropriate choices of NII technologies for use in inspecting cargo that is entering U.S. ports.

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Investigate Existing Non-Intrusive Inspection (NII) Technologies for Port Cargo Inspections

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Research Report SWUTC/11/161042-1

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ABSTRACT

Currently, U.S. port authorities use various non-intrusive inspection (NII) technologies to inspect incoming cargo. The quantity of cargo handled by United States ports has increased significantly in recent years. Based on 2004 data, almost 2.7 billion tons of cargo passed through the ports in one year. To protect the U.S., all of this cargo must be inspected by U.S. customs officials in the most effective manner possible. The NII technologies that are currently used for this purpose include radiation detectors and X-ray imaging systems, which have both strengths and weaknesses. Recently, newer and more advanced technologies have been developed, such as pulsed photonuclear assessment (PPA) inspection technology, passport systems (PS), and muon radiography (MR), that may help customs officials detect shielded nuclear material with less delay.

The goal of this research was to identify the most effective and efficient combination of NII technologies for inspecting cargo arriving at U.S. ports. For this purpose, a discrete-event simulation model was developed to simulate the cargo inspection procedure. By simulating the operations of different combinations of NII technologies, the effectiveness and efficiency of the various combinations were evaluated. This information was used to provide recommendations about the most effective and efficient combinations of NII technologies for detecting a wide range of contraband. The results of this research are helpful in making decisions concerning the appropriate choices of NII technologies for use in inspecting cargo that is entering U.S. ports.

Keywords: non-intrusive inspection (NII), advanced spectroscopic portals (ASP), passport systems (PS), Arena model, discreet simulation

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EXECUTIVE SUMMARY

Today, the United States Port Security is using various nonintrusive (NII) methods of screening technologies to inspect incoming cargos. The United States ports are growing every day and cargo must be inspected by U.S. customs officials in the most effective manner to protect our borders. The NII technologies that are currently being employed include radiation detectors, X-ray imaging systems, and Gamma-ray imaging systems. These existing NII technologies have their own strengths and weakness. Recently, newer and more advanced technologies have been developed, such as the Pulsed Photonuclear Assessment (PPA) inspection technology, Passport Systems (PS), Muon Radiography (MR), and Advanced Spectroscopic Portal (ASP), etc that may help the United States Customs Officials detect shielded nuclear material without delay.

This research will conduct discrete-event simulations to compare the capabilities and the costs of different types of NII technologies. In addition, it will provide recommendations about the most efficient combinations of NII technologies that can detect a wide range of contraband, to protect the borders.

Literature review and a field study were conducted in order to design the study, and qualitative data from surveys were used to determine important parameters in the simulation process. The accuracy and effectiveness of the different combinations of NII technologies will be compared by queue time, total processing time, and detection rate. To recommend the most effective NII combinations, three simulation scenarios will be generated. The first case is currently in practice at most U.S. Ports. The second case uses an existing primary method of screening and a new secondary method of screening. The third case uses a new primary method of screening and an existing secondary method of screening. Each scenario will have a primary

method of inspection where all incoming cargo will be checked, and then either 3%, 5%, or 10 % of cargo will proceed to the secondary method of cargo inspection. The results of simulations will be analyzed to make recommendations on the most effective and efficient NII combinations based on detection rate and time. The results of this research will be helpful for decision making when choosing the right NII technologies for port cargo inspection.

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LIST OF ACRONYMS

ASP: Advanced Spectroscopic Portal

X-Rays: X-Radiation

NII: Non-Intrusive

PPA: Pulsed Photonuclear Assessment

PS: Passport Systems

MR: Muon Radiography

CBP: Custom's Borders Patrol

NRF: Nuclear Resonance Fluorescence

PHA: Port of Houston Authority

NII: Non-Intrusive Inspection

RPMs: Radiation Portal Monitors

NORM: Naturally Occurring Radioactive Material (NORM)

RIID: Radioisotope Identification Device

GAO: Government Accountability Office

SUV: Sports Utility Vehicle

WMD: Weapons of Mass Destruction

CHAPTER 1: INTRODUCTION

1.1 Background

Currently, U.S. port authorities use various non-intrusive inspection (NII) technologies to inspect incoming cargo. The quantity of cargo handled by United States ports has increased significantly in recent years. Based on 2004 data, almost 2.7 billion tons of cargo passed through the ports in one year. To protect the U.S., all of this cargo must be inspected by U.S. customs officials in the most effective manner possible. The NII technologies that are currently used for this purpose include radiation detectors and X-ray imaging systems, which have both strengths and weaknesses. Recently, newer and more advanced technologies have been developed, such as pulsed photonuclear assessment (PPA) inspection technology, passport systems (PS), and muon radiography (MR), that may help customs officials detect shielded nuclear material with less delay.

However, like earlier technologies, each of these new technologies also has strengths and weaknesses. Thus, Custom's Borders Patrol (CBP) officers must have extensive knowledge of the existing NII technologies in order to select the proper tools for use in inspecting the cargo that comes into U.S. ports.

1.2 Research Objectives

The objective of this research was to identify the most cost-effective combinations of NII technologies that can detect a wide range of contraband to protect U.S. interests. To achieve this objective, a thorough literature review was conducted to gain an understanding of the state-of-the-art practices used to inspect incoming cargo and to identify NII technology candidates for further evaluation. Also, CBP officers at the Port of Houston Authority (PHA) were interviewed to acquire information about the general process of cargo inspection and the NII technologies that are currently used for this purpose. Then, a discrete-event simulation model was developed to compare the effectiveness of different combinations of NII technologies, and the most efficient and effective combinations of NII technologies were identified. To achieve the objective of this research, the following steps were taken:

a. Thorough literature reviews were conducted to gain a feel for the state-of-the-practice on part cargo security and identify the candidates NII technology for further evaluation.
b. An interview was conducted with the CBP officer at PHA to seek information about the general process for port cargo inspection and the NII technologies that are currently employed for cargo inspection.
c. Discrete-event simulation tools such as Arena were used to simulate the inspection process. These tools use the discrete-event simulation paradigm that allows programming to simulate the cargo flow under different types of inspection strategies with different types of inspection technologies. The simulation with different combinations of NII technologies were conducted based on the information collected during the literature review and interview. The different combinations of NII technologies were chosen based on a list of criteria gathered through literature review including the screening time, the type of hazardous material that can be detected, the non-detection rates, and the installation cost. Based upon these criteria, combinations of the best and most effective technologies were chosen to be simulated.
d. The effectiveness of the different combinations of NII were evaluated by comparing the average queue time, processing time, waiting time, detection rate, and non-detection rate.

1.3 Organization of the Chapters

This research is organized in the following order: Chapter 2 reviews the related published research and summarizes them in form of literature review. Chapter 3 identifies the design and methods of this study. Chapter 4 presents the results and recommendations of this research. Finally, Chapter 5 provides the conclusions and recommendations.

CHAPTER 2: LITERATURE REVIEW

In this research, pertinent literature was reviewed that related to NII technologies for the inspection of cargo coming into U.S. seaports, including 1) Existing technologies used in U.S. Ports, and 2) New NII inspection technologies.

2.1 Existing Technologies Used in US Ports

Currently, the United States Customs Ports have an existing system of detection which can be improved upon. The existing Radiation Portal Monitors (RPM) can detect gamma rays or neutrons emitted by nuclear materials, but it can only detect unshielded nuclear material, meaning it cannot distinguish the difference between false radioactive materials such as a banana or actual potassium, leading to a false alarm, thus causing delays. However, these conventional radiation-detection technologies cannot differentiate between threat objects and naturally occurring radioactive material (NORM), which could lead to high non-detection rates. In order to acquire detailed information about a suspect cargo that emits radiation, the suspect cargo must undergo a secondary inspection, where CBP officers will examine it with a handheld Radioisotope Identification Device (RIID). RIID can identify whether the source is a NORM, a threat object, or other radiopharmaceuticals used in medicine and industrial radiation sources. However, the process would delay the cargo by five to 15 minutes or more, which would affect the throughput of the ports. In addition, if the nuclear materials are shielded by rock or heavy metal, the conventional radiation detector would not be able to detect the nuclear materials. According to the Government Accountability Office the radiation portal monitors cost approximately $12,000 per year to operate and maintain.

2.2 New NII Inspection Technologies

The newer technologies offer more as far as reduction in non-detection rate and better detection and distinction of nuclear materials. The ones reviewed by this study include Advanced Spectroscopic Portal (ASP), Muon Radiography (MR), and Pulsed Photonuclear Assessment (PPA), and Passport System (PS).

The ASP system uses both gamma ray detectors and neutron detectors. ASP radiation detection technology has a very low non-detection rate and is able to detect hazardous nuclear material in less than 10 seconds. It can distinguish between threat objects and NORM and can function well under different amounts of natural background radiation, environmental stress, and different weather conditions. The newly available ASP radiation detection technology can be a good solution for the high non-detection rates, problem as mentioned by Raytheon (2006). It is able to sense nuclear materials by detecting the radiation emitted from cargos in less than 10 seconds, confirmed by Harbison (2009). It can distinguish between threat objects and NORM and can function well under different amounts of natural background radiation, environmental stress, and different weather conditions. Shea et al. (2009) introduced the ASP) program, which was viewed as the next-generation replacement for the existing RPMs) program for detecting nuclear materials. However, the potential increase in operational effectiveness of ASP program has yet to be identified. The following figure shows the application of ASP in cargo inspection:

Figure 1 Advanced Spectroscopic Portal (ASP) radiation detector
(Source: Raytheon, 2006)

This system employs thallium-activated sodium iodide detectors as the gamma ray detectors, which is different from polyvinyl toluene based plastic scintillation detectors that are currently used in radiation detection systems. The sodium iodide detectors are able to distinguish between threat objects and NORM. According to The National Research Council of the National Academies (2009), for neutron detectors, the non-detection rates will be low, since very few materials can emit neutrons and almost all of them are of security interest.

The ASP system is now under testing and evaluation. Shea et al. (2009) have examined the previous test results and have shown that using ASP as the secondary inspection system can significantly decrease the cargo inspection time. However, the ASP system is more expensive than the currently utilized radiation detection systems. The cost of the ASP program, analyzed by the Government Accountability Office (GAO), would be $3.1 billion for the previously planned full deployment of about 1,400 systems at land and sea ports of entry. According to Raytheon (2006), the system can be moved by vans and SUVs. The deployment cost covers all costs related to acquisition, design, maintenance, and so on. The purchase price of ASP is $377,000 per unit as listed by the GAO. The GAO expects ASP maintenance costs to be between $65,000 and $100,000 per year per unit.

Jones et al. (2005) studied PPA inspection technology developed primarily to detect shielded materials, especially highly enriched uranium (HEU), in less than 60 seconds. The nuclear materials undergo photofission and generate prompt/delayed neutrons and gammas. Thus, the presence of nuclear materials can be determined through the analysis of delayed neutrons and photons between accelerator pulses. This technology has almost 0% non-detection rate, which is the highest of all the technologies used in the study. PPA is also mobile by truck. Figure 2 shows the PPA system.

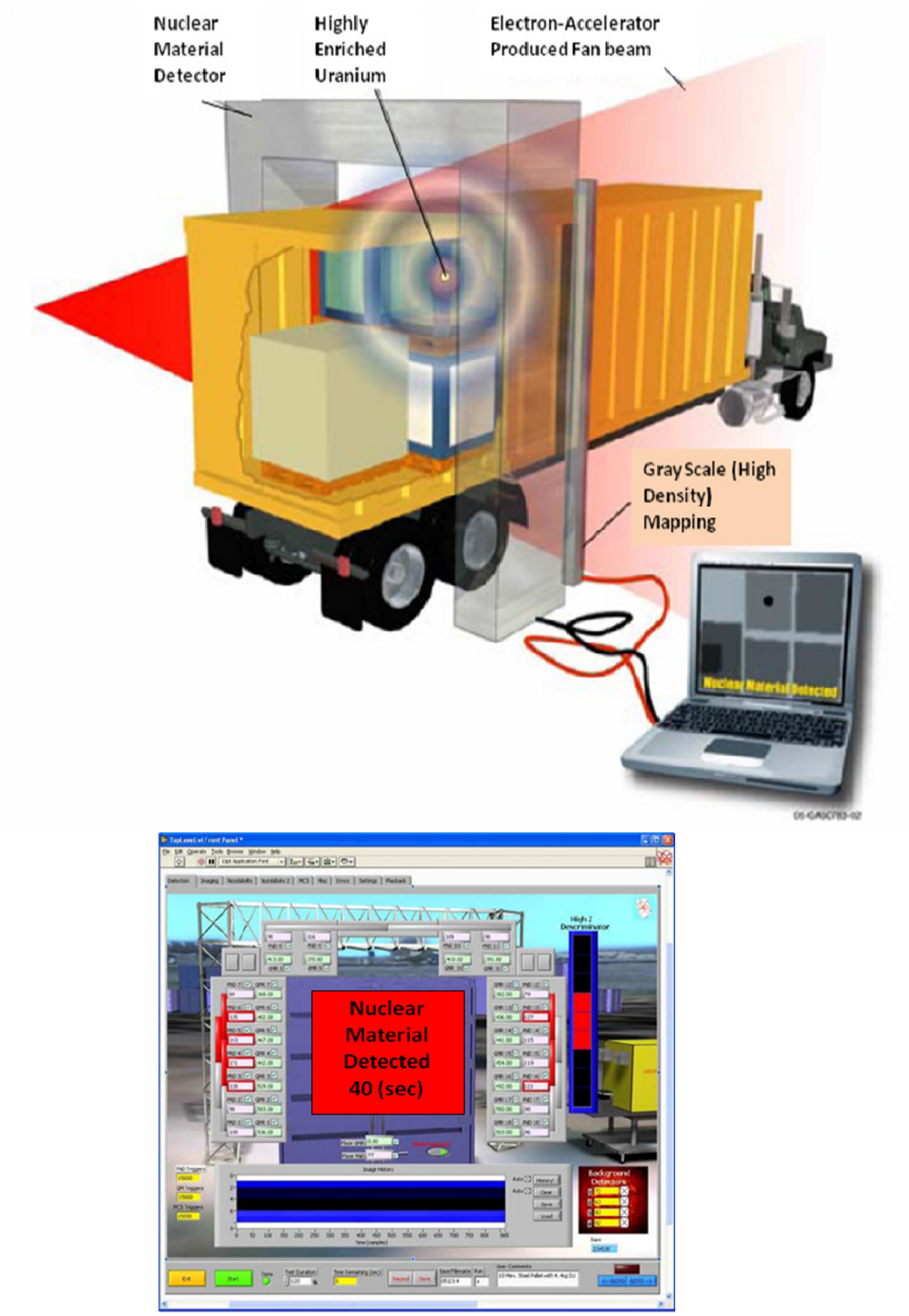


Figure 2 Pulsed Photonuclear Assessment (PPA) Cargo Inspection System
(Source: Jones et.al 2006)

The MR detector is able to detect shielded and unshielded nuclear materials within 20 to 60 seconds with less than a 3% non-detection rate. It does this by penetrating lead or other heavy shielding in truck's trailers or cargo containers to detect uranium, plutonium or other dense materials. Fishbine (2003) noted that MR can detect shield nuclear materials because 1) Cosmic-ray muons are energetic enough to pierce thick rock or heavy metals, and 2) nuclear materials have a large number of protons and tightly packed nuclei, which cause the nuclear material to produce stronger electromagnetic forces and deflect muons of more than less dense materials such as steel, aluminum, or plastic. In addition, MR technology is far more sensitive than x-rays. Furthermore, it causes none of the radiation hazards of x-ray or gamma-ray detectors. The rate of false positives and false negatives for the MR detector is less than 3%. The following figure shows a MR inspection system:

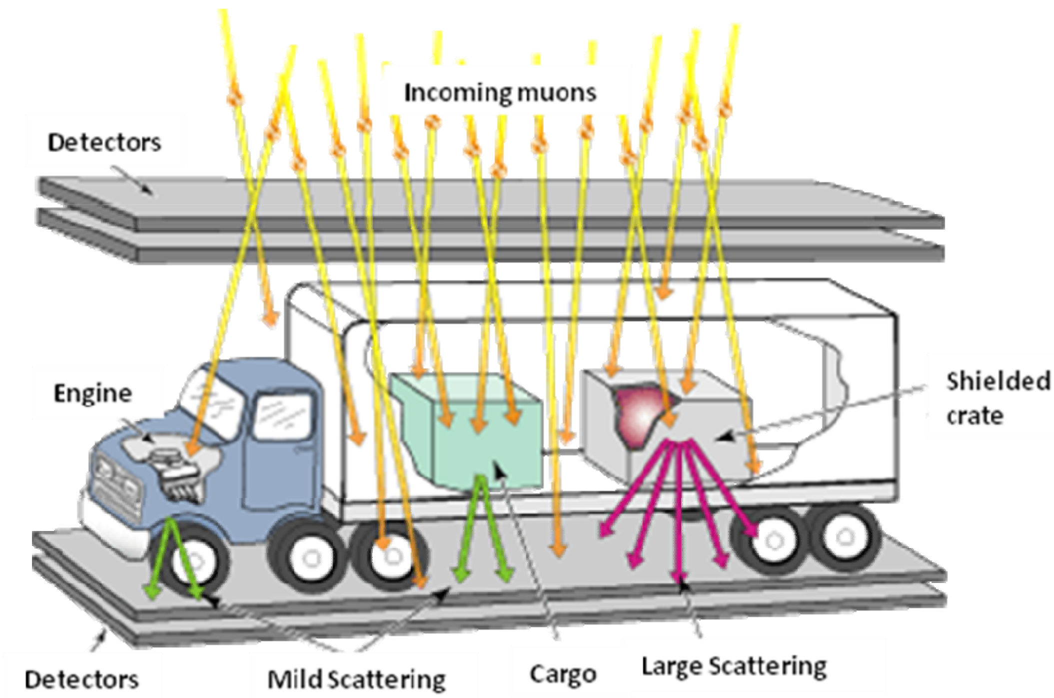


Figure 3 MR Inspection
(Source: http://commons.wikimedia.org/wiki/File:Muon_Radiography.gif)

Lastly, the PS detector can detect a wide range of illegal materials, including weapons, nuclear materials (shielded and unshielded), drugs, and so on. According to the Passport Systems Company (2009), the PS system is efficient enough to be used as a secondary method because of its very low detection time of less than 15 seconds to generate an alarm and less than two minutes to locate the contraband. By using deeply penetrating photons and detectors, it can determine the elemental content of the cargo – literally, what the cargo is made of. Because it relies on elemental information to determine the contents of the cargo, if dangerous materials are present, it can recognize them automatically by comparing their chemical characteristics against a known database. Additionally, there is a very low non-detection rate of less than one percent. The PS is able to detect weapons of mass destruction (WMD), toxic substances, nuclear materials, high-atomic-number shielding materials, high-energy explosives, most classes of economic contraband, and other hazardous materials. PS can also provide detailed information about the elemental composition of the inspected cargo items and can provide immediate alerts of suspect materials without waiting for image analysis. In addition, the system can create a 3D map identifying all the contents of the container, which can make locating the contraband quick and efficient. According to the PS systems manufacturer, the initial purchase price of the PS system is estimated at five million dollars and the operation and maintenance costs are estimated to be approximately $75,000 per year.

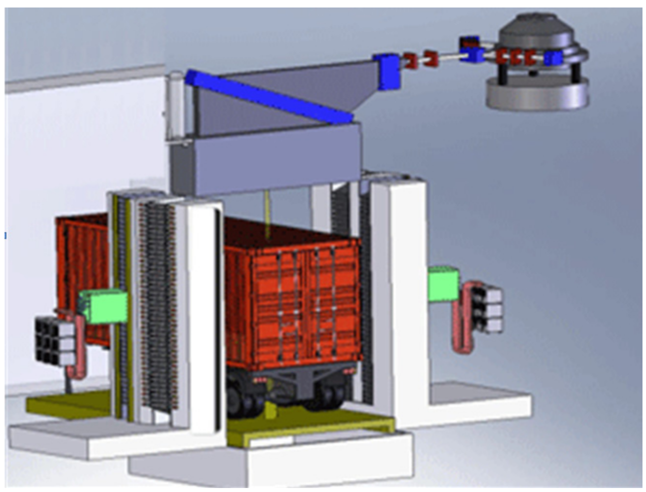


Figure 4 PS Inspection
(Source: http://www.passportsystems.com/howitworks.htm)

PS consists of two complementary technologies: Nuclear Resonance Fluorescence (NRF) imaging and EZ-3DTM. NRF can unambiguously determine the detailed information about the elemental composition of the inspected cargo items by analyzing the isotopic composition of the cargo items. It uses high-energy photons to excite nuclei in order to prompt materials to emit photons across an emission spectrum, by which it can accurately analyze the isotopic composition of the cargo items. EZ-3DTM is a unique technology that is developed and patented by PS for mapping cargo containers in 3-D. The PS instantaneously classify the container's contents by atomic number and mass, and then it automatically alerts the presence of suspect cargo and its location.

The PS can provide affordable cost of operation and ownership, and it can generate alarms in less than l5 seconds and locate the suspect materials in less than two minutes with a non-detection rate of less than 1%.

2.3 ARENA

Rountree and Demetsky (2004) developed the discrete-event Arena simulation model to evaluate the capabilities of different technologies for the inspection of airport cargo. The Arena simulation model was based on the information collected about the general procedure of cargo inspection in U.S. airports. Based on the results of this study, it was found that the Arena simulation software package is the easiest to use and the most economical software package available for simulating the flow of cargo.

2.4 Summary

These NII technologies all have their strengths in at least one specific aspect compared with existing technologies, which are all listed in Table 1:

1) Compared with existing radiation detection systems:
    - ASP can detect nuclear materials with only less than 0.1% non-detection rate by distinguishing threat objects from NORM;
    - PPA can detect shielded nuclear materials;
    - MR detector is able to detect shielded nuclear materials without causing radiation hazards to inspection personnel.
2) Compared with existing imaging based technologies:
    - PS can provide detailed information about the elemental composition of the inspected cargo items and can provide immediate alerts when it detects suspect materials without waiting for image analysis. In addition, the system can create a 3D map identifying all the contents of the container, which can make locating the contraband quick and efficient.

- ASP can replace traditional radiation detection systems as the primary inspection system for detecting nuclear materials.
- PPA or MR systems can be used to detect shield nuclear materials after the detection of ASP.
- PS can replace traditional x-ray or gamma ray imaging systems as the secondary inspection system to detect different types of contraband.

Table 1 List of NII Technologies

	Category	NII technologies	Cost	Screen for	Inspection time	Non-Detection Rate	Material description	Installation
Primary Inspection	Detecting nuclear materials	Existing RPMs	$55,000	Nuclear materials (unshielded only)	In seconds	2%	No	Fixed
		Existing RIID	~$20,000	Nuclear materials (unshielded only)	5 to 15 minutes	<0.1%	Yes	Handheld
		ASP	$377,000	Nuclear materials (unshielded only)	<10 seconds	< 0.1%	Yes	Mobile by vans or SUVs
		PPA	Relatively low	Nuclear materials (shielded and unshielded)	< 60 seconds	~0%	No	Mobile by truck
		MR	$1 million	Nuclear materials (shielded and unshielded)	20-60 seconds	<3%	No	Mobile by a tractor trailers
Secondary Inspection	Detecting elemental composition and Images	Existing X-ray systems	$1 - 10 million	WMD, explosives, nuclear materials, drugs, and so on	2-5 minutes	<2%	No	Fixed or mobile by vans or SUVs
		NELIS	Relatively low	Explosives, Illicit drugs	<5 minutes	Low	Yes	Mobile by truck
		TNIS	< $1,000	Explosives, illicit drugs,	10 minutes	Low	Yes	Portable as a small brief case
		PS	Relatively low	WMD, explosives, nuclear materials, drugs, and so on	<15 seconds to generate alarm < 2 minutes for locate the suspect materials	<1%	Yes	NA

CHAPTER 3: DESIGN OF THE STUDY

The overall design of this research is depicted in this chapter. To achieve the objective of this research, i.e. develop the guidelines for selecting technologies, building models, and simulation, the design of the study mainly focused on three aspects: 1) methods and 2) techniques and tools.

3.1 Methods

The research objectives are to compare the capabilities and the costs of the NII technologies. Based on the comparison results, it will provide recommendations about the most cost-effective and efficient combinations of NII technologies that can detect a wide range of contraband to protect the US ports. For this purpose, three approaches have been used; literature review, interview and the simulation based study. The literature review is introduced in Chapter 2. The following is the description of the interview and the simulation based study methods.

3.1.1 Interview

To understand the general screening process that is used by U.S. CBP, an interview was conducted with a CBP officer in November 2010. Questions, which were critical to our study, were asked that pertained to the screening process and daily activities of the Port of Houston. The list of questions that were asked during the interview is presented below:

- What percentage of containers goes through a primary method of screening?
- What percentage of containers goes through a secondary method of screening?
- What is the average wait time for a container?
- How long does it take for one ship to unload and be screened?
- How many containers go through the port annually?
- How many containers are physically inspected?
- What is the capacity for the port?
- What do Custom Border Officer’s look for during preliminary inspection?
- How are exports inspected?

3.1.2 Simulation Based Study

A discrete-event simulation tool, ARENA, was used to simulate the inspection procedure. Three simulation cases were generated for evaluating the effectiveness of three different NII combinations. Each case had a primary method of inspection in which all incoming cargo must be checked. Then, if the cargo was not detected through the primary mode of inspection and was shielded, it proceeded to a secondary inspection method for further screening. If it was not shielded, only a small percentage (X%) proceeded to the secondary inspection. Also, all suspicious importers, meaning, first time importers, shippers who did not provide proper ship manifests prior to docking or to the CBP's liking proceeded to secondary inspection. It was estimated that 80% of the carriers of weapons and explosives are suspicious importers. The 80% estimate was based on the field interview of the CBP officers and their experiences with various importers and incoming cargo containers that are suspicious. Finally, all cargo was cleared after both secondary and random inspections. See Figure 5 for the general inspection process:

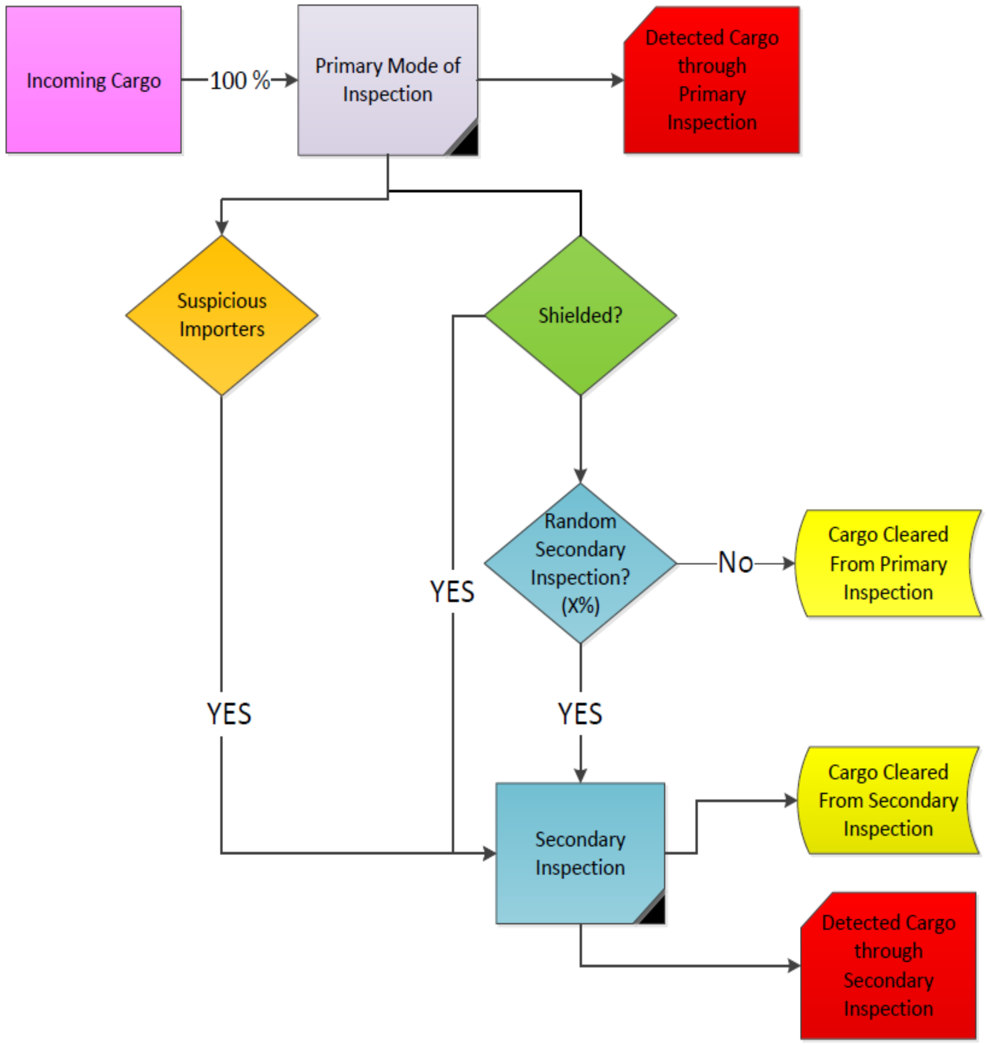


Figure 5 Cargo Inspection Flow Chart

The data that will be collected are total processing time and detection rate. These data will be analyzed to make recommendations on the most effective combination based on time and cost. A discrete-event-based simulation model will be built and replicated 15 times each for 10 hours a day for five years for each model and derive the performance measures in minutes.

Table 2 Evaluation of Screening Methods

Screening Method	Simulate?	Reason for Not Simulating
Existing RPMs	Yes	--
Existing RIID	Yes in Combination W/ Existing RPMS	--
ASP	Yes	--
PPA	No	More information needed
MR	No	High non-detection rate
Existing X-ray systems	Yes	--
NELIS	No	Does not detect WMD
TNIS	No	Long Detection Time (10 minutes)
PS	Yes	--

Table 2, evaluates all the screening methods available to the U.S. Ports for the future simulation based study. Based on the current practices and literature review, three combinations of NII inspection technologies that were chosen for simulation are listed in Table 3. The selection of these combinations is based on different factors, including items screened for, detection time, non-detection rates and costs.

Case 1 is the current practice at the ports. It uses existing RPMS and existing RIID as the primary method of inspection and existing X-ray systems as the secondary method of inspection. This combination is relatively low in cost and somewhat quick in detecting hazardous materials. However, 15 minutes to fully detect hazardous material is too long, which results in high costs to shippers and consumers. Also, the existing RPMS/RIID technology can only detect unshielded nuclear materials and weapons, and, if the cargo does not proceed to the secondary method of screening, shielded nuclear material may not be detected. The existing X-ray systems can detect, for example, Weapons of Mass Destruction (WMD), explosives, nuclear materials, and drugs, but only a certain percentage of the cargo will proceed to the secondary inspection. Additionally, the existing X-ray systems can take up to five minutes to detect hazardous material. The existing RPM and existing RIID were chosen as the primary methods of inspection primarily based on cost and their currently use in the field. Therefore, it is a good baseline measure.

Case 2 uses existing RPMs and existing RIID as the primary methods of inspection and a new technology called PS as the secondary method of inspection. This combination was chosen based on the high detection rate and shortened detection time of the PS system. The PS system can detect WMD, explosives, and nuclear materials, which is critical for screening methods, especially considering that it takes less than 15 seconds to generate an alarm and less than two minutes to detect hazardous material.

Case 3 is a combination that uses a new technology called ASP as the primary method of inspection and existing X-ray systems as the secondary method of screening. ASP can detect both unshielded and shielded nuclear materials very quickly, requiring less than 10 seconds to generate an alarm. This is very beneficial as a primary method of screening because it would save time, and less cargo would have to go through the secondary method of inspection. Additionally, ASP offers a very high detection rate (>99.9%) and it is the only combination that is fully mobile and is handheld for inspection.

3.2 Techniques and Tools

Each NII technology will be evaluated in combination with other technologies to determine which technologies results in the lowest cost and time required, as well as greatest detection coverage of various threat materials. In order to accomplish this task, simulation will be used for the NII combinations.

- ARENA 7.1 is discrete event simulation software simulation and automation software. In Arena, the user builds an experiment *model* by placing *modules* that represent processes or logic. While modules have specific actions relative to entities, flow, and timing, the precise representation of each module and entity relative to real-life objects is subject to the modeler. Statistical data, such as cycle time and work in process (WIP) levels, can be recorded and outputted as reports. The simulation package selected for modeling this case study was ARENA, a commercially available modeling tool. ARENA provides the modeling elements for defining the entities and their attributes, logical connections between activities and their resource requirements, required animation to simulate the traffic system at the bridge, and automated statistics reduction.

    - The models will be run for simulation for a replication of 15 times for duration of 10 hours a day for five years for each of the three combinations.

- The outputs will be then exported to Microsoft Excel for analysis. Microsoft Excel is one of the most widely used computer software in data analysis. In this research, this software will be used to assist in the calculations of average and total queue times, waiting time, processing time, non-detection rate, and detection rate, etc. for each of the combinations.
- SPSS is a computer statistics program for data management and analysis. SPSS will be used in the research to determine the simulation sample size and compare the simulation results.

Table 3 Experimental Screening Combination Methods

	Method		Initial Cost		Maintenance Cost		Screen for		Time		Detection Rate	
	Primary	Secondary	Primary	Secondary	Primary	Secondary	Primary	Secondary	Primary	Secondary	Primary	Secondary
Case 1 (Base Case)	Existing RPMs	Existing X-ray systems	$55,000	$1 - 10 million	$12,000/ year	$75,000/ year	Nuclear materials (unshielded only)	WMD, explosives, nuclear materials	seconds	2-5 minutes	98%	>98%
	Existing RIID		~$20,000				Nuclear materials (unshielded only)		5 to 15 minutes		>99.9%	
Case 2	Existing RPMs	PS	$55,000	Relatively low *	$12,000/ year	N/A*	Nuclear materials (unshielded only)	WMD, explosives, nuclear materials	seconds	<15 seconds to generate alarm	98%	>99%
	Existing RIID		~$20,000				Nuclear materials (unshielded only)		5 to 15 minutes	2 minutes for locate the suspect materials	>99.9%	
Case 3	ASP	Existing X-ray systems	$377,000	$1 - 10 million	$65,000 - $100,000 /year/unit	$75,000/ year	Nuclear materials (unshielded/ shielded)	WMD, explosives, nuclear materials	<10 seconds	2-5 minutes	>99.9%	>98%

Note: *: PS is not on the market yet, so the cost is estimated based on the information collected from PS representative

CHAPTER 4: RESULTS

In this chapter, the results from the field interview and the simulation based study will be discussed in detail.

4.1 Results of the Field Interview

In order to understand the screening process via CBP Officers, an interview was conducted with a CBP officer in November 2010. We asked questions that were pertinent to the screening process and daily activities of the Port of Houston, such as the percentage of containers that go through a primary method of screening and the percentage of containers that go through a secondary method of screening. Additionally, it was critical in our study to ascertain the average wait time for a container, how many containers go through the port annually, how many containers are physically inspected, and the capacity for the port and how exports are inspected, amongst other topics. The following is the information collected through this interview:

- As of the summer of 2010, the average daily capacity for the Port of Houston terminal was 2500 cargo boxes.
- The current capacity is only at 30%, which, in the CBP's opinion, leaves room for expansion.
- The current inspection procedure at the Port of Houston is as follows:
    - All cargo must go through the RPM detection system, whereas only a few container boxes go through actual physical inspection, and a small percentage goes through a secondary method of screening.
    - The port receives a manifest of all incoming cargo and only select cargo is inspected before leaving the terminal.
    - All containers go through RPM inspection when they exit the Port for export.
    - A small percentage of cargo containers are opened for physical inspection, which includes a small percentage of agricultural containers that are opened for physical inspection, after which the containers are returned to the customer.

- It was noted that all cargo goes through the primary inspection. All CBP officers are trained to supervise incoming cargo and immigration for crew members aboard the ships.
- It is the CBP officer's discretion for which cargo goes through additional physical inspection in addition to the cargo that sets off alarms.
- First time importers are checked more thoroughly, along with shippers who provide an incorrect manifest.
- Shipments are randomly scanned. Exports require 24 hours to be loaded and cleared through security.
- A clear manifest must be provided in which the files are reviewed for red flags and incomplete items. Red flags can delay shipments, and are checked again with a scoring system and cleared after being scanned.
- CBP officers estimate that the existing screening process of both primary and secondary inspection takes approximately 30-35 minutes, which includes manual screening as well.

4.2 Simulation Based Study

The models were built in Arena 7.1, and then simulation process began. A pilot simulation was conducted with 15 simulation runs and a sample size of 30. Equation (1) was used to determine simulation sample size, n, with a 95% confidence interval, standard deviation, σ, and a margin of error of 1% for the detection rates and 30 seconds for the total inspection times. Based on the pilot 15 simulation runs, the minimum required sample sizes, i.e. n, for different simulation scenarios were, all less than or equal to 10. It was then determined that each model would run for a course of five years for validity of the study. Therefore, the 15 simulation runs is adequate for this study.

$$n = 1.96^2\ \sigma^2/\varepsilon \qquad (1)$$

where ε is the margin of error and is equal to 1% for the estimation of detection rate and is equal to 0.5 minutes for the estimation of processing time

Additionally, 100% primary inspection percentage is selected due to CBP's official regulations that all cargo containers incoming must go through inspection upon arrival at the port. The random secondary inspection percentage, X%, shown in Figure 5 was chosen based on information gathered during the field interview. It is noted in the field interview results, that CBP offers mentioned that a small percentage of cargo goes through random secondary inspection; based upon this information, 3%, 5%, and 10% were chosen as the standards of random secondary inspection as small feasible percentages. These numbers are believed to be realistic after conducting preliminary test runs of the simulation model as well.

The number of units of cargo that are put in daily is an important number because it determines the amount of cargo that can ultimately be detected by the various NII technologies being studied. The percentage of hazardous cargo is believed to be low as discussed by CBP officers during the field interview. The total numbers of hazardous items input on a daily basis are two explosives, two shielded nuclear materials, two unshielded nuclear materials, and two weapons, with 300 incoming normal safe cargo containers, so roughly 3% of the daily incoming material is hazardous.

4.3 Simulation Results

The simulation results are presented in Tables 4, 5, and 6 and Figures 6, 7, and 8. Table 4 compares all the cases and their capabilities in detecting different hazardous materials by type and lists the detection rate for each material as well as the total detection rate. Table 5 is the Queue Wait Time (in minutes) table which compares all the different queue times between all the different cases. Queue time is the time a cargo waits while it is waiting to be screened. This time is included in the Total Processing Time. Table 6 is The Processing Time per Cargo (in minutes) table at the 3% secondary inspection level which is the total amount of time that it takes for one cargo to go through the complete screening process from start to finish. This included the queue time. It also accounts for both the primary and secondary method of screening. Table 8 gives an overall cost comparison of cost while looking at the main factors of the cases, detection rate, and queue time.

Figure 6 compares the detection rate for all the cases at all secondary inspection levels. It is a progression, where Case 1 is the least, then Case 2, and then Case 3 with the highest detection rate of 89.32%, which will be further discussed. Figure 6 compares the detection rate for all the cases as they went through only 5% secondary inspection. Figure 6 also compares the detection rate for all the cases as they went through only 10 % secondary inspection. Figure 7 is a queue time (in minutes) comparison for 3%, 5% and 10% secondary inspection levels where the queue times vary greatly from Cases 1 and 3 and Cases 2 and 3. Figure 8 represents the total processing time (in minutes) for 3%, 5% and 10% secondary inspection levels. The significance lies in the difference for Case 3, as it has the least amount of time, and will be discussed further. Figure 8 is the total processing time for all the cases categorized by 3%, 5%, and 10% secondary inspection levels. It can be seen that as the secondary inspection is increased, the total processing time is also increased regardless of the case.

4.4 Simulation Discussion

Case 1 is the case that is in current practice - Existing RPMs/RIID and Existing X-rays. When tested, the hypothesis was that it would be the slowest and most ineffective, and while the test results show that it is comparable in terms of detection rate, only 0.57% less than the best detection case in this study. As seen in Table 5, the overall detection rate was 88.75%. However, the Queue Time of 9.77 minutes and Total Processing Time of 23.44 minutes are very high, as seen in Table 6 and Table 7, respectively and do not make up for this matter. If Case 1 were to be used for 5% secondary inspection, the Total Processing time would be 24.12 minutes, Figure 8, which is a little over one full minute longer than what is in current practice or 0.03% more. Therefore, it is not a good choice when there are newer technologies available.

Case 2 uses Existing RPMs/RIID and Existing X-rays as the primary method of screening which is beneficial for cost, and uses the newer technology PS as the secondary method of screening. This combination proves to be better than Case 1, but only slightly, with an overall detection rate of 89.07 %, as seen in Table 5. The Total Processing Time for Case 2 is 20.24 minutes which is 0.14% less than Case 1. The Queue Time for Case 2 is 8.83 and can be found on Table 6. Additionally, by increasing the secondary inspection to 5%, the detection rate increases to 89.65% which can be found in Figure 6, however the Total Processing Time increaseed to 20.41 minutes, or a 0.01% increase which can be found in Figure 8. When the secondary inspection in this case is increased to 10% the detection rate is 89.78%, Figure 6, and the Total Processing Time increased to 20.55 minutes, or a 0.01% increase, which can be found in Figure 8. From 3% to 10% secondary inspection, there was only a 0.02% increase in time, almost less than thirty seconds. The detection rate was increased by 0.71%, more than 0.5%. This is a slight trade-off in time and is well worth the detection rate increase. This shows that by using a newer technology, time is saved in detection and more cargo may be inspected.

Case 3 uses a new technology as the primary method, ASP and the Existing X-rays as the secondary method of screening. This combination is by far the best method of screening in all aspects. The overall detection rate is 89.32%, as seen in Table 5. The Total Processing Time is the lowest of all the cases, at only 5.58 minutes and the Queue Time is 1.86 minutes, as seen in Figure 8 and Figure 7. This shows that using a newer technology that detects both shielded cargo in the primary method will save detection efforts in the secondary screening process. Also, because ASP's detection time is so fast, it could be possible to send more cargo through the secondary method of screening, thereby screening more cargo for such things as WMD and explosives. This by far is the best combination tested.

Table 4 Overall Detection Rates for 3% Secondary Inspection

	Case 1 Existing RPMs/RIID & Existing X-rays			Case 2 Existing RPMs/RIID and PS			Case 3 ASP and Existing X-rays		
	Detected Cargo	Number of Cargo in by Type	Detection Rate	Detected Cargo	Number of Cargo in By type	Detection Rate	Detected Cargo	Number of Cargo in By Type	Detection Rate
Explosive	582	734	79.32	592	746	79.36	584	732	79.78
Shielded Nuclear Materials	725	736	98.47	741	748	99.06	710	723	98.20
Unshielded Nuclear Materials	733	749	97.92	724	740	97.84	729	730	99.86
Weapons	553	703	78.64	583	730	79.86	595	746	79.76
Total	2593	2922		2640	2964		2618	2931	
Total Detection Rate			88.75%			89.07%			89.32%

Table 5 Total Queue Wait Time 3 % Secondary Inspection (Minutes)

	Existing RPMs/RIID and Existing X-rays		Existing RPMs/RIID and PS		ASP and Existing X-rays	
		Waiting Time		Waiting Time		Waiting Time
Primary	Existing RPMs	7.73	Existing RPMs	7.10	ASP	0.63
Secondary	Existing X-Rays	2.04	PS	1.73	Existing X-Rays	1.23
	Total	9.77		8.83		1.86

Table 6 Total Processing Time Per Cargo 3 % Secondary Inspection (Minutes)

Time in minutes	Case 1		Case 2		Case 3	
		Average		Average		Average
Primary	Existing RPMs	17.89	Existing RPMs	17.30	ASP	0.80
Secondary	Existing X-Rays	5.54	PS	2.94	Existing X-Rays	4.78
	Total Time	23.44	Total Time	20.24	Total Time	5.58

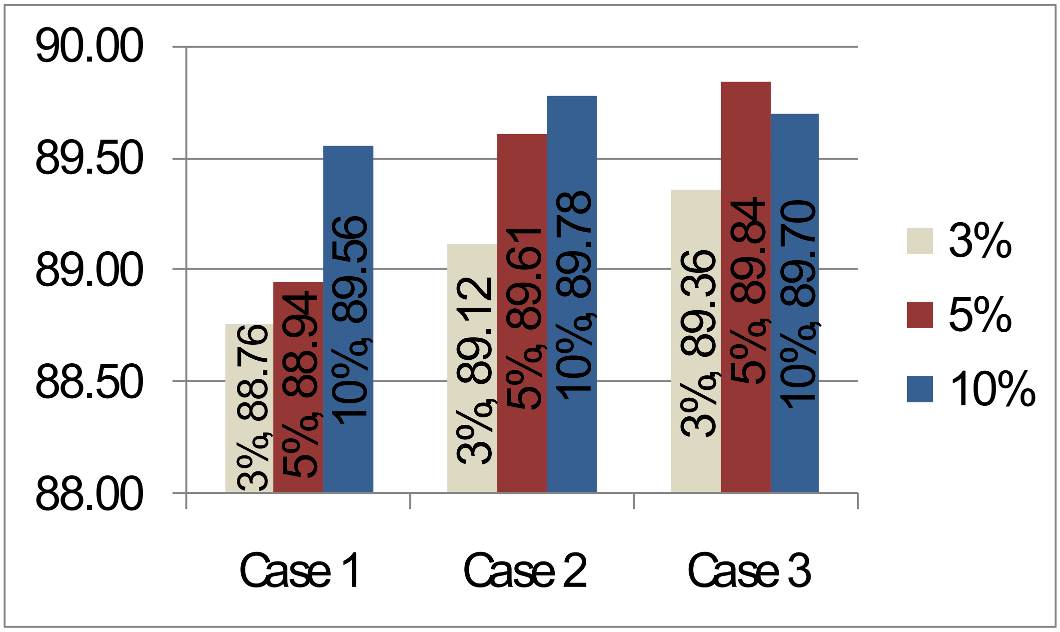


Figure 6 Detection Rate for all Secondary Inspection Levels

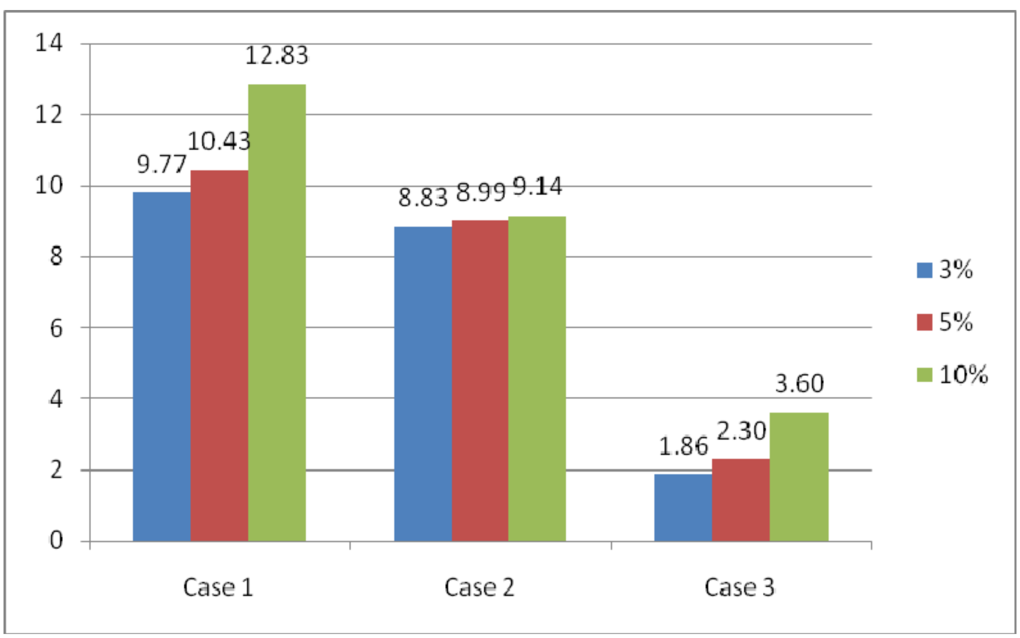


Figure 7 Queue Time (mins) for all Cases by Comparison for all Secondary Inspection Levels

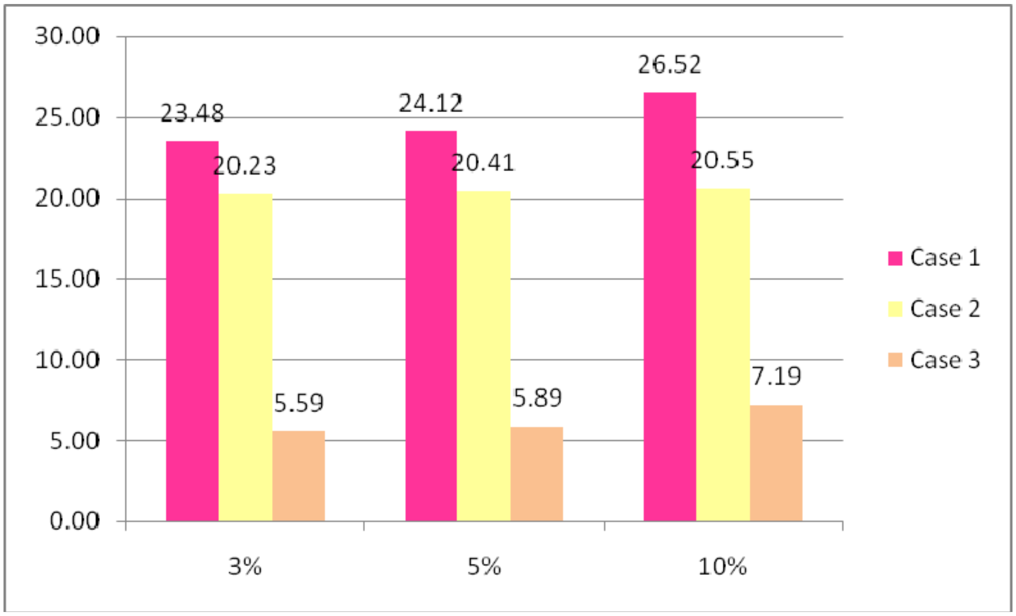


Figure 8 Total Processing Time (mins) for all Cases By Comparison for all Secondary Inspection Levels

4.5 Summary of Preliminary Results

For Case 1) Existing RPMs/RIID and Existing X-rays:

- It is in current practice at many U.S. Ports and was used as a standard.
- It has the lowest detection rate and the longest Queue time and Total Processing Time.
- Based on the results above, Case 1 is not the most effective but is the least expensive combination in this study, in both initial purchase price and maintenance costs.

For Case 2) Existing RPMs/RIID and PS

- Case 2, though it also employs the Existing RPMs, it is used in conjunction with the PS systems which detects more hazardous materials in a shorter amount of time, as noted in Table 3.
- The Queue time and Total Processing Times for the PS is less than the Existing X-rays, making it a better choice as a secondary method of screening.
- There is a higher detection of shielded nuclear materials and weapons rate through the secondary method of screening, PS.

- This method is more expensive than case 1.

For Case 3) ASP and Existing X-rays

- This case has this highest detection rate of all the combinations of at most levels of secondary inspection rates as noted in Figures 6, 7 and the lowest Queue Time and Total Processing Time for each cargo.
- ASP, as a primary method, is able to detect both shielded and unshielded nuclear materials, which saves times. Therefore, it is not necessary for an excessive amount of cargo to go through a secondary screening method.
- ASP has the highest initial purchase price and the highest maintenance cost of approximately $100,000 per year.

4.6 Statistical Analysis

To compare detection rates and total processing times further for the different cases, the statistical T-test was conducted by using the 15 samples generated by the 15 simulation runs. The T-test analysis is a statistical tool used to compare the relationship between two means to determine whether a significant difference exists between them. In this study, all T-tests were conducted using a 90% confidence interval.

- The T-test results for detection rates comparison are presented in Figure 13. The T-test results for total processing time comparison is presented in Figure 14.
- Table 9 is an overview of Case 1, Existing RPMs/RIID and Existing X-rays, and detection rate. When broken down by each individual replication it can be seen that it increases with each increase in Secondary Inspection percentage.
- Table 10 shows Case 2, Existing RPMs/RIID and PS, detection rate by replication for each secondary inspection percentage. The increase in detection rate can be seen as more cargo is allowed through the secondary inspection.
- Table 11 shows Case 3, ASP and Existing X-rays, detection rate by replication for each secondary inspection percentage. The increase in detection can be seen from 3% to 5% secondary inspection, but since the variance is so low, the lower detection rate for 10% secondary inspection is insignificant.

- Table 12 is an overview of Case 1, Existing RPMs/RIID and Existing X-rays, for Total Processing Time. When broken down by each individual replication, it can be seen that it increases with each increase in Secondary Inspection percentage.
- Table 13 shows Case 2, Existing RPMs/RIID and PS, for Total Processing Time by replication. It can be seen that it increases with each increase in Secondary Inspection percentage, which is discussed further in detail.
- Table 14 shows Case 3, ASP and Existing X-rays, Total Processing Time by replication for each secondary inspection percentage where it can be seen that with each increase in secondary percentage the time also increase.

Table 7 Case 1 Detection Rate by Replication and Various Secondary Inspection Rates

Case 1

Replication	3%	5%	10%
1	88.18	88.08	87.96
2	88.88	88.92	90.14
3	89.22	89.10	90.03
4	89.24	88.28	89.40
5	88.45	89.07	89.03
6	88.63	89.09	89.84
7	88.83	89.08	89.68
8	88.37	89.36	89.91
9	89.54	87.88	90.08
10	88.85	90.07	89.88
11	89.74	88.91	90.08
12	88.14	89.52	88.10
13	87.99	89.88	89.76
14	88.44	88.96	89.45
15	88.90	87.94	90.01
Averages	**88.76**	**88.94**	**89.56**

Table 8 Case 2 Detection Rate by Replication and Various Secondary Inspection Rates

Case 2

Replication	3%	5%	10%
1	88.571	90.014	90.024
2	89.832	89.734	90.317
3	89.516	88.863	89.071
4	88.644	90.818	89.936
5	88.449	90.144	89.819
6	88.840	89.204	90.060
7	88.580	89.364	90.189
8	89.819	88.182	90.047
9	89.902	89.658	89.559
10	88.959	89.787	90.028
11	89.232	89.880	88.951
12	88.245	89.252	88.819
13	89.871	89.454	90.338
14	88.936	90.226	89.646
15	89.370	89.501	89.903
Averages	**89.118**	**89.605**	**89.780**

Table 9 Case 3 Detection Rate by Replication and Various Secondary Inspection Rates

Case 3

Replication	3%	5%	10%
1	89.007	88.411	90.400
2	89.550	90.385	89.385
3	90.094	89.042	89.857
4	89.204	90.798	89.882
5	88.580	89.343	89.802
6	89.717	89.509	89.424
7	88.349	90.085	90.169
8	88.768	90.804	88.986
9	89.281	89.251	89.616
10	90.382	90.373	90.303
11	89.823	90.135	90.041
12	89.063	89.536	88.580
13	88.551	90.293	89.381
14	90.315	90.447	90.573
15	89.725	89.125	89.079
Averages	89.361	89.836	89.698

Table 10 Total Processing Times (mins) by Replication for Case 1

Case 1			
Replication	**3%**	**5%**	**10%**
1	23.39	23.93	26.42
2	23.53	23.89	27.13
3	23.71	24.10	26.54
4	23.53	24.20	26.41
5	23.39	24.56	26.53
6	23.49	23.84	26.15
7	23.02	24.27	26.76
8	23.33	24.28	26.58
9	23.44	24.15	26.18
10	23.48	24.40	26.62
11	23.51	23.93	26.23
12	23.89	24.01	26.31
13	23.16	24.10	26.79
14	23.56	23.90	26.10
15	23.79	24.33	27.00
Averages	**23.48**	**24.12**	**26.52**

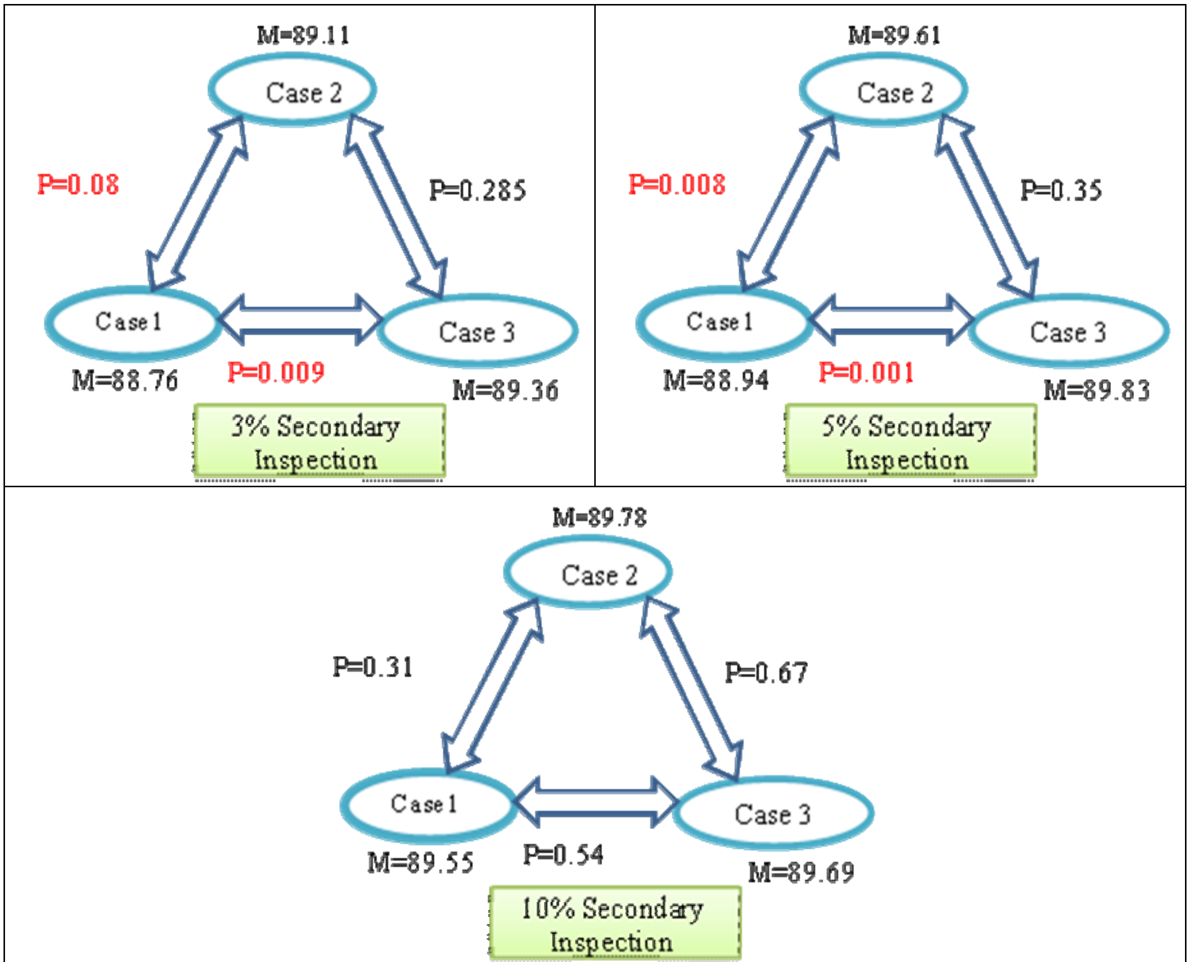
Table 11 Total Processing Times (mins) by Replication for Case 2

Case 2			
Replication	**3%**	**5%**	**10%**
1	20.04	20.44	20.46
2	20.33	20.64	20.84
3	20.16	19.99	20.51
4	20.28	20.69	20.61
5	20.42	20.54	20.55
6	20.25	20.32	20.50
7	20.28	20.41	20.59
8	19.96	20.49	20.32
9	20.16	20.20	20.51
10	20.18	20.55	20.48
11	20.33	20.37	20.36
12	20.33	20.27	20.25
13	20.19	20.29	20.96
14	20.13	20.56	20.55
15	20.39	20.40	20.84
Averages	**20.23**	**20.41**	**20.55**

Table 12 Total Processing Times (mins) by Replication for Case 3

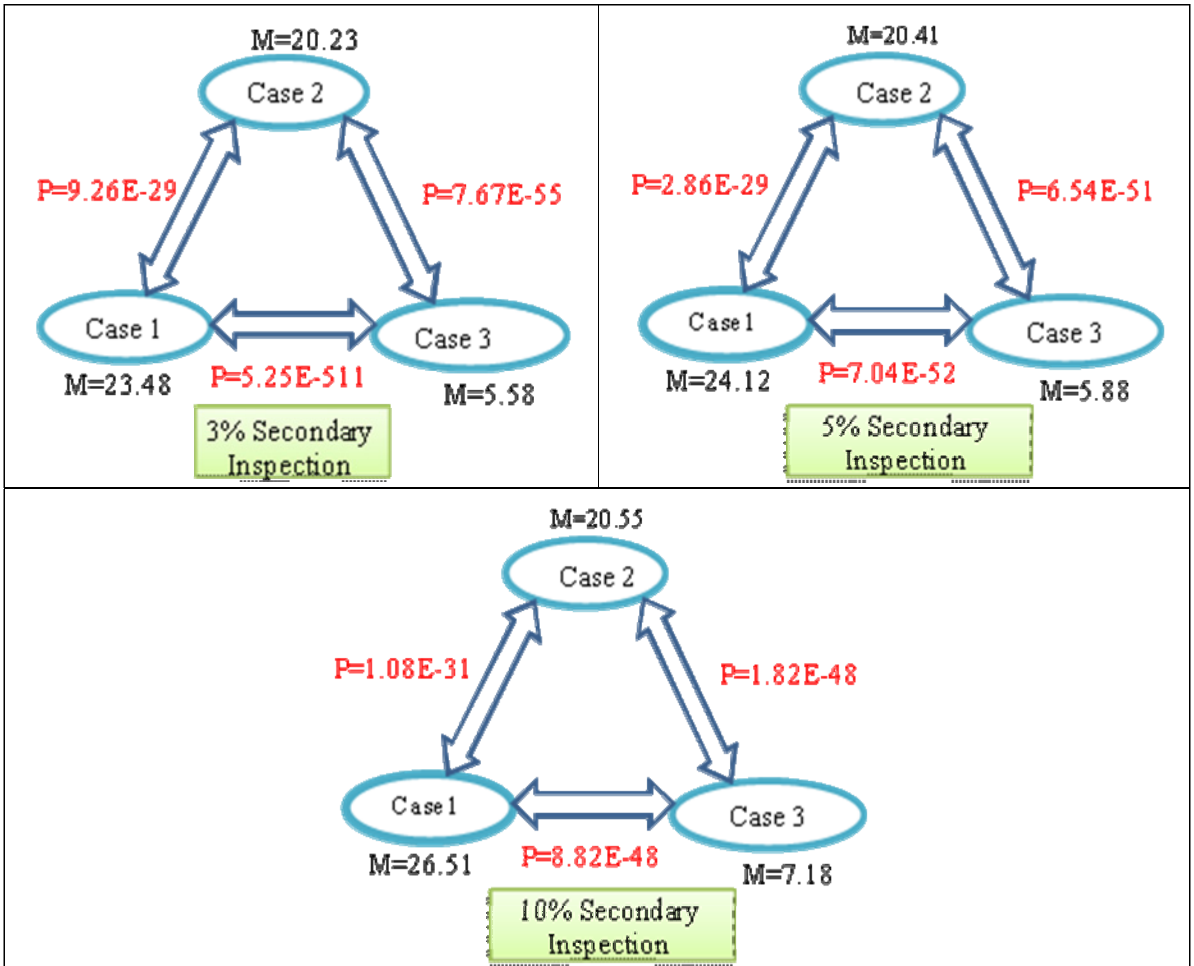
Case 3			
Replication	**3%**	**5%**	**10%**
1	5.62	5.87	7.18
2	5.63	5.88	7.29
3	5.57	5.88	7.20
4	5.61	5.87	7.10
5	5.61	5.88	7.21
6	5.56	5.93	7.17
7	5.58	5.88	7.25
8	5.51	5.89	7.24
9	5.55	5.87	7.10
10	5.57	5.92	7.14
11	5.60	5.90	7.15
12	5.53	5.87	7.26
13	5.61	5.89	7.17
14	5.60	5.86	7.12
15	5.64	5.90	7.25
Averages	**5.59**	**5.89**	**7.19**

The next step is to conduct a t-test to verify compare these cases to see which case is the best fit.



Note: M: Mean of cargo Screened by Case Combination.
P: P-Value of paired T-test, small P-value (<5%) indicates that the difference between means are statistically significant (Marked in red)

Figure 9 Mean and P-Value Comparison for All Cases for Detection Rate by Various Secondary Inspection Rates



Note: M: Mean of cargo Screened by Case Combination.
P: P-Value of paired T-test, small P-value (<5%) indicates that the difference between means are statistically significant (Marked in red)

Figure 10 Mean and P-Value Comparison for All Cases for Total Processing Time by Various Secondary Inspection Rates

4.6.1 Case 1 vs. Case 2

- In Figure 9, Case 2 (Existing RPMs/RIID and PS) has a better overall mean detection rate over Case 1's (Existing RPMs/RIID and Existing X-rays) at 3% and 5% secondary inspection rates. There is no significant difference between Case 1 and Case 2 when the secondary inspection rate increases to 10%.
- In Figure 10, the t-test P-value for Total Processing Time comparing Case 1 and Case 2 shows that Case 2 is significantly better than Case 1 at all secondary inspection rate levels, thus making Case 2 the better option for detection screening.

4.6.2 Case 1 vs. Case 3

- In addition, Case 3 (ASP and Existing X-rays) has a higher mean detection rate at all secondary inspection levels. When compared to Case 1 (Existing RPMs/RIID and Existing X-rays), Case 3 is significantly better at the 3% and 5% secondary inspection levels. However, there is no significant difference between Case 1 and Case 3 when the secondary inspection rate increases to 10%.
- In Figure 10, the t-test comparisons results between Case 1 and Case 3 for Total Processing Time the observed P-value for all secondary inspection rates of 3%, 5%, and 10% are statistically significant; therefore, Case 3 is the better screening method.

4.6.2 Case 2 vs. Case 3

- When comparing Case 2 (Existing RPMs/RIID and PS) and Case 3 (ASP and Existing X-rays), it must be noted that both cases use an existing technology as either the primary inspection method or as the secondary inspection method, respectively.
- In Figure 9, the P-value observed for detection rate for all secondary inspection rates of 3%, 5%, and 10% show no significance, therefore, they are not statistically significantly different. However, Case 3 does have a higher mean detection rate in all the scenarios when compared to Case 2, making Case 3 the better screening method.
- In Figure 10, the t-test comparison for Case 2 and Case 3 for Total Processing the p-value shows that Case 3 is statistically better than Case 2 at all secondary inspection rate levels, thus making Case 3 the better option for detection screening. Although the detection is not statistically significant, the total processing times in these cases are crucial and that is where Case 3 would be there better option.

4.6.4 Summary of Statistical Analysis

Overall, Case 3, ASP and Existing X-rays, proves to be the leading case in total processing time and has a higher detection rate than all the other cases to compensate for any insignificant p-values. Case 2, Existing RPMs/RIID and PS is a better choice when compared to Case 1. Case 1, Existing RPMs/RIID and Existing X-rays, did not perform well statistically due to the fact that the detection rate was low and the total processing was high.

CHAPTER 5: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This research assessed non-intrusive technologies in order to simulate the best case scenario for real-world applications for cargo inspections at U.S. ports. Through a literature review, a list of current technologies was compiled and current practices at ports were determined. Then, a field interview was conducted at the Port of Houston with CBP officers to obtain more information for the design of the simulation study. After that, a model was developed to simulate the procedures used for the inspection of cargo. Based on the results of the analysis, the major findings of this study are summarized as follows:

- Considering effectiveness (high detection rate), both Case 2 and Case 3 were significantly more effective than Case 1, and there was no significant difference between Case 2 and Case 3.
- Considering efficiency (less total processing time), both Case 2 and Case 3 were significantly better than Case 1, and Case 3 was significantly better than Case 2.
- Considering equipment costs, Case 1 was the least expensive, and Case 3 was the most expensive.

Based on these findings, Case 1, Existing RPMs/RIID and Existing X-rays, is not very efficient although it is currently used. The Total Processing Time is very high when compared to the other cases. However, it is the least expensive combination for both primary and secondary inspection modes. The initial purchase price of the Existing RPMs/RIID is low, approximately \$75,000, and the operation and maintenance cost is only about \$12,000 (GAO).

Case 2, Existing RPMs/RIID and PS is also comparable to Case 3, as far as detection rate; however, from the statistical analysis in chapter 4, it was shown that the total processing time for Case 2 is much longer, thus making Case 3 the better choice. However, as mentioned before, if budget is a constraint when considering a system upgrade, the Existing RPMs/RIID and PS in Case 2 may be a suitable option because it is less expensive than Case 3. The current maintenance cost for the Existing RPMs/RIID is approximately \$12,000, which is less than the primary cost in Case 3. The maintenance and operation costs for the PS are not available because it is still in development. However, estimates according to the Passport systems manufacturers are about \$75,000. Moreover, the PS system of Case 2 is faster than the current practice of Case 1's secondary method of Existing X-rays method.

Case 3, ASP and Existing X-rays's detection, is very efficient and quick. The queue time and total processing time are kept to a minimum, which keeps Port operation costs down. Case 3 is a combination of one new technology, Advanced Spectroscopic Portal and an existing technology, Existing X-rays, which, from simulations, proves to be the most effective form of cargo inspection as it minimizes cost of long total processing time in addition to improving detection rate. ASP as a primary method is very beneficial, because it has an ability to detect both shielded and unshielded nuclear materials at the primary screening stage which will improve security, thereby reducing the operation costs. Although ASP's initial purchase price of $377,000 and yearly operation cost of approximately $100,000 is higher than Case 1 and Case 2, Case 3 is by far the best choice by detection rate, total processing time.

The following recommendations are provided:

- If budgets allow, Case 3, which uses ASP and existing X-ray detection, should be selected because it is the most effective and the most efficient case.
- If budgets are limited, Case 2, which uses existing RPMs/RIID and PS, should be considered because it is more effective and more efficient than Case 1.

For future study, more information should be obtained on items that should go through a manual inspection screening process. Such items may not be detected by the non-intrusive technologies used in the primary and secondary methods of screening. Costs, times, and detection rates for the manual screening process should be obtained and used in future simulations. In addition, a more thorough study of the cost per screening and maintenance cost should be conducted so that these costs can be used to create a better cost-benefit analysis. In addition, more information should be obtained from various Ports of Entry in the U.S. by conducting field interviews with different Customs Officials with a list of more detailed questions, including what types of training customs officials undergo and how long their shifts are in order to go beyond the simulation to get a sense of the CBP officers. Also, since newer non-Intrusive technologies are emerging, an additional literature review should be conducted to determine whether useful, new candidates for future simulation studies are available.

APPENDIX A
SPSS TABLES USED FOR T-TEST COMPARISON

Case 1 vs. Case 2 Detection Rates

3 % Secondary Inspection	*Case 1*	*Case 2*
Mean	88.76114	89.11778
Variance	0.267651	0.326832
Observations	15	15
Pooled Variance	0.297241	
Hypothesized Mean Difference	0	
df	28	
t Stat	-1.79146	
P(T<=t) one-tail	0.042017	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.084035	
t Critical two-tail	2.048407	

5% Secondary Inspection	*Case 1*	*Case 2*
Mean	88.94329	89.60531
Variance	0.432796	0.385433
Observations	15	15
Pooled Variance	0.409115	
Hypothesized Mean Difference	0	
df	28	
t Stat	-2.83454	
P(T<=t) one-tail	0.004211	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.008423	
t Critical two-tail	2.048407	

10% Secondary Inspection	*Case 1*	*Case 2*
Mean	89.55689	89.78047
Variance	0.475469	0.232805
Observations	15	15
Pooled Variance	0.354137	
Hypothesized Mean Difference	0	
df	28	
t Stat	-1.02894	
P(T<=t) one-tail	0.156158	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.312315	
t Critical two-tail	2.048407	

Case 1 vs. Case 3 Detection Rates

3 % Secondary Inspection	*Case 1*	*Case 3*
Mean	88.76114	89.36058
Variance	0.267651	0.420302
Observations	15	15
Pooled Variance	0.343976	
Hypothesized Mean Difference	0	
df	28	
t Stat	-2.79907	
P(T<=t) one-tail	0.004588	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.009176	
t Critical two-tail	2.048407	

5% Secondary Inspection	*Case 1*	*Case 3*
Mean	88.94329	89.83577
Variance	0.432796	0.509474
Observations	15	15
Pooled Variance	0.471135	
Hypothesized Mean Difference	0	
df	28	
t Stat	-3.56088	
P(T<=t) one-tail	0.000673	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.001345	
t Critical two-tail	2.048407	

10% Secondary Inspection	*Case 1*	*Case 3*
Mean	89.55689	89.69849
Variance	0.475469	0.317972
Observations	15	15
Pooled Variance	0.39672	
Hypothesized Mean Difference	0	
df	28	
t Stat	-0.61569	
P(T<=t) one-tail	0.271537	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.543074	
t Critical two-tail	2.048407	

Case 2 vs. Case 3 Detection Rates

3 % Secondary Inspection	*Case 2*	*Case 3*
Mean	89.11778	89.36058
Variance	0.326832	0.420302
Observations	15	15
Pooled Variance	0.373567	
Hypothesized Mean Difference	0	
df	28	
t Stat	-1.08792	
P(T<=t) one-tail	0.142954	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.285908	
t Critical two-tail	2.048407	

5% Secondary Inspection	*Case 2*	*Case 3*
Mean	89.60531	89.83577
Variance	0.385433	0.509474
Observations	15	15
Pooled Variance	0.447453	
Hypothesized Mean Difference	0	
df	28	
t Stat	-0.94352	
P(T<=t) one-tail	0.176744	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.353488	
t Critical two-tail	2.048407	

10% Secondary Inspection	*Case 2*	*Case 3*
Mean	89.78047	89.69849
Variance	0.232805	0.317972
Observations	15	15
Pooled Variance	0.275388	
Hypothesized Mean Difference	0	
df	28	
t Stat	0.427842	
P(T<=t) one-tail	0.33602	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.672039	
t Critical two-tail	2.048407	

Case 1 vs. Case 2 Total Processing Time

3 % Secondary Inspection	*Case 1*	*Case 2*
Mean	23.48151	20.22927
Variance	0.048843	0.016422
Observations	15	15
Pooled Variance	0.032633	
Hypothesized Mean Difference	0	
df	28	
t Stat	49.30467	
P(T<=t) one-tail	4.63E-29	
t Critical one-tail	1.701131	
P(T<=t) two-tail	9.26E-29	
t Critical two-tail	2.048407	

5% Secondary Inspection	*Case 1*	*Case 2*
Mean	24.12469	20.41074
Variance	0.044899	0.033285
Observations	15	15
Pooled Variance	0.039092	
Hypothesized Mean Difference	0	
df	28	
t Stat	51.44258	
P(T<=t) one-tail	1.43E-29	
t Critical one-tail	1.701131	
P(T<=t) two-tail	2.86E-29	
t Critical two-tail	2.048407	

10% Secondary Inspection	*Case 1*	*Case 2*
Mean	26.51693	20.55428
Variance	0.096042	0.038829
Observations	15	15
Pooled Variance	0.067435	
Hypothesized Mean Difference	0	
df	28	
t Stat	62.88191	
P(T<=t) one-tail	5.41E-32	
t Critical one-tail	1.701131	
P(T<=t) two-tail	1.08E-31	
t Critical two-tail	2.048407	

Case 1 vs. Case 3 Total Processing Time

3 % Secondary Inspection	*Case 1*	*Case 3*
Mean	23.48151	5.585151
Variance	0.048843	0.001522
Observations	15	15
Pooled Variance	0.025182	
Hypothesized Mean Difference	0	
df	28	
t Stat	308.8502	
P(T<=t) one-tail	2.62E-51	
t Critical one-tail	1.701131	
P(T<=t) two-tail	5.25E-51	
t Critical two-tail	2.048407	

5% Secondary Inspection	*Case 1*	*Case 3*
Mean	24.12469	5.886816
Variance	0.044899	0.000411
Observations	15	15
Pooled Variance	0.022655	
Hypothesized Mean Difference	0	
df	28	
t Stat	331.8326	
P(T<=t) one-tail	3.52E-52	
t Critical one-tail	1.701131	
P(T<=t) two-tail	7.04E-52	
t Critical two-tail	2.048407	

10% Secondary Inspection	*Case 1*	*Case 3*
Mean	26.51693	7.188943
Variance	0.096042	0.003831
Observations	15	15
Pooled Variance	0.049937	
Hypothesized Mean Difference	0	
df	28	
t Stat	236.8683	
P(T<=t) one-tail	4.41E-48	
t Critical one-tail	1.701131	
P(T<=t) two-tail	8.82E-48	
t Critical two-tail	2.048407	

Case 2 vs. Case 3 Total Processing Time

3 % Secondary Inspection	*Case 2*	*Case 3*
Mean	20.22927	5.585151
Variance	0.016422	0.001522
Observations	15	15
Pooled Variance	0.008972	
Hypothesized Mean Difference	0	
df	28	
t Stat	423.3995	
P(T<=t) one-tail	3.83E-55	
t Critical one-tail	1.701131	
P(T<=t) two-tail	7.67E-55	
t Critical two-tail	2.048407	

5% Secondary Inspection	*Case 2*	*Case 3*
Mean	20.41074	5.886816
Variance	0.033285	0.000411
Observations	15	15
Pooled Variance	0.016848	
Hypothesized Mean Difference	0	
df	28	
t Stat	306.4361	
P(T<=t) one-tail	3.27E-51	
t Critical one-tail	1.701131	
P(T<=t) two-tail	6.54E-51	
t Critical two-tail	2.048407	

10% Secondary Inspection	*Case 2*	*Case 3*
Mean	20.55428	7.188943
Variance	0.038829	0.003831
Observations	15	15
Pooled Variance	0.02133	
Hypothesized Mean Difference	0	
df	28	
t Stat	250.6195	
P(T<=t) one-tail	9.09E-49	
t Critical one-tail	1.701131	
P(T<=t) two-tail	1.82E-48	
t Critical two-tail	2.048407	

REFERENCES

Anjos, D., Mirchandani,P., Hickman, M., Lee, S., and Chiu, Y. Data Collection and Calibration of Simulation Models of Border Inspection Facilities. Washington, D.C.: Transportation Research Board, 2010

Barzilov, A.P., Womble, P.C., and Vourvopoulos, G. NELIS - a Neutron Inspection System for Detection of Illicit Drugs. Application of Accelerators in Research and Industry: 17th Int'l. Conference, 2003

Donzella, A., Boghen, G., Bonmi, G., Fontana, A., Formisano, P., Pesente, S., Sudac, D., Valkovic,V., and Zenoni, A.. Simulation of a Tagged Neutron Inspection System Prototype. EPS Euroconference XIX Nuclear Physics Divisional Conference, 2006.

Ensco, Inc. *MicroSearch, cargo/vehicle inspection for human presence*. http://www.ensco.com/Products-Services/Technical-Security/MicroSearch.htm. Assessed July 1, 2009.

Fishbine, B. Muon Radiography, Detecting Nuclear Contraband. Spring 2003

Harbison, G.F. *ASP-Advanced Spectroscopic Portal Program*. http://www.maineptac.org/documents/Raytheon%20IDS%20ASP%20Program%20Overview%20PTAC%20June%202009.pdf**.** Assessed July 1, 2009

Jones, J. L., Yoon,W. Y., Haskell, K. J., Norman, D. R., Zabriski, J. M., Sterbentz, J. W., Watson, S. M., Johnson, J. T., Bennett, B. D., Watson, R. W., and Folkman, K. L.. *Pulsed Photonuclear Assessment (PPA) Technique: CY 04 Year-End Progress Report.* Publication INEEL/EXT-05-02583, February 2005

Jones, J.L., Blackburn, B.W., K.J. Haskell, J.T. Johnson, D.R. Norman, J.W. Sterbentz, S.M. Watson, J.F. Harmon, and A.W.Hunt. *Pulsed Photonuclear Assessment (PPA) Technology Enhancement Study*. Publication INL/EXT-06-11175.

Kelton, W., Sadowski, R. and Sturrock, D. *Simulation with ARENA.*McGraw Hill, Inc. New York, NY., 1998.

LOS ALAMOS, N.M. *Los Alamos Muon Detector Could Thwart Nuclear Smugglers. Feb. 19, 2005.* http://www.sciencedaily.com/releases/2005/03/050322135547.htm. Assessed July 1, 2009.

Muon Opportunists: Detecting the Unseen With Natural Probes, Feb 2005. http://psychcentral.com/news/archives/2005-02/aaft-mod021205.html. Assessed July 1, 2009.

Nagesh, G. *Requirement to Scan All Inbound Sea Cargo Sparks Concerns.* 08/19/2008. http://www.nextgov.com/nextgov/ng_20080819_1134.php. Assessed July 1, 2009

Passport systems Company. *Passport's Technologies Identify Container Contents* http://www.passportsystems.com/tech.htm. Assessed July 1, 2009

Perret, G., Perot, B. and Mariani, A. EURITRACK Tagged Neutron Inspection System Design. EPS Euroconference XIX Nuclear Physics Divisional Conference, 2006

Qi, Y. and Wang, Y. Review of Available Non-Intrusive Inspection (NII) Technologies for Inspection of Cargo at Ports of Entry. Washington, D.C.: Transportation Research Board, 2009

Raytheon. *Advanced Spectroscopic Portal (ASP)*. http://www.raytheon.com/businesses/rids/products/rtnwcm/groups/public/documents/content/rtn_bus_ids_prod_asp_pdf.pdf. Assessed July 1, 2009

Risks From Air Cargo Transport. Publication No. UVACTS-5-14-63, July 2004

Rountree, C. D. and Demetsky, M. J. *Development Of Counter Measures To Security*

Shea, S.A., Moteff, J.D. and Morgan, D. *The Advanced Spectroscopic Portal Program: Background and Issues for Congress*. Publication CRS Report for Congress, March 25, 2009

Subcommittee on emerging Threats, Cybersecurity, and Science and Technology. *Nuclear Smugging Detection: Recent Tests of Advanced Spectroscopic Portal Monitors*. Publication No. 110-99, March 5, 2008

The National Research Council of the National Academies. *Evaluating Testing, Costs, and Benefits of Advanced Spectroscopic Portals for Screening Cargo at Ports of Entry: Interim Report (Abbreviated Version)*. Publication The National Academies Press, Washington, D.C., 2009

Viesti G., Botosso, C., Fabris, D., Lunardon, M., Moretto, S., Nebbia, G., Pesente, S., Zenoni, A., Donzella, A., Perot, B., Carasco, C., Bernard, S., Marianf, A., Szabo, J.-L., Sannie, G., Valkovic, V., Sudac, D., Nad, K., Peeranf, P., Sequeir, V., Salvato, M., Moszynski, M., Gierlik, M., Klamra, W., Le Tourneur, P., Lhuissier, M., Colonna, A., Tintori, C. Scanning Cargo Containers with Tagged Neutrons. American Institute of Physics, 2007