Spring 2007

Analysis of truck delays at container terminal security inspection stations

Dae-Gwun Yoon

New Jersey Institute of Technology

ABSTRACT

ANALYSIS OF TRUCK DELAYS
AT CONTAINER TERMINAL SECURITY INSPECTION STATIONS

by
Dae-Gwun Yoon

After September 11, 2001, special attention has been given to the vulnerability at container transportation to terrorist activities. United States Customs and Border Protection (CBP) has set up inspection stations for containers at seaport terminals to screen containers, but this practice affects the truck turnaround time in the seaport by generating additional processing delays.

This dissertation analyses the additional truck turnaround time incurred at the inspection stations under various levels of security. Queuing models were used to estimate truck delay as containers are inspected at two successive security inspection stages. Each stage may utilize one or more inspection equipment. The objective is to determine the number of equipment needed to keep the total delay at an acceptable level. Homeland security, CBP, seaport terminal officers, truck and marine carriers may use this research to develop an effective and efficient plan for handling marine freight and containers.

ANALYSIS OF TRUCK DELAYS
AT CONTAINER TERMINAL SECURITY INSPECTION STATIONS

by
Dae-Gwun Yoon

**A Dissertation
Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in Transportation**

Department of Industrial and Manufacturing Engineering

May 2007

ANALYSIS OF TRUCK DELAYS
AT CONTAINER TERMINAL SECURITY INSEPCTION STATIONS

Dae-Gwun Yoon

Dr. Janice R. Daniel, Dissertation Advisor	Date
Associate Professor of Civil and Environmental Engineering, NJIT	

Dr. Lazar Spasovic, Committee Member	Date
Professor of Civil and Environmental Engineering, NJIT	

Dr. Athanassios Bladikas, Committee Member	Date
Associate Professor of Industrial and Manufacturing Engineering, NJIT	

Dr. Steven I-Jy Chien, Committee Member	Date
Professor of Civil and Environmental Engineering, NJIT	

Dr. Rongfang Liu, Committee Member	Date
Associate Professor of Civil and Environmental Engineering, NJIT	

BIOGRAPHICAL SKETCH

Author: Dae-Gwun Yoon

Degree: Doctor of Philosophy

Date: May 2007

Undergraduate and Graduate Education:

- Doctor of Philosophy in Transportation Engineering,
  New Jersey Institute of Technology, Newark, NJ, May 2007

- Master of Science in International Transportation Management,
  State University of New York – Maritime College, Bronx, NY, January 2004

- Master of Science in Maritime Transportation,
  Korea Maritime University, Busan, South Korea, February 2000

- Bachelor of Science in Maritime Transportation,
  Korea Maritime University, Busan, South Korea, February 1996

Major: Transportation

Presentations and Publications:

Dae-Gwun Yoon, "A risk analysis and optimization for inspection station versus marine
terminal security". 2nd GBAT Conference on Cutting-Edge Issues in Shipping.
State University of New York – Maritime College, Bronx, New York, February
2007.

Dae-Gwun Yoon and Sang-Gap Park. "A study on the risk management of oil tanker
operation". Journal of Navigation and Port Research. Busan. South Korea.
February 2001.

Dae-Gwun Yoon, "A study on the risk management of oil tanker operation – Focusing on
Insurance Cover," Master Thesis in Korea Maritime University, Busan, South
Korea, February 2000.

To my beloved family

A root of my all achievement came from my wife (Miyoung Yoon)'s
support and dedication, and
Gahyun (Daughter), Jiwoong (Son)'s loving eyes.

Do thousand times if others are doing hundred times of the work.

Being patient allows the entire world to be under your control.

- Dr. Sang Gap Park -

Like a huge diamond, be strong, clean and brilliant in your body and spirit.

All true and really valuable things come from the foundation, not from above.

One can only swim with freedom within God's absolute truth.

- In becoming Ph.d -

ACKNOWLEDGMENT

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background

The globalization of the world economy has led to an increasingly important role of international transportation and supply chain management. In particular, container transportation and maritime trade are important parts of international transportation as about 90 percent of the world's cargo moves by container. Each year, about 16 million containers enter seaport container terminals in the United States. After September 11, 2001, special attention has been given to the vulnerability of container transportation to terrorist activities. This fact has made it impossible for the United States to ignore potential terrorists' dangers and threats and the potential use of dangerous goods such as nuclear and radiological weapons at seaport container terminals.

As international trade continues to increase, there is greater opportunity for terrorists to conceal their attack materials within commercial cargo and containers. To provide protection from these dangerous and dirty materials entering into the U.S., Customs Border Protection (CBP) developed a five-year Non-Intrusive Inspection (NII) Technology Plan which received $134 million of support from the United States Congress in related and supplemental funds. The plan ranges from sophisticated analytical computer databases to gamma-ray and X-ray imaging systems, radiation isotope identifiers, explosive detectors, as well as sensors and cameras located along isolated stretches of the national border.

As the requests of shippers and customers for the timely delivery of international goods and containers increase, even a little delay in the time needed to inspect international containers in a security system at a seaport could result in serious economic disadvantage for the U.S. Therefore, CBP is exploring several measures to minimize the potential costs and delays including the use of a "Green Lane" which would allow pre-certified containers to pass freely through the terminal without the need for inspecting them. This approach would reduce truck turnaround time within the port terminal.

To address the security inspection concerns, the U.S is taking the initiative to provide a framework for security requirements that daily port operations must meet. These initiatives aim at moving part of such security efforts overseas, where goods are prepared for shipping into the US. One such example is the Container Security Initiatives (CSI), implemented by the CBP in January, 2002. Thirty six of the largest seaports in 2005, in terms of containerized exports to the US, have implemented bilateral agreements that would permit pre-shipment screening by the countries involved.

Another security agreement is the Customs-Trade Partnership Against Terrorism (C-TPAT), a voluntary government-business agreement made by importers, exporters, carriers, brokers and warehouse operators of the supply chain. Under this agreement, customs officers are stationed overseas to work in foreign ports, thus ensuring the overall security level of containers from transmarine areas. To participate in these programs, seaports need to add container inspection processes into the daily terminal operations without interrupting port productivity.

1.2 Problem Statement

The success of maintaining goods movement through container transportation depends on the efficient and seamless transfer of containers, which calls for faster transfer and less paper work. The delay caused by the inspection of containers and documents needs to be minimized, and thus it is likely that there may be a tendency to resort to tactics for bypassing inspection. It is unfortunate that some of the measures for enhancing security will be counterproductive for the efficiency of intermodal freight transportation including truck turnaround time at the seaport container terminal (Chatterjee, 2003).

Across the United States after September 11, 2001, Customs Border Protection (CBP) conducted the design, development, testing, and deployment of inspection stations at marine container terminals. Despite the benefits of the inspection process which inspects containers entering into the U.S. to protect people and transportation facilities, the process directly affects the truck turnaround time in a seaport. Truck turnaround time in a seaport container terminal is a key indicator of the port throughput. Therefore, this additional truck turnaround time caused by the need for inspection has a direct effect on concerned parties such as shippers, shipping companies, CBP, and seaport terminal operators. The increase of foreign containers entering the U.S. has a direct impact on truck turnaround times in the inspection station.

Furthermore, this additional truck turnaround time will rapidly increase during times of high security levels. The additional truck turnaround time occurring at inspection stations needs to be further studied to assist all parties involved in international trade in making better decisions about the design of the inspection station, the number of equipment needed and the impact due to the use of alternative inspection policies.

A large number of containers may need to be inspected at more than two stages especially if the government security level rises. In the first stage, stage 1, the type of equipment used includes Radiation Isotope Identifiers and/or Portal Monitors, and in the second stage, stage 2, Large-scale Gamma-ray/X-ray Imaging Systems are used. Truck turnaround time varies and is a function of several variables including the national and/ or port's security level, the percentage of containers using the Green Lane, and the size of the staging area. In summary, 1) the seaport inspection station must be integrated into existing terminals to minimize delay, 2) truck delay will continue to increase as the number of imports increase, 3) there is a lack of information for terminal operators on the number and placement of inspection equipment, 4) there has been little research on the impact of the security level and inspection station design on truck delays, and 5) as more inspections are performed, there is potential for increased delay.

1.3 Research Objectives

This research determines the number of initial lanes and inspection equipment needed of a seaport terminal inspection station. Truck turnaround time is used as the primary measure to evaluate the impact of various inspection designs.

The research seeks to develop methodologies to reduce truck turnaround time as a result of implementing an inspection station and by so doing assist terminal operations. To assist the terminal operator in deciding whether or not additional inspection equipment are needed and if needed how many should be provided, this research uses queuing theory to explain the relationship between the number of inspection equipment and truck turnaround time. In addition, this research develops a framework from which the Green Lane system can be designed to allow free passage of pre-certified containers.

In summary, this research does the following:

1. Demonstrates the impact of new security measures on seaport container terminal operations.

2. Models terminal operations at inspection stations to better understand the impact of the inspection measures on port efficiency.

3. Using queuing theory, determines the number of inspection equipment needed to keep shorter than a given target truck turnaround time.

4. Uses the model developed to analyze the impact of national security levels, the extent of "Green Lane", and container inspection staging on truck turnaround time.

5. Provides recommendations on the inspection procedures that keep delays at seaport container terminals below a given target.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This literature review provides background information on seaport container terminal operations, container security measures and container inspection procedures, and a review of previous studies dealing with seaport security and truck turnaround time. An understanding of these operations of a container terminal is necessary before discussing the remaining chapters.

2.2 Terminal Structure and Handling Equipment

To understand the operation of the seaport container terminal, a discussion of the terminal structure and the handling equipment is provided.

2.2.1 Terminal Structure

When a container vessel arrives at a seaport, the vessel is berthed based on the availability of cranes to load and unload containers. Unloaded containers are carried to one location of the yard as close as possible to the unloading area before they can be transported to a second location. Containers arriving by truck from inland at the terminal are handled within the terminal by the internal equipment and delivered to the export yard near to the vessel (Liu et al., 2002). Figure 1.1 shows the general layout of a typical container terminal.
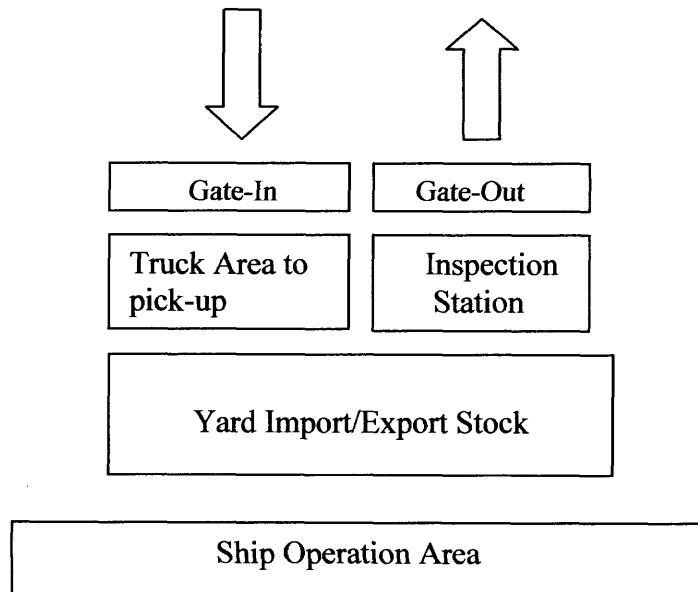
Figure 1.1 General layout of container terminals.

Truck turnaround time is the time spent by a truck in the terminal area from gate-in to gate-out for picking and/or dropping a container. Ravichandran (2005) stated that the turnaround time includes the time from the arrival, loading of material, inspecting a truck, and completion of commercial formalities. The time in a seaport container terminal is an important indicator of the port terminal efficiency. The truck turnaround time also directly affects the freight carrier's profits.

2.2.2 Handling Equipment

Handling equipment of a seaport container terminal consists of two parts including cranes and transport vehicles. There are two types of equipment; Quay (or Gantry) Cranes are used when loading and unloading from/to ships. These types of cranes include Single-Trolley Cranes which travel along the arm of a crane and are equipped with spreaders. Spreaders are specific devices used to pick up containers. The main trolley moves the container from the ship to a

platform while a second trolley picks up the container from the platform and moves it to the shore. The other types of cranes include Yard Cranes including Rail Mounted Gantry Cranes (RMG) or Rubber Tired Gantries (RTG). RTGs are more flexible in operation while RMGs are more stable. Over-head Bridge Cranes (OBC) are mounted and fixed on concrete or steel pillars.

The other handling equipment of a seaport container terminal are Transport Vehicles including Automatic Guided Vehicles (AGV). AGVs are passive vehicles in a sense that they are not able to lift containers by themselves. Loading and unloading of these vehicles is done by cranes, either quay cranes or yard cranes, and Straddle Carriers (SC). SCs are active vehicles in a fact that they are able to lift containers by themselves. Also SCs not only transport containers, but are also able to stack containers in the yard (Steenken et al., 2004).

2.3 International Agreements and Initiatives

There are four processes for insuring the integrity of a container: 1) collecting advance cargo information to identify high-risk containers; 2) establishing an efficient pre-screen system at loading ports; 3) ensuring the integrity and security of containers during their trip to the final destination; and 4) expanding container inspection at destinations. To performing these processes efficiency, the United States government and the private sector have recently set up several container security programs such as the container security initiative (CSI), a customs-trade partnership against terrorism (C-TPAT), and adopted other container security technologies. The following describes these security programs.

2.3.1 Container Security Initiative (CSI)

CSI is a bilateral agreement between the United States customs and foreign customs. Once the CSI agreement is signed, United States Officers, who are dispatched to the origin port, target and pre-screen US bound cargo containers before they are shipped. As of February 2005, a total of 45 ports have signed the CSI agreement. By the end of 2006, the number is expected to grow to 50 ports covering 82 percent of transpacific maritime containerized cargo shipped to the United States. (US CBP, 2006)

CSI consists of four core elements:

1. Using intelligence and automated information to identify and target containers that pose a risk for terrorism;

2. Pre-screening those containers that pose a risk at the port of departure before they arrive at U.S. ports;

3. Using detection technology to quickly pre-screen containers that pose a risk; and

4. Using smarter, tamper-evident containers which make inspectors alert if the container was tampered.

Under the CSI program, the screening of containers that pose a risk for terrorism is accomplished by teams of Customs and Border Protection (CBP) officials deployed to work in concert with their host nation counterparts (US CBP, 2006). CSI is a deterrent to terrorist organizations that may seek to target any foreign port. This initiative provides a significant measure of security for the participating port as well as the United States. CSI will also provide better security for the global trading system as a whole. If terrorists were to carry out an attack on a seaport using a container, the maritime trading system would be stopped until seaport security is improved. Those seaports participating in the CSI will be able to begin handling

containerized cargo far sooner than other ports that have not taken steps to enhance security. In short, CSI is an insurance policy against the threat of a terrorist attack (Collins et al., 2005).

2.3.2 Customs-Trade Partnership Against Terrorism (C-TPAT)

C-TPAT is a voluntary government-business initiative to build cooperative relationships that strengthen and improve overall the international supply chain and U.S. border security. C-TPAT recognizes that U.S. Customs and Border Protection (CBP) can provide the highest level of cargo security only through close cooperation with the users of the international supply chain such as importers, carriers, consolidators, licensed customs brokers, and manufactures. Through this initiative, CBP is asking businesses to ensure the integrity of their security practices and communicate and verify the security guidelines of their business partners within the supply chain (US CBP, 2006). Business types related to the U.S. import supply chain cargo handling and movement have been enrolled to this C-TPAT and include:

* U.S Importers of record

* U.S./Canada Highway Carriers

* U.S./Mexico Highway Carriers

* Rail Carriers

* Sea Carriers

* Air Carriers

* U.S. Marine Port Authority/Terminal Operators

* U.S. Air Freight Consolidators, Ocean Transportation Intermediaries and Non-Vessel Operating Common Carriers (NVOCC)

* Mexican Manufactures

* Certain Invited Foreign Manufacturers

* Licensed U.S. Customs Brokers

CBP is responsible for screening all import cargo transactions. Utilizing risk management principles, C-TPAT seeks to enroll compliant low-risk companies who are directly responsible for importing, transporting, and coordinating commercial import cargo into the United States. The goal is to identify compliant trusted import traders who have good supply chain security procedures and controls to reduce screening of their imported cargo. In turn, this enables CBP to focus screening efforts on import cargo transactions involving unknown or high-risk import traders (Keane, 2005). To become a certified C-TPAT participant, a company must submit two documents to Customs. The first is a signed "Agreement to Voluntarily Participate". The second is a Security Profile describing the applicant's international trade operations, facilities and currently existing security processes and procedures covering (a) facilities security, (b) theft prevention, (c) shipping and receiving controls, (d) information security controls, (e) internal controls, (f) personnel security procedures and processes, and (g) requirements for the applicant's service providers (i.e., product suppliers, carriers and forwarders). CBP created a public-private and international partnership with nearly 5,800 businesses including most of the largest U.S. importers. C-TPAT, CBP and partner companies are working together to improve baseline security standards for supply chain and container security. CBP reviews the security practices of not only the company shipping the containers, but also the companies that provided them with services.

2.4 Container Security Technologies

There are several container security technologies that are being used by CBP to reduce overall delay time and to detect high risk containers efficiently. These technologies include a Smart container, Radio Frequency Identification (RFID), and Automated Targeting System (ATS).

2.4.1 Smart Container

Smart containers are remote real time monitoring systems equipped with a high-security seal or an electronic seal for detecting whether the door of the container has been opened during transport. All parties can monitor the container from point of packing to delivery and have access to information on a real time basis from PC's, Mobile Phones, etc. The information obtained by manifest and the shipper's notice for the container are condensed at base station on ship and sent by satellite, and then relayed to a server. Data are analyzed and translated into meaningful quality information and delivered by internet or e-mail to all parties.

A smart container configured for transporting cargo on a transportation vehicle and a method for transporting the smart container on the transportation vehicle are disclosed. The smart container includes a container housing that has an opening for loading and unloading cargo. The opening can be sealed and unsealed. Within the container housing is at least one detector for detecting deviations that could be indicative of possible threats (security concerns). A communications link also exists within the container housing. The communications link is capable of transmitting the possible threat information to a central cargo data collection location. For example, the container(s) on a transportation vehicle (e.g., a ship) transmits information about the container to a central data collector onboard the ship. The central data collector may then transmit that information off of the ship.

The Department of Homeland Security and CBP are now pursuing 'Smart Container' projects which are still in the initial stage. Standard requirement and implementation methods (mandatory regulations, or voluntary programs) have not currently been set up. A working group including the CBP, carriers and shippers was established to draft an implementation guideline.

2.4.2 Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) is a generic term for technologies that use radio waves to automatically identify people or objects. There are several methods of identification, but the most common is to store a serial number that identifies a person or object, and perhaps other information, on a microchip that is attached to an antenna. The antenna enables the chip to transmit the identification information to a reader. The reader converts the radio waves reflected back from the RFID tag into digital information that can then be passed on to computers that can make use of it. The most common applications are payment systems, access control and asset tracking.

Just as radio tunes in to different frequencies to hear different channels, RFID tags and readers have to be tuned to the same frequency to communicate. RFID systems use many different frequencies, but generally the most common are low-frequency (around 125 KHz), high-frequency (13.56 MHz) and ultra-high-frequency or UHF (860-960 MHz). Microwave (2.45 GHz) is also used in some applications. Radio waves behave differently at different frequencies, so companies have to choose the right frequency for the right application. Most countries have assigned the 125 KHz or 134 KHz area of the radio spectrum for low-frequency systems, and 13.56 MHz is used around the world for high-frequency systems. But UHF RFID systems have only been around since the mid-1990s, and countries have not agreed on a single

area of the UHF spectrum for RFID. Europe uses 868 MHz for UHF, while the U.S. uses 915 MHz. Until recently, Japan did not allow any use of the UHF spectrum for RFID, but it is looking to open up the 960 MHz area for RFID. Many other devices use the UHF spectrum, so it will take years for all governments to agree on a single UHF band for RFID. Governments also regulate the power of the readers to limit interference with other devises. Some groups, such as the Global Commerce Initiative, are trying to encourage governments to agree on frequencies and output. Tag and reader makers are also trying to develop systems that can work at more than one frequency, in order to get around the problem.

Increased container security can be achieved through a wide range of technologies, from increased inspections to systems that incorporate radio frequency identification (RFID) tags with wireless sensors. RFID is an automatic identification method, relying on storing and remotely retrieving data using devices called RFID tags or transponders. An RFID tag is a small object that can be attached into a carton, pallet, or container. RFID tags contain silicon chips and antennas to enable them to receive and respond to radio frequency queries from an RFID transceiver. Passive tags require no internal power source, while active tags needs this source.

2.4.3 Automated Targeting System (ATS)

The Automated Targeting System (ATS) is an aggressive, sophisticated expecting technology that enhances CBP ability to perform narcotics enforcement operations. CBP employs computer models to review documentation on all arriving containers and helps select or "target" high-risk containers for physical inspection and/or additional documentary review. This system, referred to as the automated targeting system, was originally designed to help identify illegal materials in containers. ATS automatically matches its expecting rules against the manifest and other

available data for every arriving container, and assigns a level of risk such as low, medium, and high to each container (US CBP, 2006).

2.5 CBP Advanced Policy

2.5.1 Green Lane

The CBP reported that containers of C-TPAT shippers will be inspected with simple security processes at the border of the United States or an inspection-free Green Lane can used. This green lane procedure has not been set up. The benefit of the Green Lane would only come to C-TPAT members who reach back in their supply chains to ensure security from the point of origin of goods to the port of entry to the United States (Keane, 2005).

Commissioner Bonner (2005) stated that the CBP will begin the use of a Green Lane through customs for virtually all US importers' shipments. This would mean "no inspection upon arrival—immediate release" for trusted shippers that adopt the highest levels of security controls by C-TPAT. Green Lane benefits are benefits granted by the U.S. government favoring container cargo that satisfies the following requirements:

- Container stuffed by C-TPAT certified shipper into Smart Container;
- Container originated from CSI port and International Ship and Port Facility Security Code (ISPS)-certified port;
- Container carried by C-TPAT certified rail/truck/ocean carriers; and
- Container delivered to C-TPAT importer.

Green Lane benefits strongly show that security factors will be an important aspect of ocean carrier's competitiveness. Shippers willing to continue doing business with the U.S. will be induced to use ocean carriers that meet all the necessary conditions for Green Lane benefits.

2.6 Container Inspection Procedure

About 90 percent of all world cargo moves by container. Almost half of the incoming trade arrives in the United States by sea containers. Nearly 9 million cargo containers arrive and are offloaded at U.S. seaports each year. Currently, CBP is installing radiation portal monitors at the borders nationwide to screen all incoming goods, containers, and conveyances.

2.6.1 First and Second Stage

In an inspection station at a port container terminal, all containers entering into the United States should be inspected in the first stage. First stage involves passive systems including vapor, trace, radiation detection, and canines. Radiation portal monitors in the first stage are detection devices that provide Customs and Border Protection (CBP) with a passive, non-intrusive means to screen trucks and other conveyances for the presence of nuclear and radiological materials. These systems are capable of detecting various types of radiation emanating from special nuclear materials, natural sources, and isotopes commonly used in medicine and industry. The inspection equipment used in the first stage is not imaging systems that transmit energy and then form an image from that energy. Passive systems read energy emitted by radioactive sources that happen to pass near it. The system is very similar to a radio receiver in that it responds to certain types of energy and provides an indication to the operator of the strength of the energy received. If the container does not pass inspection at the first stage,

then the container is inspected at the second stage using an active system. Large-scale Gamma-ray/X-ray Imaging Systems in the second stage separate transmissions whose reflections generate images of the contents of a cargo container, rail car, vehicle or trailer-truck. CBP officers analyze these images to determine where there are anomalies associated with the cargo listed on the manifest. There are 166 systems in use in the U.S, with more to be added (US CBP, 2006).

The Radiation Portal Monitor is a typical first stage detection device that provides CBP with a passive, non-intrusive means to screen trucks, cargo containers, rail cars, passenger vehicles, and other conveyances for radiation emanating from nuclear devices, dirty bombs, special nuclear materials, natural sources, and isotopes commonly used in medicine and industry. There are more than 473 installed nationwide with plans for continued expansion. CBP installed these radiation portal monitors nationwide – at seaports, land border ports of entry and crossings, including rail crossings, international airports, and international mail and express consignment carrier facilities in an effort to screen 100 percent of all incoming goods, people, and conveyances for radiation.

Large-scale Gamma-ray/X-ray Imaging Systems are typical second stage devices. CBP officers analyze the general images to determine where there are anomalies associated with the cargo listed on the manifest. There are 166 systems in use, with more to be added. Gamma ray/X-ray imaging should be useful for detection of weapons of mass destruction (either uranium or plutonium based) in loaded containers, even if shielding is present. With both gamma ray and high-energy X-ray screening, any attempt to shield a device from the portal monitors will make it even more easily seen in the image. The speed of this inspection is limited by the flux from normally available gamma ray sources. About 20 containers per hour can be processed using

today's gamma ray /X-ray systems. Since the average rate through a large port is several hundred containers per hour, this approach clearly can only inspect a small fraction of the containers. Since gamma ray / X-ray systems are commonly used at US ports, this explains why a small percentage of containers are screened currently.

2.6.2 Inspection Steps

In coordination with the Department of Homeland Security, CBP will be deploying inspection stations nationwide (international mail and express consignment courier facilities, land border crossings, seaports, international airports and border rail crossings) in an effort to screen 100 percent of all incoming goods, containers, and conveyances for radiation (US CBP, 2004).

Inspection stations at the Port Elizabeth terminal in New Jersey consist of two stages. Inspection using Radiation Isotope Identifiers and/or Portal Monitors constitutes the first stage). Large-scale Gamma-ray/X-ray Imaging Systems are used in the second stage (Feeney et al., 2004). All of container inspection procedures used in this research follows this process.

2.7 Seaport Security and Truck Turnaround Time

Much research has been performed on the operation and design of seaport container terminals. Previous literature related to this research deals with three areas; seaport security, truck turnaround time and other related issues.

2.7.1 Seaport Security

Lewis et al. (2003) described an approach for aiding the management of a container transshipment seaport to decide on the balance between the percentage of containers to undergo security inspection and the concomitant departure delays of outbound vessels with focusing on a highly simplified problem formulation by modeling security and efficiency. This problem formulation considered the following approach for quantifying the impact of security on port efficiency by using minimum time, denoted as $\tau(S_I, S_O, S_S)$, required to unload inbound vessels with stow plans S_I and load out-bound vessels with stow plans S_O, assuming that each container in the set S_S is to undergo a security inspection. It is remarked that determination of $\tau(S_I, S_O, S_S)$ is an unsolved optimization problem on which the research was focused. Given S_I, S_O, and S_S, security inspection delay ($\Delta(S_I, S_O, S_S)$) is stated as follows:

$$\Delta(S_I, S_O, S_S) = \tau(S_I, S_O, S_S) - \tau(S_I, S_O, \phi) \tag{2.1}$$

where, ϕ = the null set.

It is assumed that the cumulative distribution function over S_I, S_O, and S_S is known and given and $|S_I| = |S_O|$. This implication can aid a port manager in deciding what percentage of containers to undergo security inspections.

Hamid et al. (2006) developed a new framework to estimate the expected number of ships $E(S)$ that are in queue and waiting to be inspected. The new framework is characterized by two regulatory regimes as two different kinds of queues such as $M/M/I/U$ inspection regime in which I inspectors are used and the upper limit on the maximum number of ships in

our port is U and a $M/M/I/I$ regime in which the number of inspectors and upper limit on the maximum number of ships in the port coincide and they are both denoted by the positive integer I. In this notation, the meaning of the first two M is the Poisson arrival process and exponential distributed service time, respectively.

The expectation of $E(S)$ for $M/M/I/U$ regime is actually the sum of two parts including the expected number of ships that are in queue, waiting to be inspected and the expected inspection time determined as

$$E(S) = \frac{P_0(I\rho)^I \rho}{I!(1-\rho)^2}[1 - \rho^{U-I+1} - (1-\rho)(U-I+1)\rho^{U-I}] + I - P_0 \sum_{k=0}^{k=I-1} \frac{(I-k)(\rho I)^k}{k!} \qquad (2.2)$$

where, ρ = utilization rate, k = number of ships in the system

I = number of inspectors, and

U = the upper limit on the maximum number of ships in the port

where,

$$P_0 = [\sum_{k=0}^{k=I-1} (1/k!)(\lambda/\mu)^k + \{(\lambda/\mu)^I / I!\}\{(1-\rho^{U-I+1})/(1-\rho)\}]^{-1} \qquad (2.3)$$

To obtain $E(S)$ for the $M/M/I/I$ regime, U is substituted for I and equation 2.4 determined as

$$E(S) = I - P_0 \sum_{k=0}^{k=I-1} \frac{(I-k)(\rho I)^k}{k!}, \tag{2.4}$$

where,

$$P_0 = [\sum_{k=0}^{k=I-1} (1/k!)(\lambda/\mu)^k + \{(\lambda/\mu)^I / I!\}]^{-1} \tag{2.5}$$

The analysis contained in this paper can be extended to several studies. For example, it is useful to investigate the properties of more general inspection regimes in which ship arrivals and the service times of inspectors are characterized by general distribution functions. It is also needed to calculate the optimal number of inspectors as a continuous choice problem.

2.7.2 Truck Turnaround Time

Truck turnaround time is the time it takes a truck to complete a transaction such as picking up an import container or dropping off a container. Usually, before the inspection station, there are four activities which can impact the truck turnaround time. These actives include the gate-in process, yard crane process, inner transport vehicle (AGV or SC) process and gate-out process. Huynh et al. (2004) addressed two common measures terminal operators are looking at to reduce the truck turnaround time at seaport container terminals. One is adding yard cranes and the other is employing a truck appointment system. This study developed methodologies to assist terminal operators in evaluating and applying the truck turnaround time reducing measures. To assist terminal operators in deciding whether or not to purchase additional cranes and to determine the number to purchase, this study developed a methodology to study the availability of cranes versus truck turnaround time. In addition, this study developed a

framework which terminal operators could use to optimally run the truck appointment system. The study sought a solution that was beneficial for both the terminal operator and truckers. Moreover, the formulation accounted for truckers with appointments showing up late or not showing up at all.

To study the availability of cranes versus truck turnaround time, the approach taken was to employ statistical models. The models included multiple regression models, polynomial regression models, and non-linear in parameter regression models. The non-linear in parameter model yielded the best fit (i.e. highest R-squared). Through the estimating procedure, it was identified that truck turnaround time is primarily affected by the ratio of road moves to be performed to the number of yard cranes available.

2.7.3 Other Related Literature

No published literature on the impact of inspections on seaport container terminals operations could be found. For this reason, the goal of this research is to estimate the additional truck turnaround time due to trucks having to be inspected at the seaport container terminal.

One related study developed a literature of truck weigh station model (Fekpe et al., 1993) to estimate the truck turnaround time based on various weigh station configurations at the seaport. The other used queuing theory to study the impact of two alternative manpower levels on the performance of continuously operated permanent weigh scales. The queuing model for the permanent scale operations represents a classic $M / E_k / 1$ model. The probability density function of the Erlang distribution is specified by the rate parameter, R, and the shape parameter, k. The density function is determined as

$$f(t) = \frac{R(Rt)(k-1)e^{-Rt}}{(k-1)!}$$
$$t > 0, k > 0, k = 1, 2, \ldots$$

(2.6)

The alternative arrangement of using only one attendant has been demonstrated to have little effect on truck delays. The queuing model is therefore a $M/E_k/1$ queue where there is random arrival and departure (Markovian) with Erlang service distribution and one server. The average queue length can be determined as

$$E(Q) = \rho + \frac{\rho^2(k+1)}{2k(1-\rho)}$$

(2.7)

and the expected waiting time in the queue can be derived from $Q = \lambda W$. The expected queue length at the permanent weigh scale can be generalized as

$$E(Q) = \rho + \frac{5\rho^2}{8(1-\rho)}$$

(2.8)

The two alternative operating strategies considered are (1) two scale attendants operating the two scales at the station (two single servers), and (2) one scale attendant operating both scales at the station (single server with multiple arrivals). The queue length for the latter case is numerically higher than that of the former case, but in either case there is no queue for the majority of the time. Furthermore, the average total waiting time per truck, irrespective of case, is less than 1 minute. Hence there is little delay to truck traffic at the scales.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Six base models for the prediction of additional truck turnaround time and determining the number of inspection equipment at an inspection station are developed and used in this research. The models include a single M/M/1 model (SMM), a multiple M/M/c model (MMM), a single channel and multiple stages model (SCMSM), and three multiple channel and multiple stages model (MCMSM) including MCMSM-Single and Multiple, MCMSM-Multiple and Single, and MCMSM-Multiple and Multiple. Each of the models is used under various layouts, inspection policies, security levels of the container seaport and government agencies. There are various critical parameters including the container arrival rate. This arrival rate varies by season, year, level of security, oil price, trade negotiation, market trend, weather, and other issues. Another variable is the inspection rate. The inspection rate depends on the type of equipment, number of equipment, equipment technology, and level of security. The rate of using the Green Lane is also a critical parameter. This rate is the rate of arrival of containers stuffed by a C-TPAT certified shipper. The container must have originated from a CSI port and ISPS-certified ports, container carried by C-TPAT certified rail/truck/ocean carriers, container delivered to C-TPAT importer, and level of security. Furthermore, this research can provide the additional truck turnaround time at a container seaport terminal in terms of several of the above variables. The developed SMM, MMM, SCMSM and MCMSM models are described in the following sections.

3.2 Single M/M/1 Model (SMM)

Some container terminals have especially small capacities and utilize a single inspection station. Therefore, the first analysis used in this research is the study of the inspection station as a queuing model with a single server. The purpose of a queuing model is to mathematically analyze waiting lines or queues. All queuing models have three factors including: (1) a random arrival process (2) a probabilistic service time distribution function, and (3) a deterministic number of available servers. In the queuing models of this research, the arrival process is the Poisson process. In this case, the times between successive arrivals of containers are exponentially distributed. The Poisson arrival process is routinely described by the letter M. The inspection times are random in terms of the container's risk and security level and the present inspection time does not affect future inspection time. Hence, in the queuing models of this research, these services times are exponentially distributed. The letter M is also used to symbolize the service time distribution functions. Finally, the non-stochastic number of servers is typically denoted by some positive integer and describes the number of inspection equipment. In the inspection system, only one container can be served at a server until the inspection is completely finished. This means that an inspection cannot be made at the same time as another container is being inspected. Therefore, in this paper, a single M/M/1 model is used for a single inspection station. It is assumed that containers are served on a first come first served basis, and assigned to equipment of inspection randomly. The queuing system of this single inspection station (SMM) can be summarized as shown in Figure 3.1.

Inspection Station
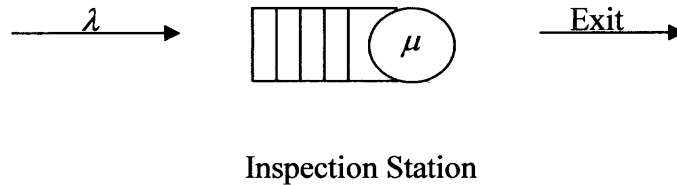
Figure 3.1 SMM at single inspection station.

where, λ = average container arrival rate

μ = average service rate at inspection station

3.2.1 Arrival Pattern

In the queuing model, the arrival pattern is represented by a probability distribution function in terms of the number of arrivals in a particular interval of time (number of inter-arrival time), while the service pattern is represented by a probability distribution function in terms of the number of units serviced in a particular interval of time.

The Poisson distribution is used to calculate the probability of a specific number of events occurring in a particular interval of time. The exponential distribution models time between Poisson events.

The Poisson Law states the following:

1. The probability that one event occurs in time interval $[t, t + \Delta t] = \lambda * \Delta t$. Therefore, the probability of no arrivals in Δt is $1 - \lambda * \Delta t$.

2. Events are orderly, meaning that more than one event cannot happen at the same time.

3. The number of events occurring in two non-overlapping intervals is independent.

4. According to (1), the number of events occurring in two equal length intervals is statistically the same because it is independent of time t.

It is assumed that a probability distribution for the number of container arrivals in a particular interval of time at the first stage in this inspection station follows a Poisson distribution determined as:

$$P(x,\lambda) = \frac{e^{-\lambda}\lambda^x}{x!}$$

(3.1)

where, λ = average container arrival rate; and
x = number of container arrivals.

3.2.2 Inspection Pattern

The inspection time refers to the length of time that a customer spends in the inspection station. The inspection pattern can be described as a probability distribution in terms of the number of containers served in a particular interval of time. The inspection rate of μ is exponentially distributed with a mean rate $1/\mu$, because the present inspection rate does not affect future rates. This exponential distribution is the only continuous distribution having a memoryless property. Therefore, it can be assumed that a probability distribution for the number of containers served in a particular interval of time at both the first inspection stage and the second inspection stage follows an exponential distribution determined as:

$$f(t) = \mu e^{-\mu t} \quad (if, t \geq 0)$$

(3.2)

where, t = inspection time; and
μ = average inspection rate.

The probability to complete the inspection within the time interval t is determined as:

$$P(T \leq t) = 1 - e^{-\mu t} \qquad (3.3)$$

As it was previously mentioned, SMM is a queuing model having a Poisson arrival process and exponential distribution of inspection times. This model has a birth-death process having a birth rate and death rate as follows:

$$\lambda_n = \lambda \ (n \geq 0), \ \mu_n = \mu \ (n \geq 1) \qquad (3.4)$$

where, n = number of container trucks in the system

Its flow-rate diagram is shown as follows:
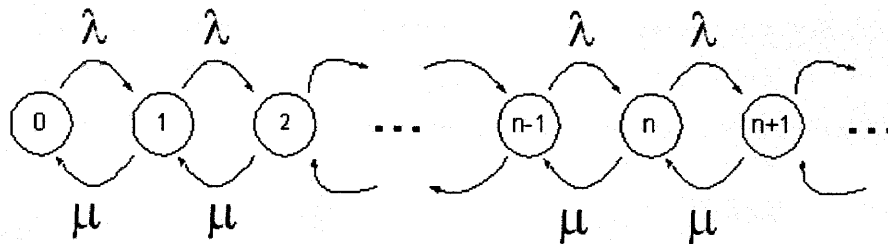
Source: Lee (2006)
Figure 3.2 Flow-rate Diagram for the Process of Customers of SMM

This diagram shows birth (λ) and death rate (μ) at each state of the inspection process for containers in a single M/M/1 model. The steady-state probability (P_n) of the above birth-death process is given in Equations 3.5 and 3.6.

$$P_n = \frac{\prod_{i=0}^{n-1} \lambda_i}{\prod_{i=1}^{n} \mu_i} P_0 = (1 - \frac{\lambda}{\mu})(\frac{\lambda}{\mu})^n = (1-\rho)\rho^n, \ (n \geq 0) \tag{3.5}$$

where,

$$P_0 = \left[1 + \sum_{n=1}^{\infty} \left\{ \frac{\prod_{i=0}^{n-1} \lambda_i}{\prod_{i=1}^{n} \mu_i} \right\} \right]^{-1} = \left[\sum_{n=0}^{\infty} \left(\frac{\lambda}{\mu}\right)^n \right]^{-1} = 1 - \frac{\lambda}{\mu} = 1 - \rho, \text{ and } \rho = \frac{\lambda}{\mu} \tag{3.6}$$

The average number of trucks in the inspection system (L) is as follows:

$$L = \sum_{n=0}^{\infty} nP_n = \sum_{n=0}^{\infty} n\rho^n (1-\rho) = \frac{\rho}{1-\rho} \tag{3.7}$$

The average number of trucks in the queue (L_q) is:

$$L_q = \sum_{n=1}^{\infty} (n-1)P_n = \frac{\rho^2}{1-\rho} \tag{3.8}$$

The average additional truck time at the inspection system ($ATTT_{SMM}$) is stated as follows:

$$ATTT_{SMM} = \frac{L}{\lambda} = \frac{\sum_{n=0}^{\infty} n\rho^n(1-\rho)}{\lambda} = \frac{1}{\mu(1-\rho)} \qquad (3.9)$$

Average additional truck time at the queue ($ATTT_{q,SMM}$) is:

$$ATTT_{q,SMM} = \frac{L_q}{\lambda} = \frac{\sum_{n=1}^{\infty} (n-1)P_n}{\lambda} = \frac{\rho}{\mu(1-\rho)} \qquad (3.10)$$

The utilization rate is defined as arrival rate over inspection rate multiply by number of inspection equipment. If the utilization rate of equipment (ψ) is close to 1 (i.e., the arrival rate is equal to the service rate), a small increase in the truck arrival rate (or a small decrease in the inspection rate) will cause the time of average additional truck turnaround time at the inspection equipment ($ATTT_{q,SMM}$) to increase dramatically. Therefore, the number of inspection equipment will affect significantly truck turnaround time at a container seaport terminal. This model can also be used at a SCMSM and MCMSM Model with single equipment.

3.3 Multiple M/M/c Model (MMM)

Some container terminals have a single inspection station with multiple inspection equipment. Therefore, the second analysis considers the inspection station as a queuing model with multiple servers at one stage. This inspection station layout is shown as follows.
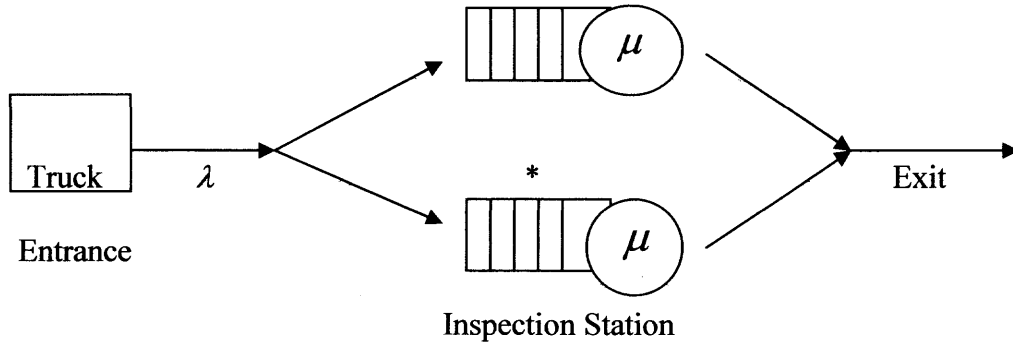
Figure 3.3 MMM at Single Inspection Station.

The M/M/c system has a birth-death process having birth and death rates as follows,

$$\lambda_n = \lambda \ (n \geq 0),$$ (3.11)

where, n = number of container trucks in the system

$$\mu_n = \begin{cases} n\mu & (1 \leq n \leq c-1) \\ c\mu & (n \geq c) \end{cases}$$ (3.12)

The steady-state probability (P_n) at each state is shown in equations 3.13 and 3.14

$$P_0 = \left[\sum_{k=0}^{c-1} \frac{a^k}{k!} + \frac{a^c}{c!} * \frac{1}{(1-\rho)} \right]^{-1}$$ (3.13)

where, $\rho = \dfrac{\lambda}{c\mu}$, $a = \dfrac{\lambda}{\mu}$

$$P_n = \begin{cases} \dfrac{(c\rho)^n}{n!} * P_0 & (1 \leq n \leq c-1) \\[4mm] \dfrac{(c\rho)^c}{c!} * \rho^{n-c} P_0 & (n \geq c) \end{cases}$$ (3.14)

The average number of trucks in the queue (Tq) in the MMM model is:

$$Tq = \sum_{n=c}^{\infty}(n-c)P_n = \frac{(c\rho)^c}{c!} * \frac{\rho}{(1-\rho)^2}P_0 = \frac{\rho}{(1-\rho)^2}P_c \tag{3.15}$$

The average number of trucks in the inspection system (T_{MMM}) in the MMM model is:

$$T_{MMM} = \sum_{n=c}^{\infty}(n-c)P_n + \frac{\lambda}{\mu} = \frac{(c\rho)^c}{c!} * \frac{\rho}{(1-\rho)^2}P_0 + \frac{\lambda}{\mu} = \frac{\rho}{(1-\rho)^2}P_c + \frac{\lambda}{\mu} \tag{3.16}$$

The average additional truck time in the queue ($ATTTq_{,MMM}$) in the MMM model is:

$$ATTTq_{,MMM} = \frac{\sum_{n=c}^{\infty}(n-c)P_n}{\lambda} = \frac{\frac{(c\rho)^c}{c!} * \frac{\rho}{(1-\rho)^2}P_0}{\lambda} = \frac{\frac{\rho}{(1-\rho)^2}P_c}{\lambda} \tag{3.17}$$

The average additional truck time at the inspection system ($ATTT_{MMM}$) in the MMM model is:

$$ATTT_{MMM} = \frac{\sum_{n=c}^{\infty}(n-c)P_n}{\lambda} + \frac{1}{\mu} = \frac{\frac{(c\rho)^c}{c!} * \frac{\rho}{(1-\rho)^2}P_0}{\lambda} + \frac{1}{\mu} = \frac{\frac{\rho}{(1-\rho)^2}P_c}{\lambda} + \frac{1}{\mu} \tag{3.18}$$

This model can be used at each stage with multiple equipment in the Multiple Channels and Multiple Stages Model – Single and Multiple (MCMSM-SM), Multiple Channels and Multiple Stages Model – Multiple and Single (MCMSM-MS), and Multiple Channel and Multiple Stages Model – Multiple and Multiple (MCMSM-MM).

3.4 Single Channel and Multiple Stages Model (SCMSM)

Some container seaports have especially high volumes of containers from risky foreign countries. These containers must pass at a minimum through two inspection stages. The first stage consists of a passive inspection, while the second stage consists of an active inspection. Even if each port has different layouts for the stages of the inspection station, a SCMSM can be applied to the port having multiple stages to analyze the impact of the layout on truck turnaround time. Truck delays at inspection stations in seaport container terminals are caused by several factors including the type and number of inspection equipment and the inspection procedure. This model considers the inspection process as having two stages. During the first stage, all containers entering into the U.S. should be inspected. During the second stage, some of containers which failed inspection or unreliable during the first stage need an inspection at the second stage with an imaging system. The SCMSM is the approach to determine expected delays for a variety of truck flow rates, service rates and inspection procedures. The delay time is the additional time required to inspect trucks at each stage of the inspection process. These additional times are combined for each stage to obtain the additional truck turnaround time due to inspection. The queuing system of this model can be summarized as shown in Figure 3.4.
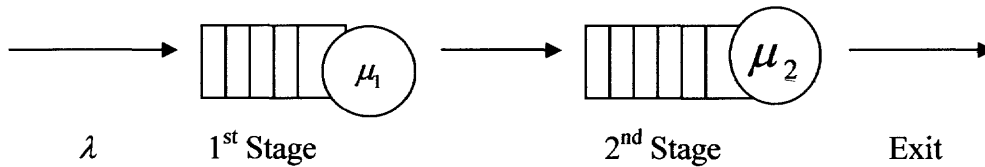
Figure 3.4 Diagram of SCMSM at Inspection Station

where, λ = average container arrival rate

μ_1 = average service rate at 1st Stage

μ_2 = average service rate at 2nd Stage

In this Figure, containers have an arrival rate λ . At the first and second stages the service rates are μ_1 and μ_2 respectively. It is assumed that there is an sufficient waiting area in both stages.

3.4.1 Departure and Arrival pattern Between Stages

According to Burke (1956) and Reich (1957), the departure (or output) process of an M/M/1 and M/M/c queue follows a Poisson process. This results in a Poisson probability distribution for the number of container arrivals to the second inspection stage.

3.4.2 Burke's Theorem

If the departure distribution is spilt into half from the first stage of a M/M/1 or M/M/c queue, the distribution will end up at the next stage of exponential servers with the Poisson arrival rate halved. Poisson processes may be evenly separated and combined. The sum of two Poison process (λ_1, λ_2) produce a Poisson process with $\lambda = \lambda_1 + \lambda_2$. Furthermore, a Poisson process (λ) may be split into two Poisson processes (λ_1, λ_2) having $\lambda = \lambda_1 + \lambda_2$. The Figure below

shows the departure rate in the SCMSM with the same arrival rate λ in each stage of the M/M/1 as well as in the exit of the inspection station if the arrival rate is less than inspection rate at the first stage.
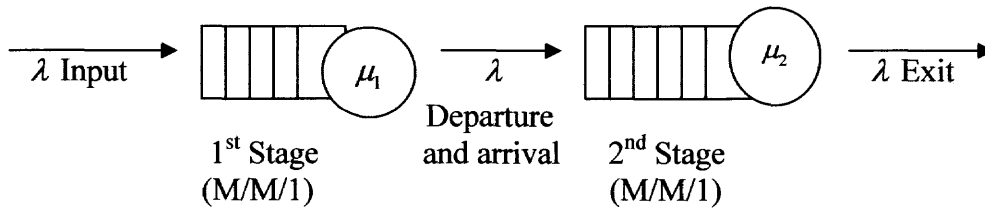
Figure 3.5 Diagram of Departure Rate in SCMSM.

Jackson (1957) developed a product-form solution for the steady-state probability $P(s_1, s_2)$ in tandem queues. This solution describes the probability of a specific number of containers is in the first stage (s_1) and a specific number of containers in the second stage (s_2) shown in Equation 3.19.

$$P(s_1, s_2) = (1 - \rho_1)\rho_1^{s_1} * (1 - \rho_2)\rho_2^{s_2} \tag{3.19}$$

$$\text{where, } \rho_1 = \frac{\lambda}{\mu_1} \text{ and } \rho_2 = \frac{\lambda}{\mu_2} \tag{3.20), (3.21}$$

According to Jackson's theorem, the numbers of containers at each stage in the SCMSM are independent of each stage and the following equations apply.

The average number of trucks at the first stage of the inspection system (T_{1s}) is:

$$T_{1s} = \sum_{n=0}^{\infty} nP_n = \sum_{n=0}^{\infty} n\rho_{1s}{}^n(1-\rho_{1s}) = \frac{\rho_{1s}}{1-\rho_{1s}} \tag{3.22}$$

The average additional truck time at the first stage of the inspection system ($ATTT_{1s,SCMSM}$) first stage is:

$$ATTT_{1s,SCMSM} = \frac{T_{1s}}{\lambda} = \frac{\sum_{n=0}^{\infty} n\rho_{1s}{}^n(1-\rho_{1s})}{\lambda} = \frac{1}{\mu_{1s}(1-\rho_{1s})} \tag{3.23}$$

The average number of trucks at the second stage of the inspection system (T_{2s}) is:

$$T_{2s} = \sum_{n=0}^{\infty} nP_n = \sum_{n=0}^{\infty} n\rho_{2s}{}^n(1-\rho_{2s}) = \frac{\rho_{2s}}{1-\rho_{2s}} \tag{3.24}$$

The average additional truck time at the second stage of the inspection system ($ATTT_{2s,SCMSM}$) is:

$$ATTT_{2s,SCMSM} = \frac{T_{2s}}{\lambda} = \frac{\sum_{n=0}^{\infty} n\rho_{2s}{}^n(1-\rho_{2s})}{\lambda} = \frac{1}{\mu_{2s}(1-\rho_{2s})} \tag{3.25}$$

Based on Jackson's theorem, a SCMSM model can be used to analyze the inspection station as though each stage of the inspection is isolated from all the others.

Therefore, the total additional truck turnaround time ($ATTT_{SCMSM}$) at the inspection system can be obtained as a sum of the additional truck turnaround time at each stage as follows:

$$ATTT_{SCMSM} = ATTT_{1s,SCMSM} + ATTT_{2s,SCMSM} \qquad (3.26)$$

3.5 Multiple Channels and Multiple Stages Model (MCMSM)

One of the objectives of this research is to determine the number of inspection equipment needed to manage or reduce truck turnaround times at inspection station with multiple channels and multiple stages (MCMSM). To avoid extremely large truck turnaround times at the inspection station when the utilization rate is close to 1, Customs Border Protection (CBP) needs to install sufficient inspection equipment. This dissertation determines how many additional inspection equipments are needed to reduce truck turnaround time to an acceptable level. An analysis of the number of container trucks and the resulting truck turnaround time will be provided as a function of the number of available equipment.

The MCMSM can be divided into three sub-models including MCMSM-Single and Multiple (MCMSM-SM), MCMSM-Multiple and Single (MCMSM-MS) and MCMSM-Multiple and Multiple (MCMSM-MM). These sub-models' layouts are shown in Figure 3.6.

Notation	Inspection Diagram
SMM **(Single M/M/1 Model)**	Single Equipment
MMM **(Multiple M/M/c Model)**	Multiple Equipment
SCMSM	Single Equipment → Single Equipment
MCMSM-SM	Single Equipment → Multiple Equipment
MCMSM-MS	Multiple Equipment → Single Equipment
MCMSM-MM	Multiple Equipment → Multiple Equipment
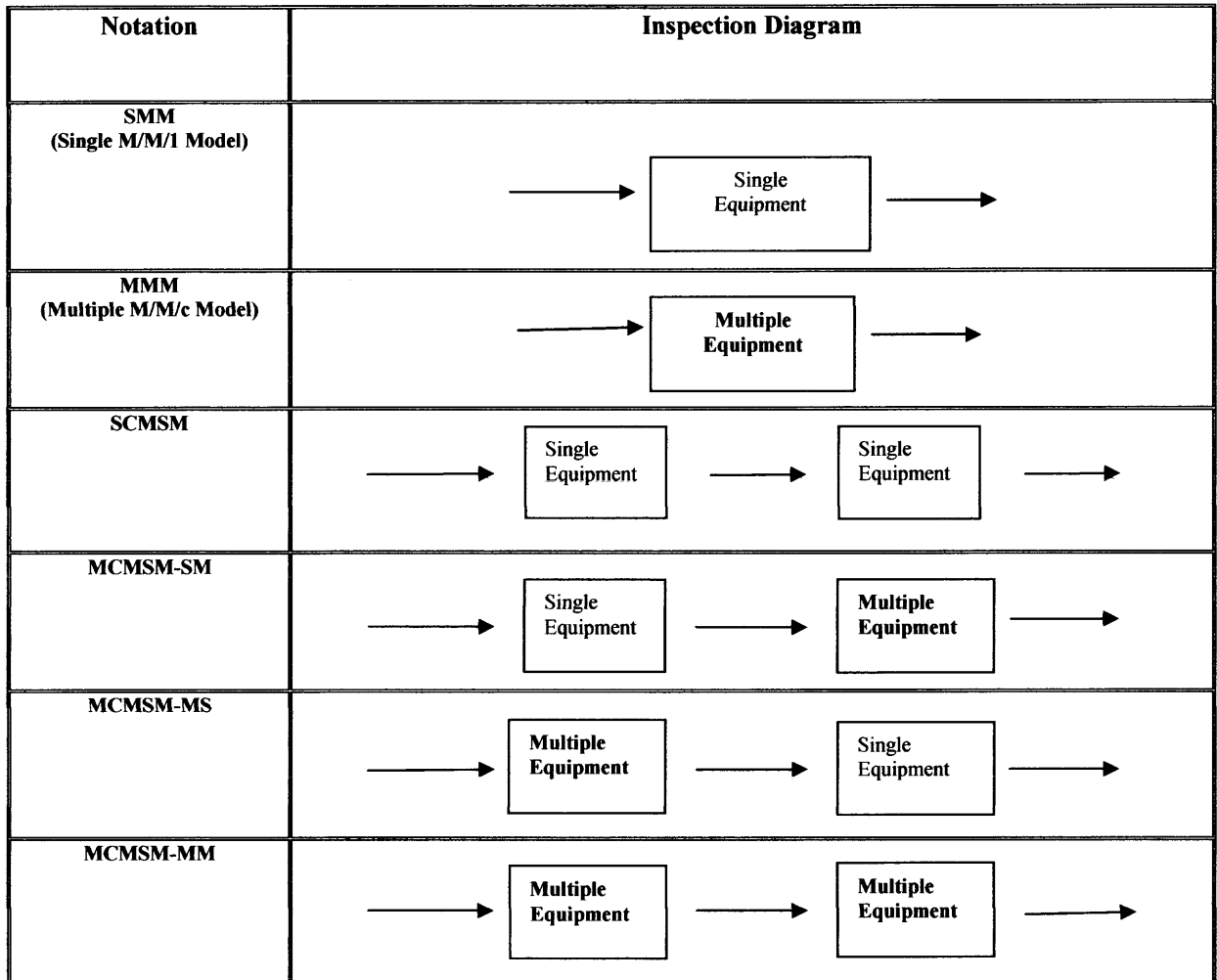
Figure 3.6 Diagram of Queuing Models

In Figure 3.6, the diagram of each model shows either a single stage inspection procedure or a two stage inspection procedure. The MCMSM-SM is used to determine the expected truck turnaround time by using one inspection equipment at the first stage and a M/M/1 queuing model and multiple equipment at the second stage using a M/M/c queuing model having identical inspection rates. Conversely, the MCMSM-MS determines the truck turnaround time by using multiple equipment having identical inspection rates and M/M/c model at the first stage and one equipment and a M/M/1 model at the second stage for a variety of truck flow

rates, service rates and a rate of Green Lane usage. The MCMSM-MM uses multiple equipments for both the first and second stages.

Figure 3.7 shows the formulation for additional truck turnaround times for the SMM, MMM, SCMSM, MCMSM-SM, MCMSM-MS, and MCMSM-MM models.

Notation	Formulation
Formulation For ATTT (SMM) (Additional Truck Turnaround Time)	$$ATTT_{SMM} = \frac{L}{\lambda} = \frac{\sum_{n=0}^{\infty} n\rho^n (1-\rho)}{\lambda} = \frac{1}{\mu(1-\rho)},$$ where, λ = container arrival rate, μ = inspection rate ψ = utilization rate.
Formulation For ATTT (MMM)	$$ATTT_{MMM} = \frac{\sum_{n=c}^{\infty}(n-c)P_n}{\lambda} + \frac{1}{\mu} = \frac{\frac{(c\rho)^c}{c!} * \frac{\rho}{(1-\rho)^2} P_0}{\lambda} + \frac{1}{\mu} = \frac{\frac{\rho}{(1-\rho)^2} P_c}{\lambda} + \frac{1}{\mu}$$ where, $P_0 = \left[\sum_{k=0}^{c-1} \frac{a^k}{k!} + \frac{a^c}{c!} * \frac{1}{(1-\rho)} \right]^{-1}$ where, $\rho = \frac{\lambda}{c\mu}, \ a = \frac{\lambda}{\mu}$ $$P_n = \begin{cases} \frac{(c\rho)^n}{n!} * P_0 & (1 \le n \le c-1) \\ \frac{(c\rho)^c}{c!} * \rho^{n-c} P_0 & (n \ge c) \end{cases}$$
Formulation For ATTT (SCMSM)	$$ATTT_{SCMSM} = ATTT_{1s,SMM} + ATTT_{2s,SMM}$$
Formulation For ATTT (MCMSM-SM)	$$ATTT_{MCMSM-SM} = ATTT_{1s,SMM} + ATTT_{2s,MMM}$$
Formulation For ATTT (MCMSM-MS)	$$ATTT_{MCMSM-MS} = ATTT_{1s,MMM} + ATTT_{2s,SMM}$$
Formulation For ATTT (MCMSM-MM)	$$ATTT_{MCMSM-MM} = ATTT_{1s,MMM} + ATTT_{2s,MMM}$$

Figure 3.7 Formulation of Queuing Models

The queuing system for these MCMSM models can be summarized as shown in Figures 3.8, 3.9 and 3.10.

$$\lambda$$

First Stage
M/M/1
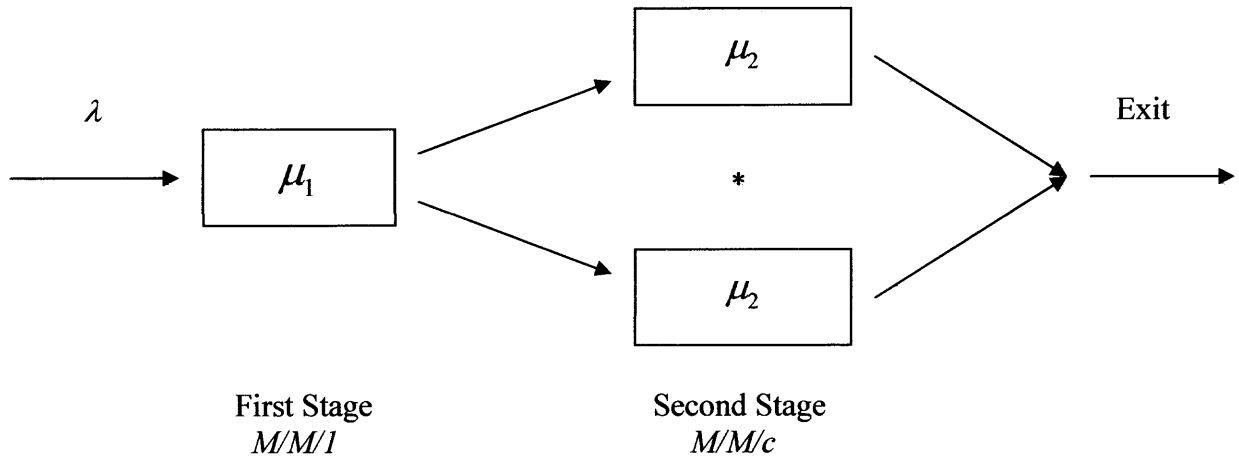
Second Stage
M/M/c

Figure 3.8 Diagram of MCMSM-SM at Inspection Station

Where, λ = average container arrival rate

μ_1 = average inspection rate at first stage

μ_2 = average inspection rate at second stage

The MCMSM-SM (Multiple Channel and Multiple Stage Model – Single and Multiple) includes a SMM (Single M/M/1) queuing model at the first stage and MMM (Multiple M/M/c) queuing model at the second stage. According to Burke's (1956) departure theorem, the departure (or output) process from the first stage of an M/M/c queuing system also follows Poisson process. This means that the probability distribution for the number of arriving containers in a particular interval of time from the first stage to the second stage in this inspection station follows a Poisson distribution with an arrival rate of λ , if the arrival rate is less than the inspection rate.

First Stage
$M/M/c$
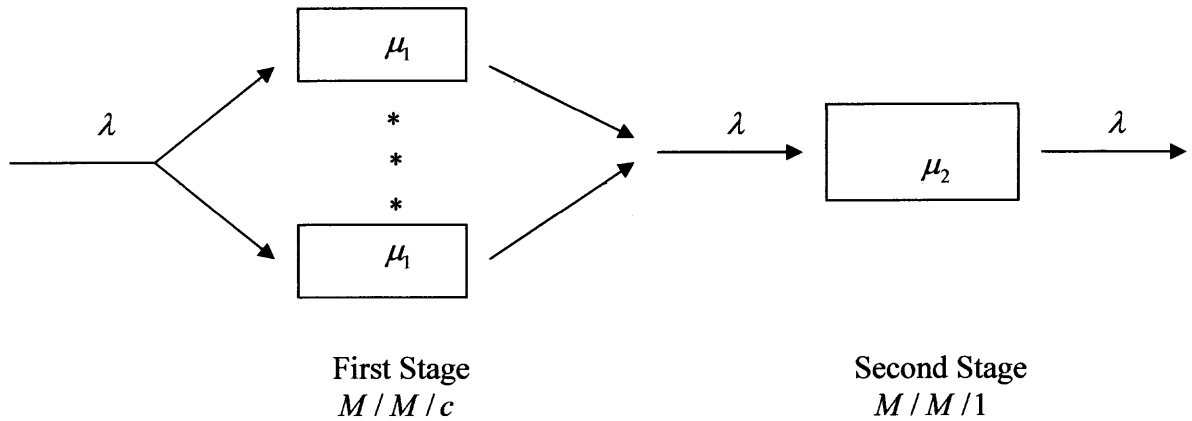
Second Stage
$M/M/1$

Figure 3.9 Diagram of MCMSM-MS at Inspection Station.

The MCMSM-MS model includes a multiple M/M/c Model at the first stage and a single M/M/1 model at the second stage.

First Stage
$M/M/c_1$
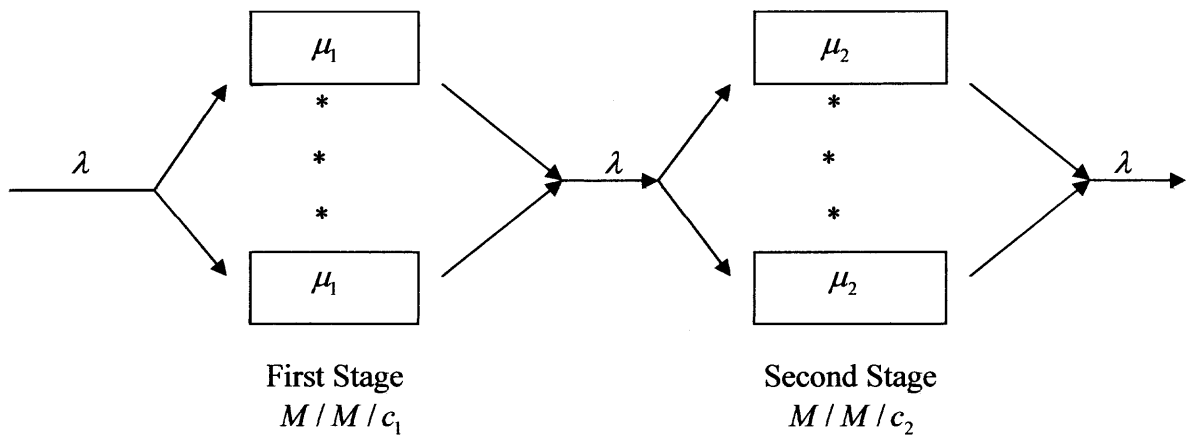
Second Stage
$M/M/c_2$

Figure 3.10 Diagram of MCMSM-MM at Inspection Station.

The MCMSM-MM model includes a multiple M/M/c model at both the first and second stages. Based on Jackson's (1957) theorem, the number of containers at each stage in the MCMSM is independent of each other. The following equations describe the Multiple Channel

and Multiple Stage Model – Multiple and Single (MCMSM – MS) and Multiple Channel and Multiple Stage Model – Multiple and Multiple (MCMSM – MM).

The average number of trucks in the queue ($T_{1s}q$) of the first stage of the MCMSM-MS and MCMSM-MM is as follows:

$$T_{1s}q = \sum_{n=c}^{\infty}(n-c)P_n = \frac{(c\rho)^c}{c!} * \frac{\rho_{1s}}{(1-\rho_{1s})^2}P_0 = \frac{\rho_{1s}}{(1-\rho_{1s})^2}P_c \qquad (3.27)$$

The average number of trucks in the inspection system ($T_{1s,MCMSM}$) in the first stage of the MCMSM-MS and MCMSM-MM is as follows:

$$T_{1s,MCMSM} = \sum_{n=c}^{\infty}(n-c)P_n + \frac{\lambda}{\mu_1} = \frac{(c\rho)^c}{c!} * \frac{\rho_{1s}}{(1-\rho_{1s})^2}P_0 + \frac{\lambda}{\mu_1} = \frac{\rho_{1s}}{(1-\rho_{1s})^2}P_c + \frac{\lambda}{\mu_1} \qquad (3.28)$$

The average truck time at the queue ($ATTT_{1s}q_{,MCMSM}$) of the first stage of the MCMSM-MS and MCMSM-MM is as follows:

$$ATTT_{1s}q_{,MCMSM} = \frac{\sum_{n=c}^{\infty}(n-c)P_n}{\lambda} = \frac{\frac{(c\rho_{1s})^c}{c!} * \frac{\rho_{1s}}{(1-\rho_{1s})^2}P_0}{\lambda} = \frac{\frac{\rho_{1s}}{(1-\rho_{1s})^2}P_c}{\lambda} \qquad (3.29)$$

The average truck time in the inspection system ($ATTT_{1s,MCMSM}$) of the first stage of the MCMSM is as follows:

$$ATTT_{1s,MCMSM} = \frac{\sum_{n=c}^{\infty}(n-c)P_n}{\lambda} + \frac{1}{\mu_1} = \frac{\frac{(c\rho_{1s})^c}{c!} * \frac{\rho_{1s}}{(1-\rho_{1s})^2}P_0}{\lambda} + \frac{1}{\mu_1} = \frac{\frac{\rho_{1s}}{(1-\rho_{1s})^2}P_c}{\lambda} + \frac{1}{\mu_1} \qquad (3.30)$$

The average number of trucks in the inspection system $(T_{2s,MCMSM-MS})$ of the second stage of the MCMSM-MS is as follows:

$$T_{2s,MCMSM-MS} = \sum_{n=0}^{\infty} nP_n = \sum_{n=0}^{\infty} n\rho_{2s}{}^n(1-\rho_{2s}) = \frac{\rho_{2s}}{1-\rho_{2s}} \qquad (3.31)$$

The average additional trucks time in the inspection system ($ATTT_{2s,MCMSM-MS}$) of the second stage of the MCMSM-MS is as follows:

$$ATTT_{2s,MCMSM-MS} = \frac{L_{2s}}{\lambda} = \frac{\sum_{n=0}^{\infty} n\rho_{2s}{}^n(1-\rho_{2s})}{\lambda} = \frac{1}{\mu_2(1-\rho_{2s})} \qquad (3.32)$$

The average number of trucks in the inspection system $(T_{2s,MCMSM-MM})$ of the second stage of MCMSM-MM is as follows:

$$T_{2s,MCMSM-MM} = \sum_{n=c}^{\infty}(n-c)P_n + \frac{\lambda}{\mu_2} = \frac{(c\rho)^c}{c!} * \frac{\rho_{2s}}{(1-\rho_{2s})^2} P_0 + \frac{\lambda}{\mu_2} = \frac{\rho_{2s}}{(1-\rho_{2s})^2} P_c + \frac{\lambda}{\mu_2} \qquad (3.33)$$

The average truck turnaround time in the inspection system ($ATTT_{2s,MCMSM-MM}$) of the second stage of the MCMSM-MM is as follows:

$$ATTT_{2s,MCMSM-MM} = \frac{\sum_{n=c}^{\infty}(n-c)P_n}{\lambda} + \frac{1}{\mu_2} = \frac{\frac{(c\rho_{2s})^c}{c!} * \frac{\rho_{2s}}{(1-\rho_{2s})^2} P_0}{\lambda} + \frac{1}{\mu_2} = \frac{\frac{\rho_{2s}}{(1-\rho_{2s})^2} P_c}{\lambda} + \frac{1}{\mu_2} \qquad (3.34)$$

The MCMSM model can be analyzed as though each stage is independent from the others. Therefore, the total truck turnaround times in the inspection system of a MCMSM-MS

model and $ATTT_{MCMSM-MM}$ of a MCMSM-MM model can be obtained by summing the times at both stages as follows:

$$ATTT_{MCMSM-MS} = ATTT_{1s,MCMSM} + ATTT_{2s,MCMSM-MS} \tag{3.35}$$

$$ATTT_{MCMSM-MM} = ATTT_{1s,MCMSM} + ATTT_{2s,MCMSM-MM} \tag{3.36}$$

CHAPTER 4

SENSITIVITY ANALYSIS

4.1 Introduction

The queuing models presented in the previous chapter will be used to analyze and evaluate the truck turnaround time at container seaport inspection stations. The rate of containers entering into the inspection station is dependent on several variables including the season, year, level of security, level of oil prices, market trends, weather, and political issues. The inspection rate is dependent on the equipment technology, number of equipment, and level of security.

In this chapter, truck turnaround time at inspection stations will be analysed as a function of the container arrival rate, inspection rate, usage of the Green Lane, and the level of security. The objectives of this sensitivity analysis are to identify relationships between security levels, inspection time and arrival rate, identifying the effectiveness of the inspection equipment's utilization rate in reducing delay time, and analyzing the number of equipment and delay time in terms of various layouts of the inspection station. This research does not use field data of seaport container inspections due to security restrictions imposed by the CBP on collecting this information. Therefore, certain assumptions were made to perform the sensitivity analysis including:

- First Come First Served Inspection;

- Container will go to empty inspection station if others are already occupied;

- In multiple channels, all inspection rates at the same stage are identical;

- All capacity at the system including between stage and stage is infinite;

- There is a 30 sec differential in inspection rates between each security level in the first stage, and 1 min in the second stage; and

- The stochastic arrival process (birth) rate and inspection (death) rate of the system is in steady state.

The probability distribution describing truck arrivals, inspection time, and the effect of Green Lane Usage is summarized in the sensitivity analysis that follows.

4.2 Probability Distribution for Truck Arrivals

Previous research performed by Andrea et al. (2002) and Sgouris et al. (2003) used a random arrival process to estimate the truck turnaround time at container pick-up yards and the entrance gate at seaport terminals. This random arrival constitutes a Poisson distribution as already stated in section 3.2.1.

Figure 4.1 shows the probability distribution for various truck arrival rates. It is assumed that the number of arrivals is independent and identically distributed. For example, when the arrival rate (AR) is 5 trucks/hr, the probability distribution peaks at approximately 0.18.
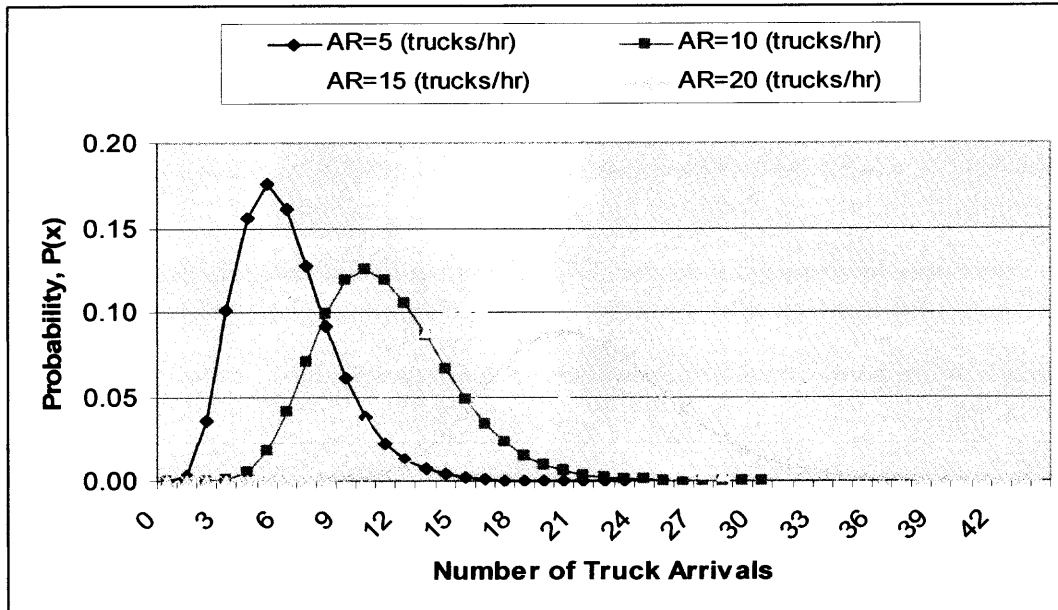
Figure 4.1 Probability Distribution for Truck Arrivals in SMM model.

The probability distribution of the interarrival time between container trucks follows an exponential distribution which is determined as stated already in equation 3.2.

Figure 4.2 shows the probability distribution of the interarrival time between trucks for the SMM Model. The distribution of truck interarrival times is exponential and it is shown for four different into arrival times.
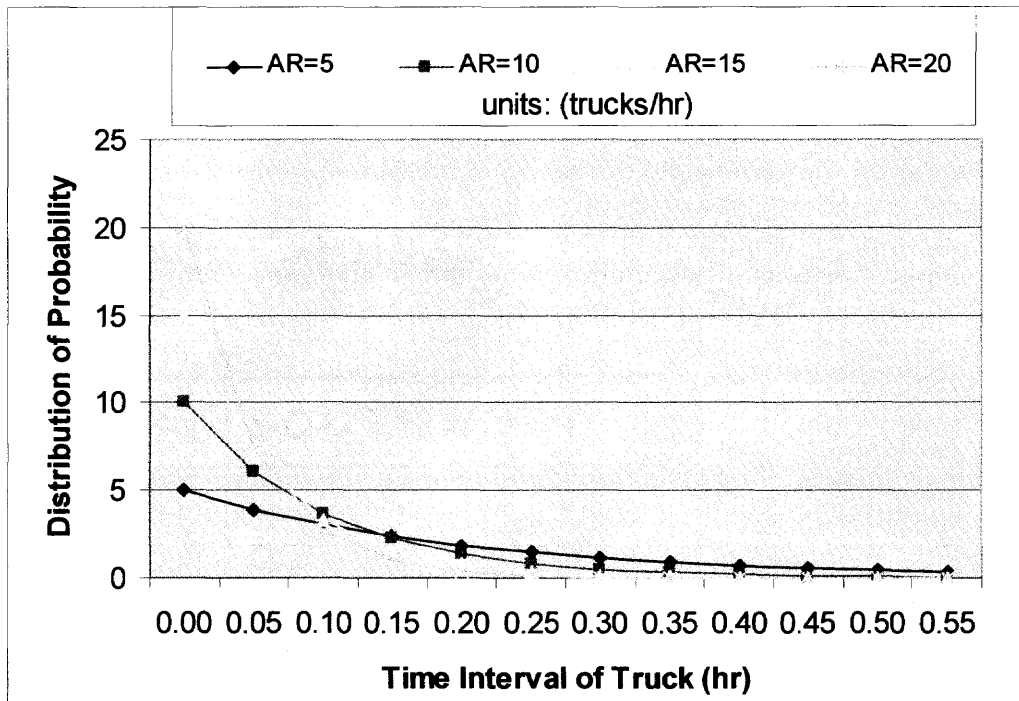
Figure 4.2 Probability Distribution for Interarrival Time of Truck Arrivals in SMM model.

The inspection time refers to the length of time that a truck spends in the inspection station. The inspection pattern can be described by the probability distribution, which governs the number of inspections completed in a particular interval of time. The service time is exponentially distributed with the rate μ and mean $1/\mu$. The inspection time will rely on the following container and inspection characteristics: contents (e.g. iron, cotton, radioactive), empty or full, type of inspection equipment (passive, active), non-C-TPAT, and CSI container (risky containers). The inspection time for individual containers does not affect the inspection time for other containers.

4.3 Security Levels and Average Inspection Time

There are five security levels in the United States including severe, high, elevated, guarded, and low. Each security level has its own color and impact on security measurements. These levels and their corresponding colors are shown in Table 4.1

Table 4.1 Security Levels in the United States

Level of Security	Color	Behavior
Severe (SSL)	Red	Severe Risk of Terrorist Attacks
High (HSL)	Orange	High Risk of Terrorist Attacks
Elevated (ESL)	Yellow	Significant Risk of Terrorist Attacks
Guarded (GSL)	Blue	General Risk of Terrorist Attacks
Low (LSL)	Green	Low Risk of Terrorist Attacks

Source: Department of Homeland Security (2006)

Based on whether the inspection system is a passive or active depends on the type of equipment, the average time taken to inspect a container. Table 4.2 shows the average time to inspect a container when a low level of security (LSL) is in effect for a variety of equipment used for inspection.

Table 4.2 Average Time to Inspect a Container Under Low Security Level (LSL)

Average Time to Inspect in Low Security Level (LSL)					
Passive Systems			**Active Systems**		
Kind of Equipment	**Screen For**	**Average Time to Inspect in LSL**	**Kind of Equipment**	**Screen For**	**Average Time to Inspect in LSL**
Vapor Detection	Prohibited gases	30~60 sec	X-ray	Explosive, stolen	2-5 min
Trace Detection	Explosives, drugs	30~60 sec	Gamma Ray	materials, drug	2-5 min
Radiation Detection	Radiation	30~60 sec	Pulsed Fast Neutron Analysis	Explosives, drugs	1 hr +
Canines	Explosives, drugs	10~60 sec	Thermal Neutron Activation	Explosives	1 hr +

Source: Roundtree (2005)

At the first stage of an inspection station at a seaport terminal, radiation detection is used. Using this equipment, an inspection of a container may take between 30 to 60 sec. This average inspection time is used as the basic inspection time under a low level of security. X-ray and Gamma ray equipment are used at the second stage to screen for explosives, stolen materials, people, and drugs. This equipment requires between 2~5 min to inspect a container.

Regarding inspection rate, Bjorkholm (2003) stated that about 20 containers per hour can be processed using in gamma ray systems, and 30 to 50 containers per hour can be inspected in the high energy X-ray screening.

4.4 Inspection Time and Rate

The exponential distribution is the only continuous distribution having a memoryless property. It can be assumed that the inspection pattern can be described by the probability distribution used to describe the number of inspections completed in a particular interval of time. The service time is exponentially distributed with rate μ and mean $1/\mu$.

The research shows the inspection rate under a low security level is between 30 and 60 seconds a passive inspection system. No data is available on how this inspection rate increases as the security level increases. In this research, it is assumed that there is a 30 second increase in the inspection rate as the security level increases by one level. Therefore, for a "Guarded" security level, which is one security level above a low security level, the inspection rate is assumed to be 30 seconds higher than the low security level or between 60 and 90 seconds. A 60 second increment between security levels is used for active systems. The inspection time is assumed to change with the level of security because inspection processes are divided by two processes such as a manual process and an inspection equipment process. The manual process has two sub-processes including the document process and opening the container. Therefore, it is considered that even if the inspection time for the equipment does not change, the inspection time for manual inspections should change as the security level increase. Therefore, the total inspection time should change as the security level increase because the operator's judgment and decision affects the final decision and has an impact on the inspection time. Table 4.3 shows the inspection rates using these assumptions.

As the inspection rate increases, it is more likely to miss containers with problems. The rate of not detecting a security breach, or a container with dangerous or hazardous materials, increases as the rate of inspection increases. Conversely, low inspection rates reduce the potential to miss containers with problems because the detection rate increases as the time to inspect increases. Therefore, the inspection rate needs to be considered in terms of delay time.

Table 4.3 Average Inspection Time by Security Level

		Passive System	Active System
	Level of Security	Average Time to Inspect	
1	Low (LSL)	30~60 sec	2~5 min
2	Guarded (GSL)	60~90 sec	3~6 min
3	Elevated (ESL)	90~120 sec	4~7 min
4	High (HSL)	120~150 sec	5~8 min
5	Severe (SSL)	150~180 sec	6~9 min

4.5 Equipment Factor and Inspection Rate

Advancing technology and the efficient use of inspection equipment allows inspection rates to be increased at all levels of security. Lockheed Martin and General Electric (GE) developed and produced inspection equipment including a Radioactive Portal Monitor and X-ray/Gamma-ray inspection equipment. The companies continue to develop advanced technologies and effective inspection systems that may reduce delay time at the inspection station. These advanced technologies may increase the inspection rates in time. Figure 4.3 shows what would happen to

the inspection rate at a passive systems, if the equipment were capable to perform inspections 1.2, 1.4, 1.6, 1.8 and 2.0 times faster than the existing equipment.
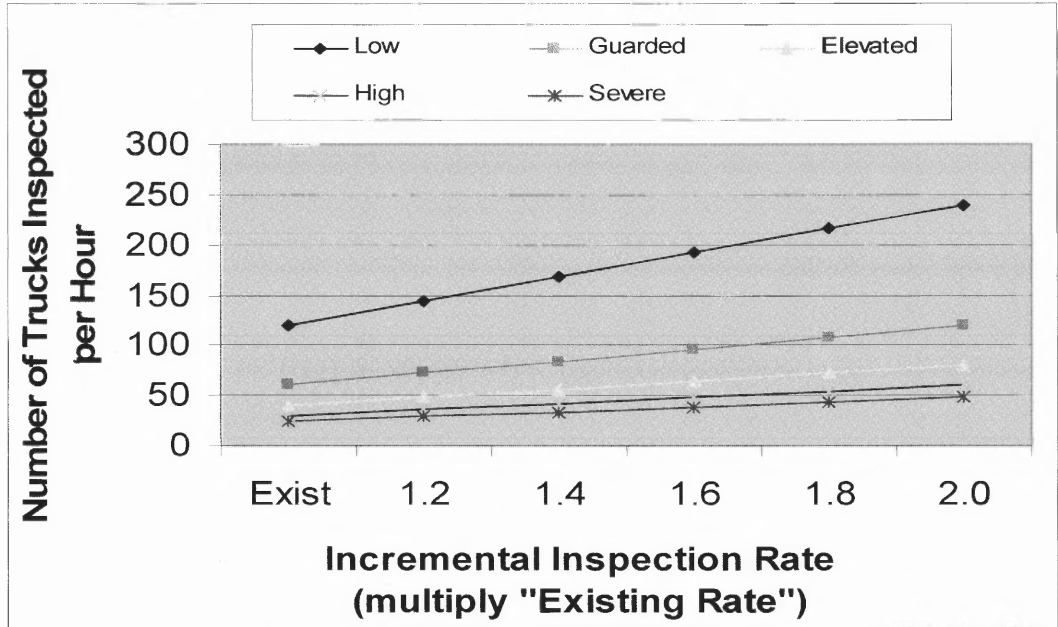
Figure 4.3 Incremental Inspection Rate for Passive Systems

Figure 4.4 shows the increase in the number of trucks inspected per hour. Its existing inspection rate was to increase by a factor ranging from 1.2 to 2.0.
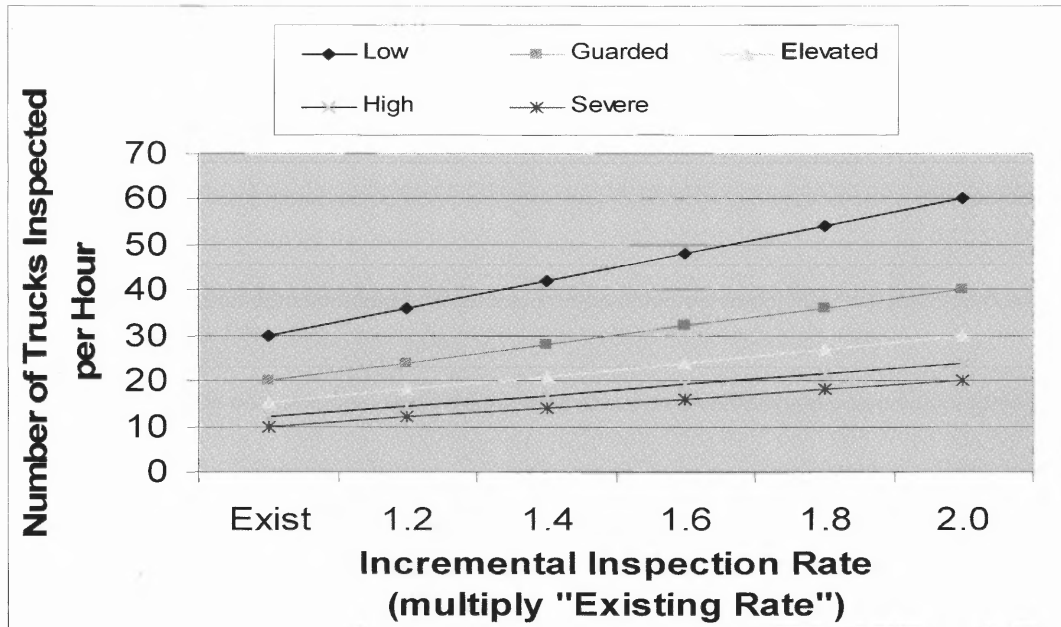
Figure 4.4 Incremental Inspection Rate to Active Systems

4.6 Effectiveness of Installing Additional Inspection Equipment

This sensitivity analysis investigated how one additional inspection equipment affects the inspection system. Figures 4.5 show the total number of trucks and average truck time in the system for X-ray and Gamma-ray inspection equipment under a M/M/1 and a M/M/c system. The Figures show that if the trucks' arrival rate is 25 (trucks/hr), a total of 5 trucks will be in the system with one server, while only 1 truck will be in the system with two servers. It will take approximately 12 minutes for the truck to clear the system with one server, and less than 3 minutes with two servers under an inspection rate of 25 trucks/hr.
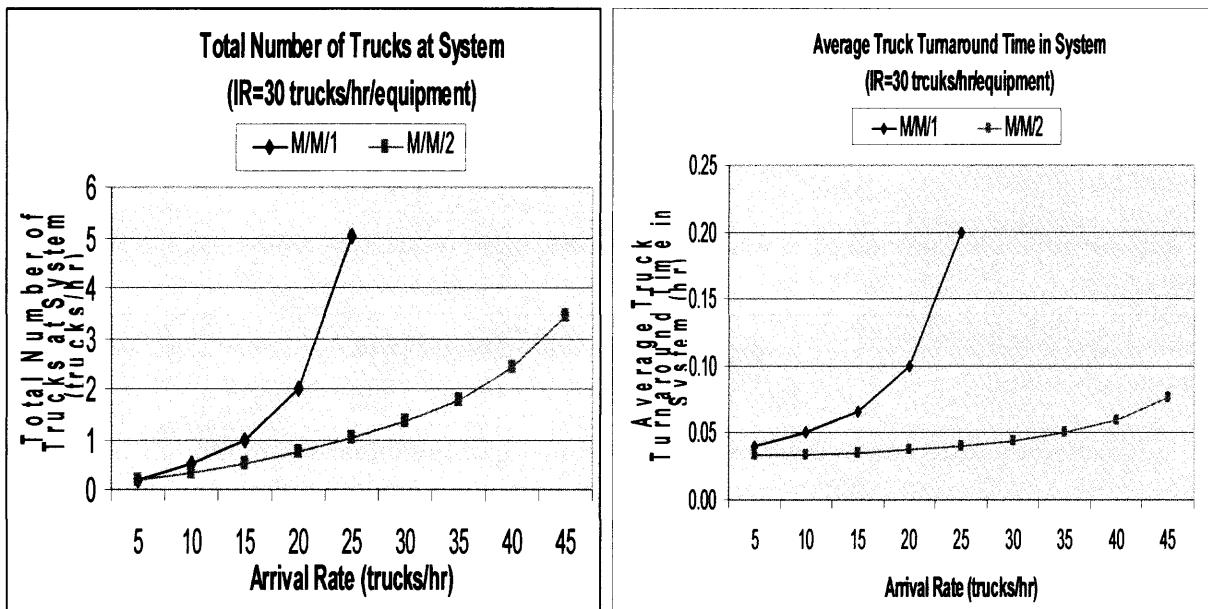
Figure 4.5 Compare M/M/1 to M/M/2 system.

Table 4.4 contains all measures of effectiveness generated by the queuing models when there is one and two servers in the system and the arrival and service rates are 2 trucks/min and 3 trucks/min respectively. The improvements generated by the addition at on server are considerable.

Table 4.4 Comparison of a M/M/1 and M/M/2 system at Single Stage (if λ =2 trucks/min and μ =3 trucks/min)

Measure of Effectiveness (MOE)	One Server $c = 1(M/M/1)$	Two Servers $c = 2(M/M/2)$
Arrival Rate (λ : trucks/min)	2	2
Inspection Rate (μ : trucks/min)	3	3
Utilization Rate ($\rho : \lambda / \mu$)	0.667	0.333
Number in Queue (L_q : trucks)	1.333	0.083
Number in System (L : trucks)	2	1.333
Delay time in Queue (W_q : min)	0.667	0.012
Delay time in System (W : min)	1	0.375

When the utilization rate is close to 1, there is a more dramatic impact from the addition of one inspection equipment as shown Table 4.5. Therefore, if the arrival rate is $\lambda = 1$ truck/min, and the average service time is $\mu = 1.01$ truck/min in the M/M/1 system, the utilization rate is $\rho = 0.99$, and $L_q = W_q = 99.01$. The average number of trucks ($L_{q,M/M/1}$) and waiting time in the queue ($ATTT_{q,M/M/1}$) are equal because $\lambda = 1$ as derived by equations 4.1 and 4.2 below:

Table 4.5 Comparison of a M/M/1 to M/M/2 system (if λ =1 truck/min and μ =1.01truck/min)

Measure of Effectiveness (MOE)	One Server $c = 1(M/M/1)$	Two Servers $c = 2(M/M/2)$
Arrival Rate (λ : trucks/min)	1	1
Inspection Rate (μ : trucks/min)	1.01	1.01
Utilization Rate ($\rho : \lambda / \mu$)	0.9901	0.4951
Number in Queue (L_q : trucks)	99.01	0.3214
Number in System (L : trucks)	100	1.3115
Delay time in Queue (W_q : min)	99.01	0.3214
Delay time in System (W : min)	100	1.3115

$$L_{q,M/M/1} = \frac{\lambda^2}{\mu(\mu - \lambda)} = 99.01 \text{ trucks} \tag{4.1}$$

$$W_{q,M/M/1} = \frac{\lambda}{\mu(\mu - \lambda)} = 99.01 \text{ minutes} \tag{4.2}$$

After setting up another inspection station in the system, the average number of trucks ($L_{q,M/M/2}$) and waiting time in the queue ($ATTT_{q,M/M/2}$) are just 0.32 trucks and 0.32 minutes, respectively. According to Equations 4.3 and 4.4.

$$L_{q,M/M/2} = \frac{\rho}{(1-\rho)^2} P_c = 0.32 \text{ trucks} \tag{4.3}$$

$$W_{q,M/M/2} = \frac{L_{q,M/M/2}}{\lambda} = 0.32 \text{ minutes} \tag{4.4}$$

Therefore, the $L_{q,M/M/1}$ of the M/M/1 model is almost 308 times the $L_{q,M/M/2}$ of the M/M/2 model. CBP officers need to consider this effectiveness when a decision for additional inspection equipment in the seaport terminal is made. Shipping companies, terminal operators, and supply chain managers should also be aware of the delay time reductions additional inspection equipment can generate.

4.7 Effectiveness of Equipment's Utilization

The utilization (ρ) rate is equal to the arrival rate (λ) over the inspection rate (μ). The inspection equipment utilization at each stage will affect the truck turnaround time in the system and can impact the number of inspection stations needed at the terminal. Figure 4.6 shows the average truck turnaround time as the utilization rate increases. As the utilization rate

in the inspection system approaches 1, a small increase in the number of arriving trucks can result in a big change in the average truck turnaround time (ATTT).
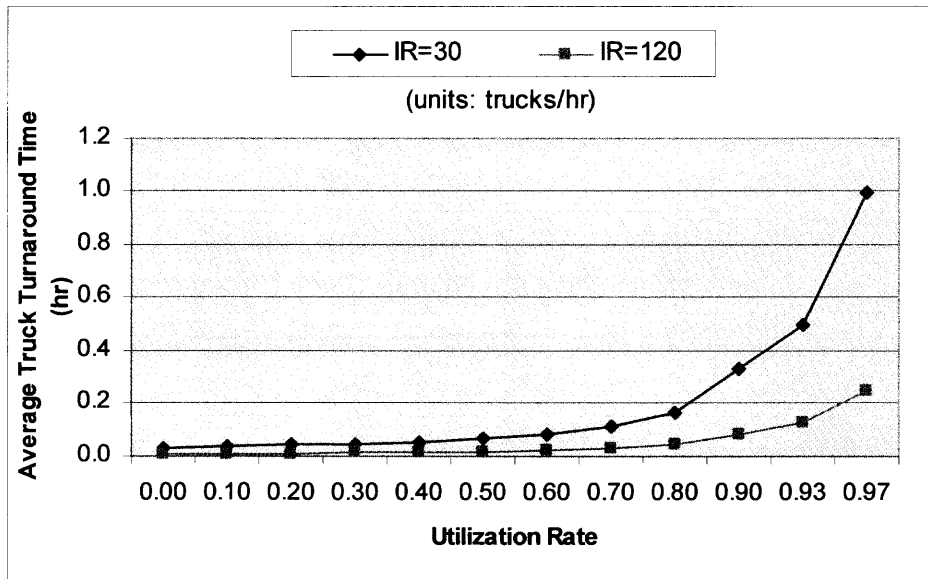
Figure 4.6 Average Truck Turnaround Time by Utilization Rate

In a passive system, if the utilization rate of an inspection equipment is under 0.9, the average truck inspection time will be less than 10 min. If the utilization rate is greater than 1, the workload of the inspection equipment will increase infinitely and the average truck turnaround time will also become infinite. CBP and/or seaport terminal operators should not allow the utilization rate of the inspection equipment to get close to 1 to prevent serious delays at the inspection station.

Figure 4.7 shows the average truck turnaround time for different numbers of equipment, arrival and inspection rates. The figure can be used assess how combination of different number of inspection equipment and inspection rates affect truck processing times. For example, the combination of c=2 and IR=120 keeps the truck time in the system to less than 10 minutes with an arrival rate more than 10 times that of the combination of c=1 and IR=30.
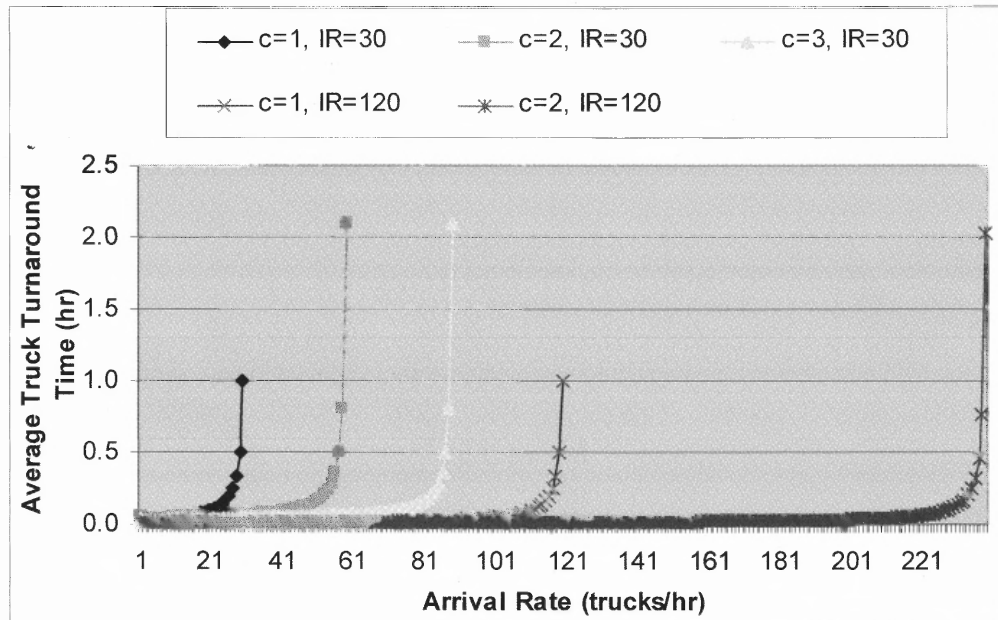
Figure 4.7 Average truck turnaround time and number of equipment.

In addition, two Radioactive Portal Monitors with IR=120 can inspect twice the number of container trucks than one equipment and still maintain an average truck inspection time within 10 minutes. Three X-ray and Gamma-ray inspection equipment with IR=30 can inspect three times the number of container trucks that one equipment can and keep the average by truck inspection time within 10 minutes.

4.8 Relationship Between Arrival Rate and Green Lane Usage Rate

Commissioner Bonner (2005) stated that the Green lane is an advanced CBP policy that would mean immediately release, without inspection, for trusted shippers that adopt the highest levels of security controls by C-TPAT. The Green Lane processes trucks outside of the inspection system, thereby removing trucks from the arrivals at the inspection station resulting in a lower truck arrival rate, as shown in Figure 4.8. The impact of the Green Lane usage on the arrival rate is shown graphically Figure 4.8 and 4.9.
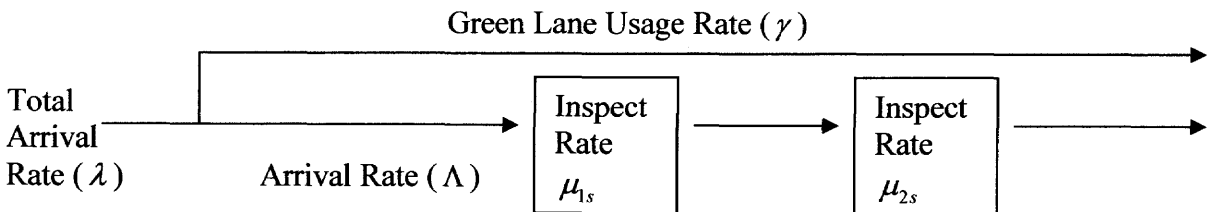
Figure 4.8 Green Lane Usage
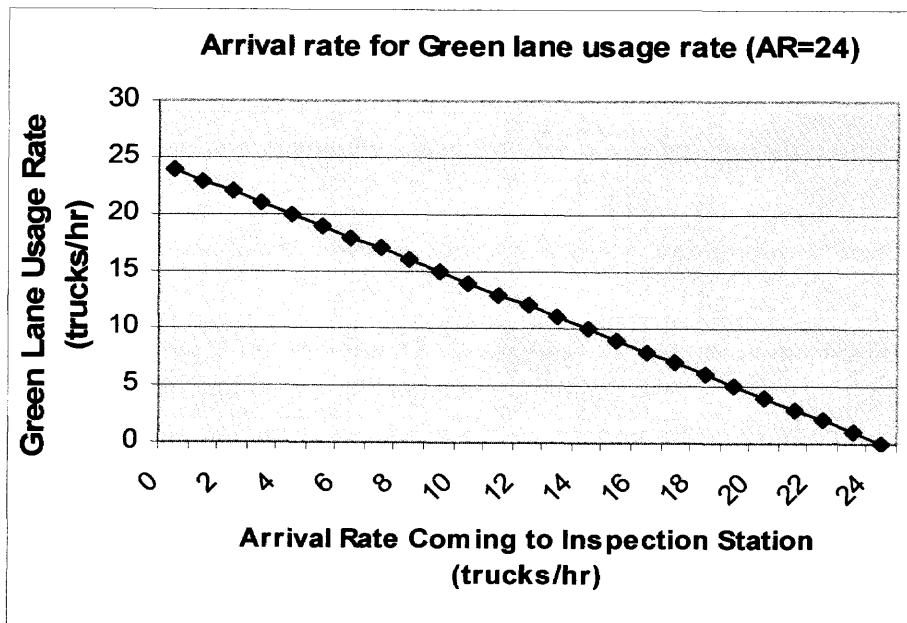
Figure 4.9 Arrival Rate for Green Lane Usage Rate

4.9 Average Additional Truck Turnaround Time in the SMM System

The average truck inspection time for a variety of the inspection rates (IR) using the SMM model is shown in Figure 4.10. This Figure can be used as a guide to determine what delays are should expect for a given truck volume to be inspected (AR) when the inspection rate has a given volume as determined by the security level and capability of the equipment.

Average Truck Turnaround Time in SMM System
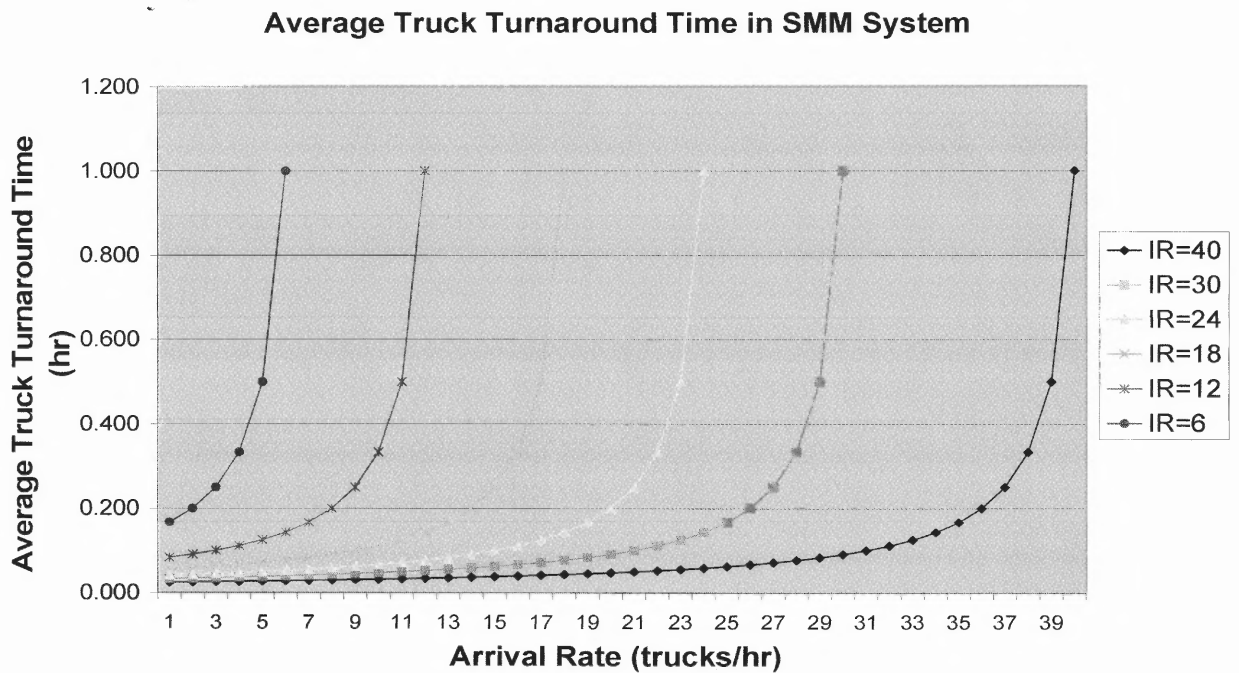
Figure 4.10. Average Truck Turnaround Time in SMM System

4.10 Number of Trucks in SCMSM System

The total number of trucks for the variety of arrival rate (AR) and inspection rate (IR) at each

stage, in the system for the SCMSM model is shown in Figure 4.11.
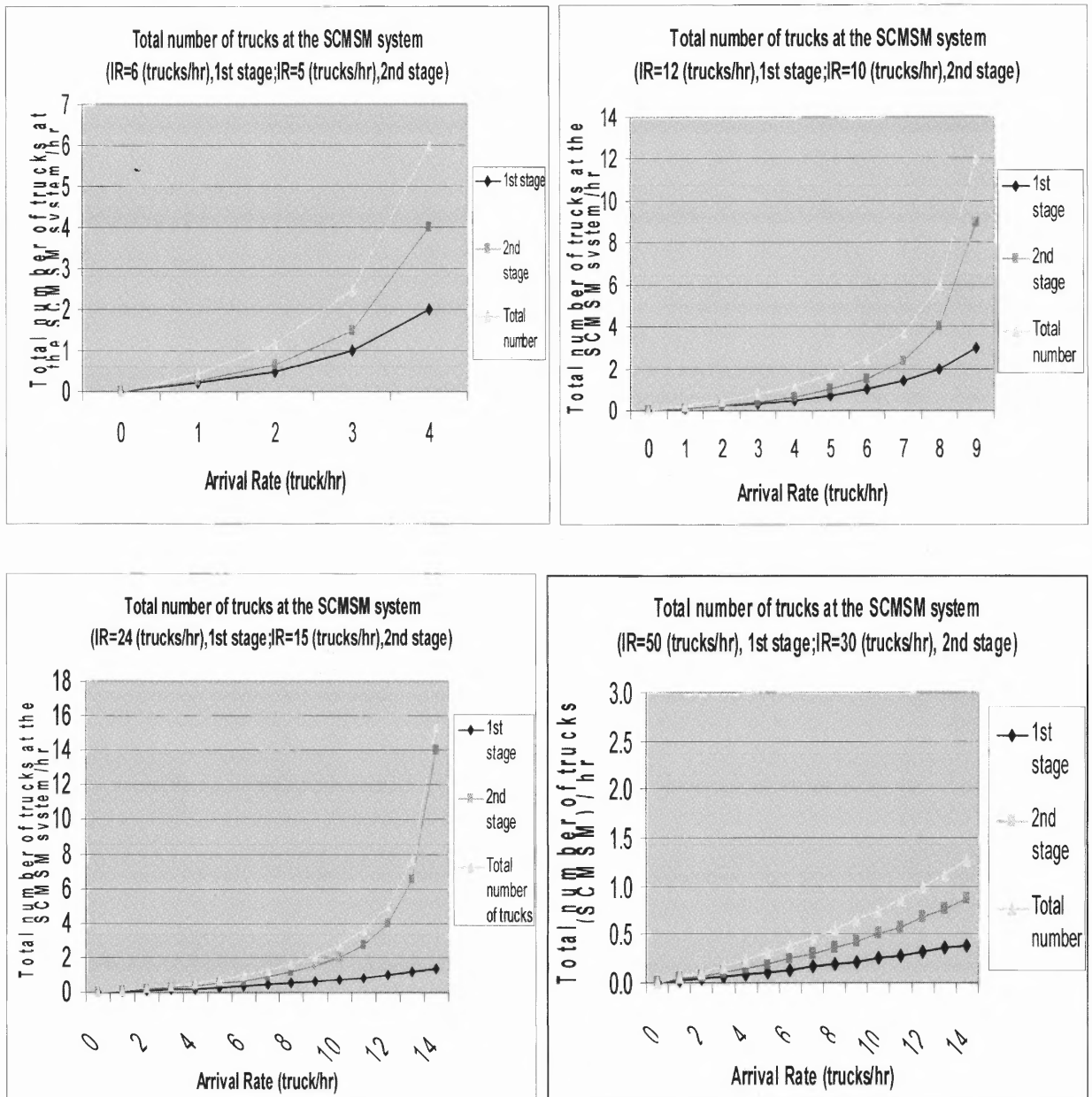
Figure 4.11. Total Number of Trucks at the SCMSM system.

At the SCMSM model, the total number of trucks in the system is very dependent on the inspection rate of the second stage. Lee (2006) stated that the average waiting time and the number of customers will increase significantly if the utilization rate approaches 1 in the M/M/1 and M/M/c models. Therefore, if the utilization rate is close to 1 (heavy traffic), small increases in the arrival rate (or small decreases in the inspection rate) will result in an extraordinary increment of average waiting time and number of customers in the system. This situation will happen not only in the M/M/1 and M/M/c systems, but also in all other queuing systems.

4.11 Sensitivity Analysis of Inspection Rates

Changes in the Security Level of the Nation, issued by the Department of Homeland Security, will affect the inspection rate of containers entering the United States. Inspection time intervals may be fixed or weighted. Fixed inspection time intervals mean that there is fixed increment in the inspection rate as the security level increases. For example, at a "Guarded" security level, the inspection rate is 30 seconds higher than the inspection rate at a low security level. The inspection rate is also 30 seconds higher for the next higher or "Elevated" security level. A 60 second increment between security levels is used for active inspection systems.

When using weighted inspection time intervals, in addition to the fixed time interval, an increment is added, which is equal to an additional time multiplied by the numerical difference between the prevailing security level and the low security level. For example for an elevated security level (3) and an incremental time of 10 seconds the additional weighted time to be added to the fixed time will be 10 (3-1) = 20 seconds.

Figure 4.12 shows the impact that various security levels have on the system's throughput for various weighted time intervals.
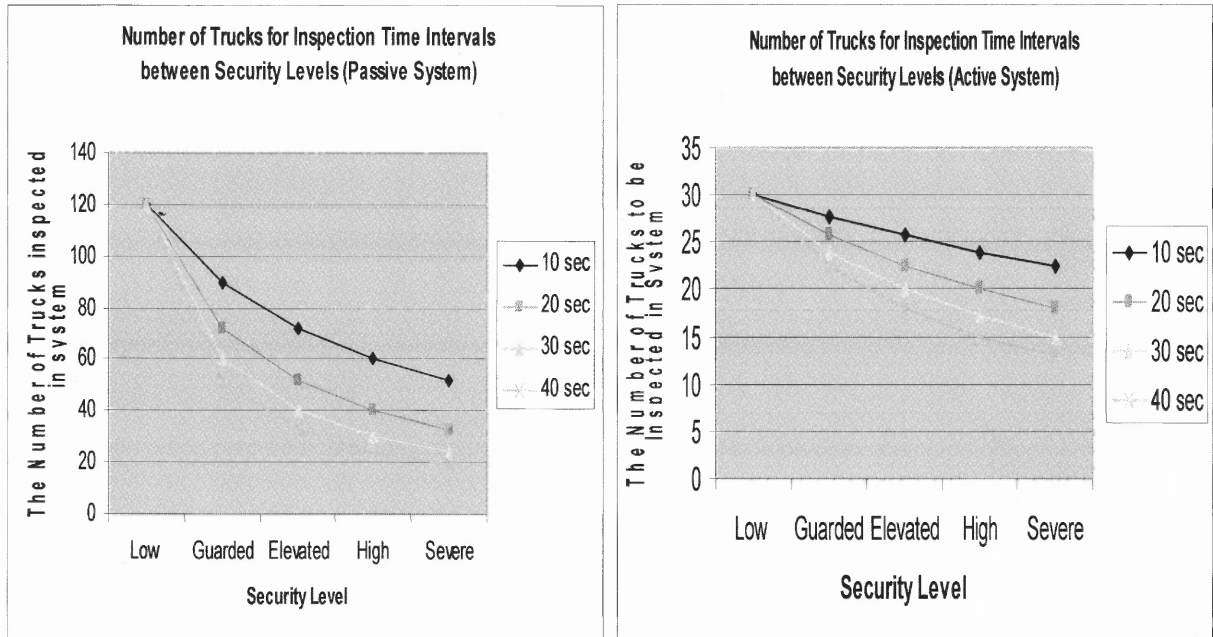
Figure 4.12 The Sensitivity Analysis of Inspection Rates with Fixed Time Interval

Figure 4.13 shows the assumed inspection time interval between security levels as a weighted time interval of 5 sec, 10 sec, and 15 sec. The Figure demonstrates that the higher the weighted inspection time is the lower trucks can be inspected, resulting in high delay at the inspection station.
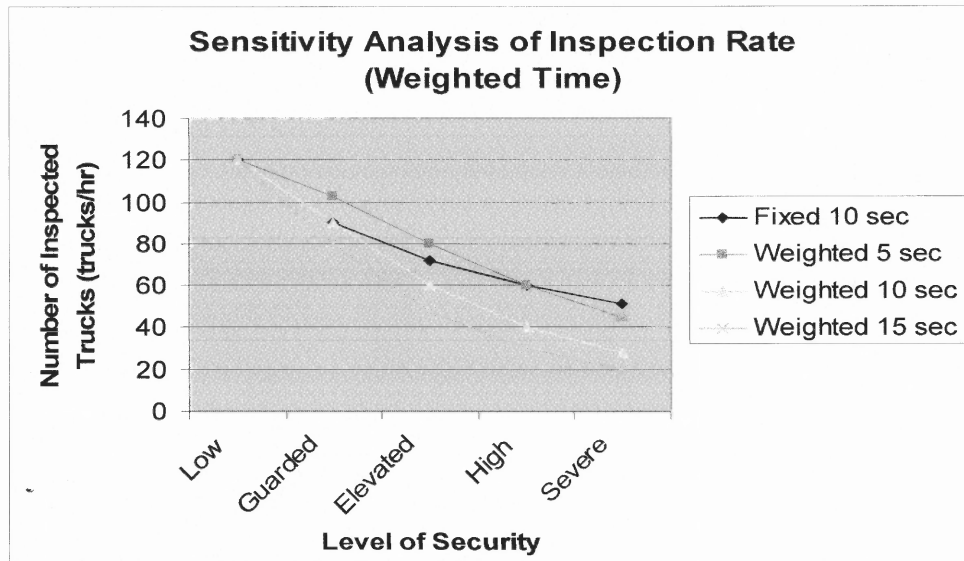
Figure 4.13 The sensitivity analysis of inspection rates with weighted time interval.

4.12 Average Truck Turnaround Time in SCMSM

The arrival rate (AR) and inspection rate (IR) at each stage determine the average additional truck turnaround time (ATTT) at the inspection station which is shown in Figure 4.14: In this case, the average truck turnaround time in SCMSM is directly affected by the second stage where there is only one inspection equipment screening trucks at a low rate.
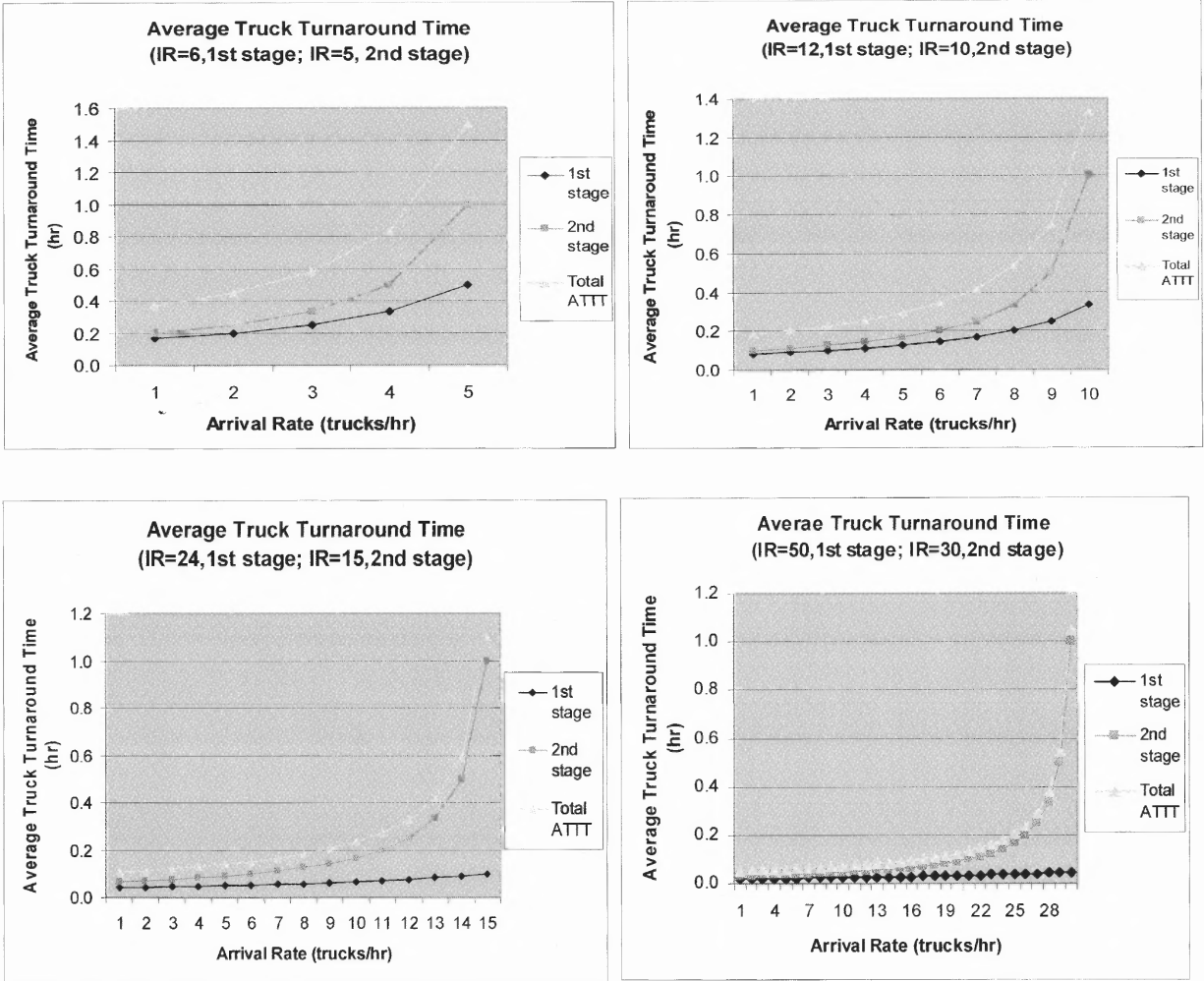
Figure 4.14 Average truck turnaround time in SCMSM.

4.13 Total Number of Trucks in the MCMSM system

The total number of trucks in the MCMSM-MS system for a variety of arrival rates (AR) and inspection rates (IR) is shown in Figure 4.15.
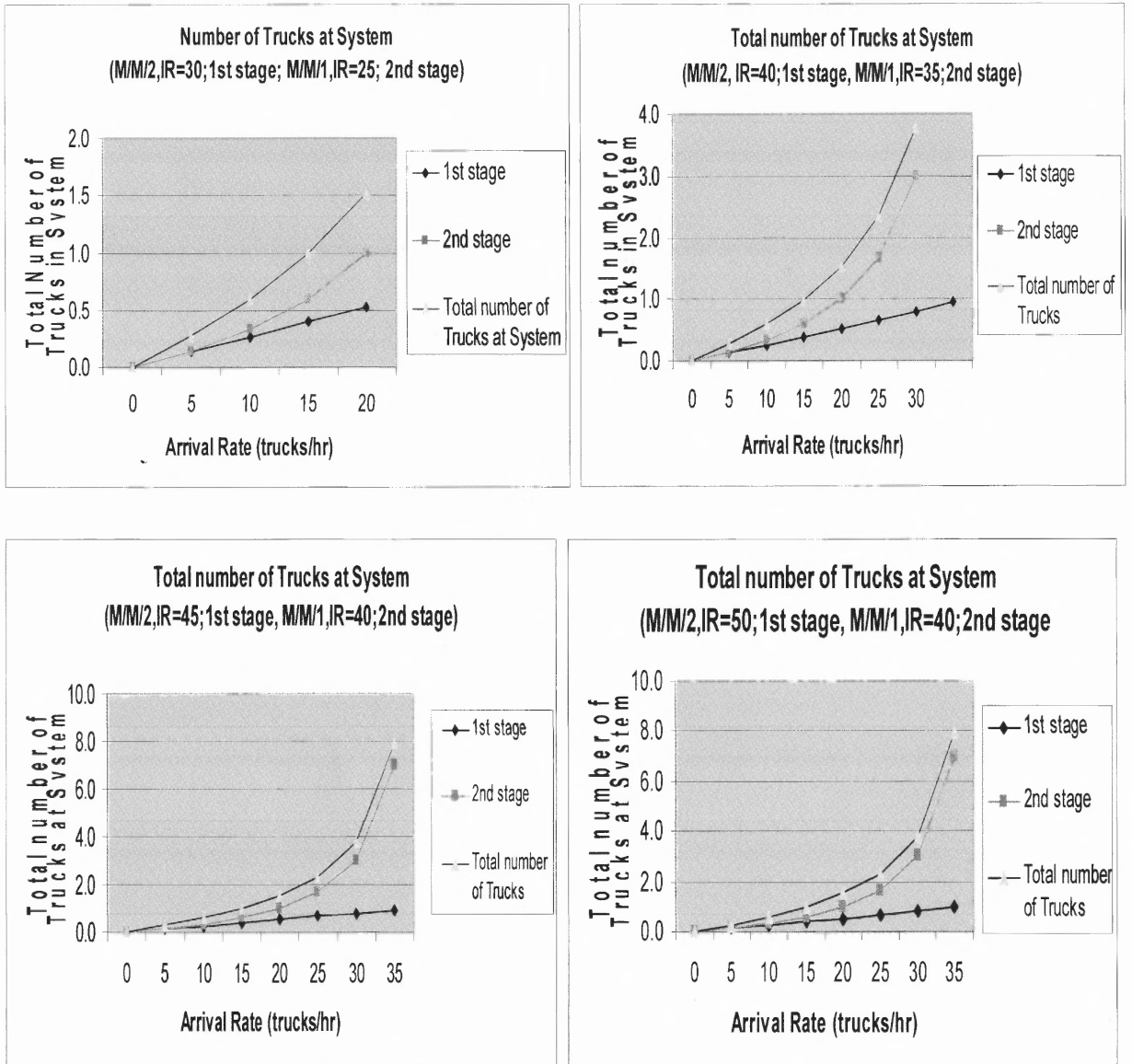
Figure 4.15 Total number of trucks at the MCMSM-MS system.

The total number of trucks in the MCMSM-MM system for a variety of arrival rates (AR) and inspection rates (IR) is shown in Figure 4.16.
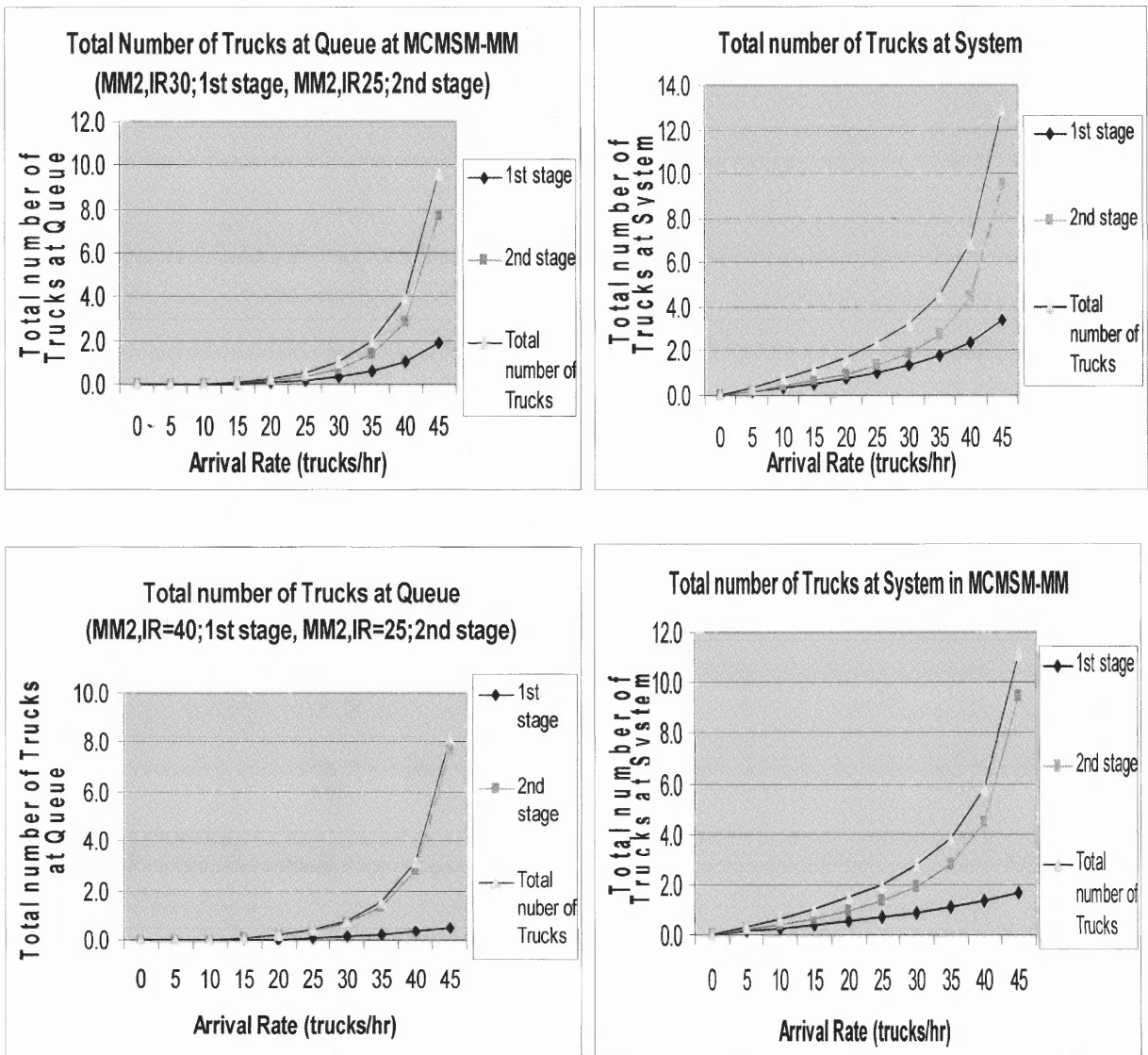
Figure 4.16. Total number of trucks at the MCMSM-MM system.

4.14 Average Truck Turnaround Time at the MCMSM system

The average truck turnaround time (ATTT) at the inspection stations of the MCMSM-MM model is shown in Figure 4.17 for a variety of arrival rates (AR) and inspection rates (IR) at each stage. In this system, if heavy delays occur due to a high utilization rate in the first and/or second stage, there are some methods for decreasing the delay including higher Green Lane usage, setting additional inspection equipment (or mobile equipment) and improving the inspection technologies.
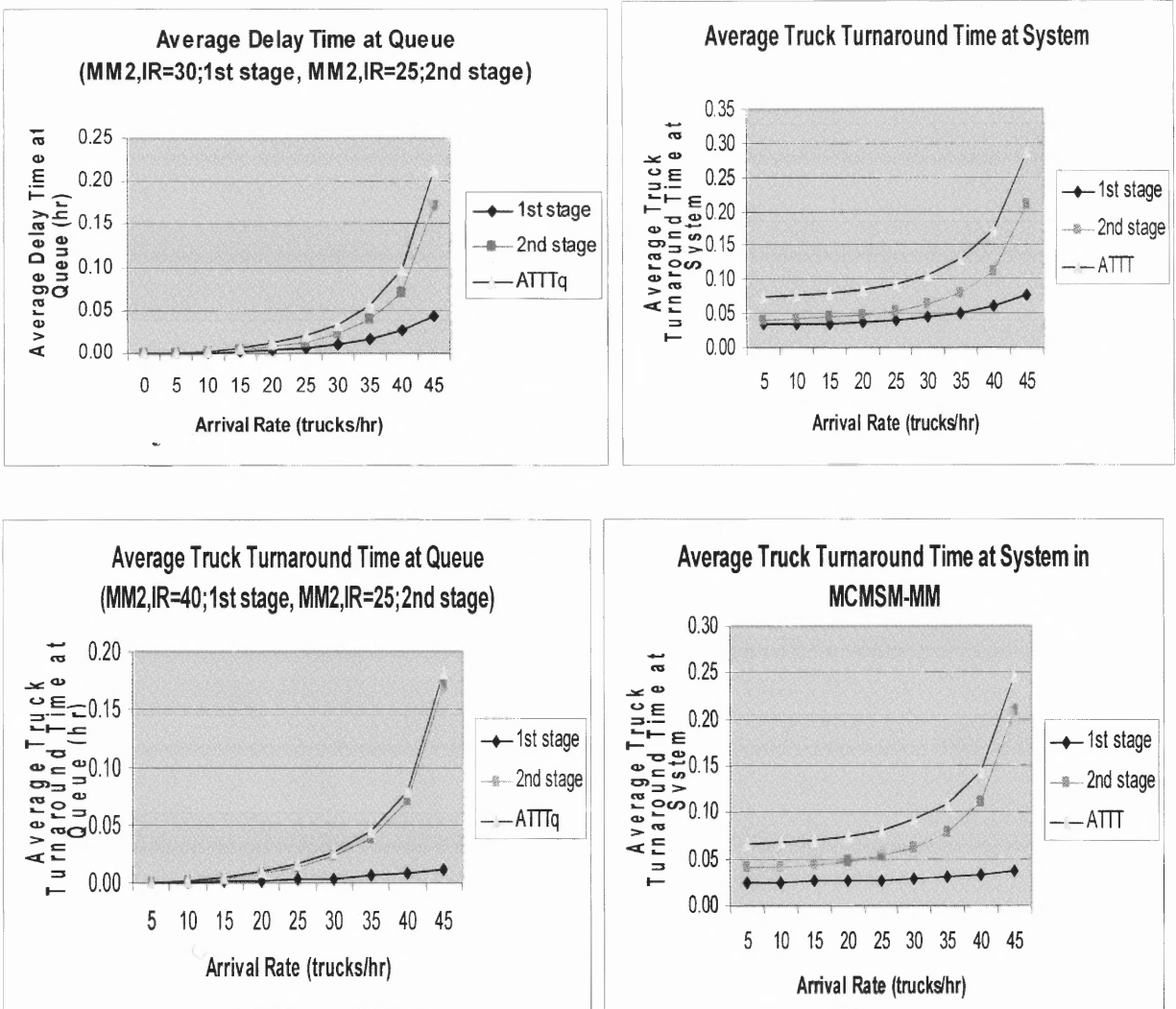
Figure 4.17 Average truck turnaround time in MCMSM-MM.

In the sensitivity analysis performed, it was assumed that the number of trucks arriving at the inspection station follows a Poisson distribution, and that the inspection time is exponentially distributed and depends on the container contents, whether the container is empty or full, the type of inspection equipment used, and whether the container is non-C-TPAT or CSI container. This sensitivity analysis assumed that there is a 30 second and 1 minute increase in the inspection rate at the first and second stages respectively as the security level increases by one level. The use of new technologies and other active inspection systems may allow the

inspection rate to increase as much as, 1.2, 1.4, 1.6, 1.8, and 2.0 times the existing inspection rate. More efficient inspection technologies will allow a higher number of containers to be inspected at all security levels. If the utilization rate in the inspection system is close to 1, a small increase in the number of arriving trucks or a small reduction in inspection rate (IR) can produce a big change in the average truck turnaround time. The higher inspection time needed as the security level is revised allows less trucks to be inspected, and result in high delays. The average truck turnaround time in the SCMSM model is directly affected by the second stage because there is only one inspection equipment screening trucks. When the utilization rate is close to 1 for the M/M/1 system, setting up one additional inspection equipment and making the system M/M/2 results in a $L_{q,M/M/2}$ number of trucks in the queue, which is almost 308 times smaller than $L_{q,M/M/1}$.

CHAPTER 5

CASE STUDY

5.1 Introduction

Bjorkholm (2003) stated that a layered inspection system combines two or more technologies serially including a radiation portal monitor, X-ray/Gamma-ray imaging, and hand inspection to attempt to achieve a better result than would be possible using either one alone. Customs Boarder and Protection (CBP, 2002) declared that a "security inspection," at a minimum, includes an inspection of a container using a radiation detector and large scale x-ray or gamma ray inspection systems. If there are irregularities in the image, or the container is so densely packed that the image is not clear, the containers require a hand-search in which the container is opened and its contents removed and examined which is estimated to occur for approximately 5 percent of the containers coming from imaging inspection (Schiesel, 2003, and Krikorian, 2004). This is a time-consuming process involving as long as four hours using 15 to 20 inspectors (Bowser and Husemann, 2004) or three days using five agents (Johnson, 2004). This research does not consider hand inspection because the volume of hand-inspected containers is too low and the processing time is too long. Furthermore, the hand inspection times are very dependent on the number and technical expertise of the inspectors. This research conducted on a radiation portal monitor at a first stage and X-ray/Gamma-ray imaging at the second stage.

5.2 Reasonable Delay Time to be a Constraint

The Customs Border Protection (CBP) has the responsibility of managing the number of inspection lanes that need to be opened at all ports in the United States. Table 5.1 shows the inspection lanes and estimated delay times by the CBP for commercial vehicles in the queue at the primary inspection equipment at ports in the United States. Table 5.1 shows each port's name and the inspection working hours in the left column. Also indicated is the maximum number of available lanes (equipment) which the CBP may use. Furthermore, the average delay time and the number of lanes open on an basis is reported.

Table 5.1 Average Delay Time and Inspection Lanes

Port Name		Commercial Vehicles		Port Name		Commercial Vehicles	
	Working Hours	Max Available Lanes	Average Delay Time		Working Hours	Max Lanes	Average Delay Time
Alexandria Bay *Thousand Islands Bridge*	24 hrs/day 2/8/2007	3	At 6pm EST 5 min delay 3 lanes open	**Andrade**	6am-10pm 2/8/2007	1	Lanes Closed
Blaine *Pacific Highway*	24 hrs/day 2/8/2007	3	At 3pm PST 25 min delay 2 lanes open	**Detroit** *Ambassador Bridge*	24 hrs/day 2/8/2007	13	At 6pm EST 10 min delay 8 lanes open
Sumas	24 hrs/day 2/8/2007	2	At 3pm PST 5 min delay 1 lanes open	**Brownsville Gateway**	24 hrs/day 2/8/2007	0	No traffic
Buffalo/Niagara Falls *Peace Bridge*	24 hrs/day 2/8/2007	7	At 6pm EST no delay 7 lanes open	**Brownsville Veterans International**	6am-Midnight 2/8/2007	4	At 5pm CST 15 min delay 3 lanes open

Table 5.1 Average Delay Time and Inspection Lanes (Cont.)

Port Name		Commercial Vehicles		Port Name		Commercial Vehicles		
	Working Hours	Max Available Lanes	Average Delay Time		Working Hours	Max Lanes	Average Delay Time	
Champlain	24 hrs/day 2/8/2007	8	At 6pm EST 10 min delay 6 lanes open	**Douglas**	24 hrs/day 2/8/2007	2	At 4pm MST 10 min delay 1 lanes open	
Hidalgo/Pharr *Pharr*	6am-Midnight 2/8/2007	5	At 5pm CST 15 min delay 4 lanes open	**Eagle Pass** *Bridge I*	7am-11pm 2/8/2007	0	No traffic	
Highgate Springs	24 hrs/day 2/8/2007	1	At 5pm EST 10 min delay 1 lanes open	**Eagle Pass** *Bridge II*	24 hrs/day 2/8/2007	2	At 5pm CST 5 min delay 1 lanes open	
Pembina	24 hrs/day 2/8/2007	3	At 5pm CST 21 min delay 3 lanes open	**El Paso** *Bridge of the Americas (BOTA)*	24 hrs/day 2/8/2007	6	At 4pm MST 25 min delay 4 lanes open	
Port Huron *Bluewater Bridge*	24 hrs/day 2/8/2007	7	At 6pm EST 15 min delay 5 lanes open	**El Paso** *Paso Del Norte (PDN)*	24 hrs/day 2/8/2007	0	No traffic	
Santa Teresa	6am-10pm 2/8/2007	2	At 4pm MST no delay 1 lanes open	**El Paso** *Ysleta*	24 hrs/day 2/8/2007	6	At 4pm MST 10 min delay 4 lanes open	

Source: U.S Customs Border Protection (2007)

Figure 5.1 was generated using the information of Table 5.1 and shows the relationship between the delay time and the number of inspection lanes for various times. In the Figure, Max means maximum number of available inspection equipment. The number in parenthesis next to the

time is the number of inspection lanes. The relationship between delay time and number of

lanes for the ports Derby Line, Detroit, Sumas, and Brownsville are shown.
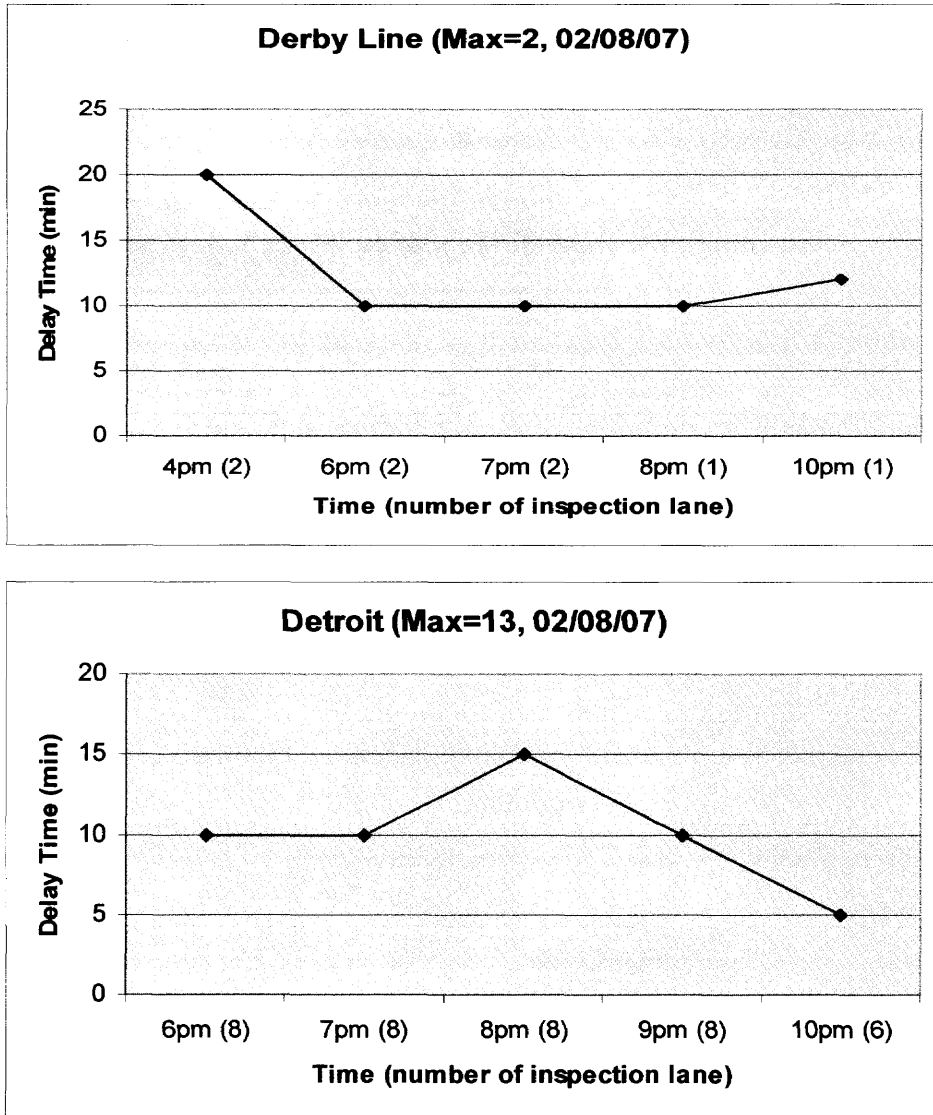
Derby Line (Max=2, 02/08/07)

Detroit (Max=13, 02/08/07)

Figure 5.1 Delay Time and Number of Inspection Lanes

Sumas (Max=2, 02/08/07)

Delay Time (min) vs **Time (number of inspection lane)**

- 3pm (1): 5
- 4pm (1): 10
- 5pm (1): 5
- 6pm (1): 15
- 7pm (1): 0

Brownsvi lle (Max=4, 02/08/07)

Delay Time (min) vs **Time (number of inspection lane)**

- 5pm (3): 15
- 6pm (2): 5
- 7pm (2): 15
- 8pm (2): 5
- 9pm (2): 5
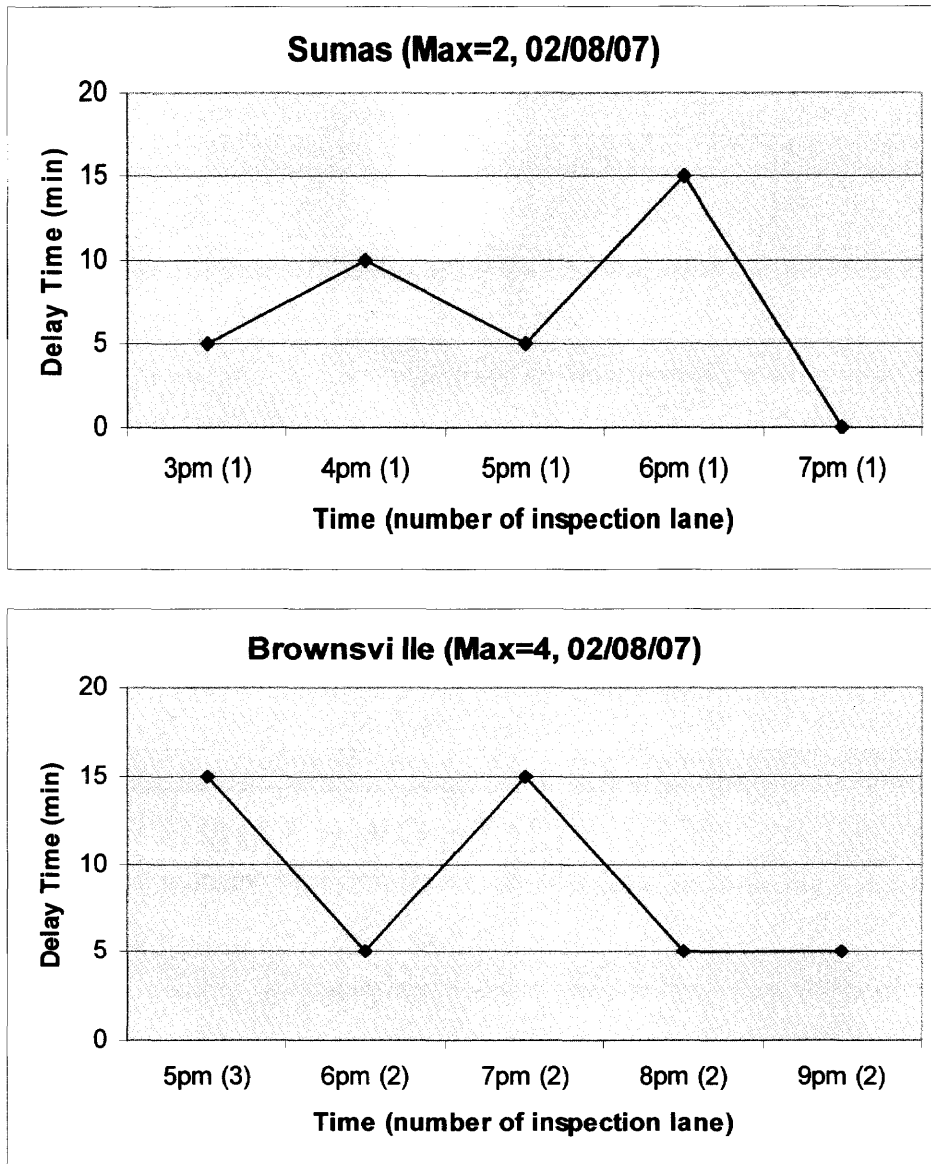
Figure 5.1 Delay Time and Number of Inspection Lanes (Cont.)

Figure 5.1 shows that the number of inspection lanes is adjusted during the day to keep the delay and between 5 and 15 minutes. It is assumed that CBP officials have determined that a reasonable delay time is in the range of 5 to 15 minutes. Therefore, this research is considering a time of approximately 10 min as the maximum tolerable delay, and this time is used to determine the required number of inspection equipment.

5.3 Case Studies

In this case study, the minimum number of inspection equipment required to keep delays below a specified delay time is obtained. The number of inspection equipment depends on the arrival rate, inspection rate, Green Lane usage rate, layout, and security level. The number of equipment can be obtained by using the queuing theory formulation as previously described.

The assumptions for the case studies are shown in Table 5.2 and include a 100 trucks/hr arrival rate (AR), 120 trucks/hr inspection rate at the first stage consisting of a radiation detector, 30 trucks/hr inspection rate at the second stage consisting of a X-ray/Gamma Ray, 25% of the arrivals use the Green Lane, the security level is Guarded, and there is a 10 sec fixed differential between levels of security.

Table 5.2 Case Studies Assumptions

Arrival Rate (AR)	100 (trucks/hr)
Inspection Rate at First Stage of Radiation Detector	120 (trucks/hr)
Inspection Rate at Second Stage of X-ray/Gamma Ray	30 (trucks/hr)
Green Lane Usage Rate (GR)	25% of AR
Inspection rate between security levels	10 sec fixed differential

Under the conditions of Table 5.1, the question to be answered for the first case study is how many radiation detectors and X-ray/Gamma ray equipment are needed to be installed to maintain less than 15 min at delay time in the system. When the security level is guarded.

The Green Lane usage rate is 25% of the current arrival rate of 100 trucks/hr, or 25 trucks/hr. The arrival rate at the inspection system can then be obtained as 100 trucks/hr minus 25 trucks/hr or 75 trucks/hr, The average IR under a Guarded Level of Security with a 10 sec differential between security levels is 90 trucks/hr at the first stage and 27 trucks/hr at the second stage. The utilization rate at the first stage ($\rho_{1s} = \lambda / \mu_1$) is then determined to be 0.833.

At the second stage, the utilization rate needs to be less than 1 to obtain an integer number of inspection equipment and maintain a stable system. Lee (2006) stated that in a single M/M/1 Model (SMM) and a multiple M/M/c Model (MMM), to obtain an integer number of equipment, the utilization rate ($\rho = \lambda / c\mu$) of the equipment has to be less than 1. In other words, the average arrival rate coming into the system during a time interval should be less than average service rate inspecting containers during the same time interval. If the utilization rate is greater than 1, the working load of the inspection equipment, and the number of containers in the system will increase unlimitedly become infinite.

Therefore, $c_{2s} = 1$ and 2 are not acceptable because the utilization rate becomes greater than 1 and results in an unstable system, and only $c_{2s} = 3, 4$, and 5 were considered. As a first step, if $c_{2s} = 3$, the utilization rate at the second stage is 0.903.

Having a SMM model at the first stage, and a MMM model at the second stage requires the computation of delays for the MCMSM-SM model.

Additional truck turnaround time at first stage inspection station is:

$$ATTT_{1s,MCMSM-SM} = \frac{T_{1s}}{\lambda} = \frac{\sum_{n=0}^{\infty} n\rho_{1s}^{n}(1-\rho_{1s})}{\lambda} = \frac{1}{\mu_{1s}(1-\rho_{1s})}$$

And, the additional truck turnaround time at second stage inspection station is:

$$ATTT_{2s,MCMSM-SM} = \frac{\sum_{n=c}^{\infty}(n-c)P_{n}}{\lambda} + \frac{1}{\mu_{2}} = \frac{\frac{(c\rho_{2s})^{c}}{c!} * \frac{\rho_{2s}}{(1-\rho_{2s})^{2}}P_{0}}{\lambda} + \frac{1}{\mu_{2}} = \frac{\frac{\rho_{2s}}{(1-\rho_{2s})^{2}}P_{c}}{\lambda} + \frac{1}{\mu_{2}}$$

Therefore, 0.067 hours at the first stage plus 0.180 hours at the second stage result in a total delay of 0.247 hours, which is a 14.82 minutes. This satisfies the a constraint of less than 15 minutes of additional truck turnaround time at the inspection station in the port. In this case, as a minimum, one equipment is needed at the first stage and three equipment at the second stage to maintain a less than 15 min delay the system.

As a second case, assume that the US department of Homeland Security declared a high level of security. The question to be answered is how many inspection equipment is needed to maintain less than 10 min delay time. A weighted time of 10 sec between levels of security is assumed in this case. The following describes the solution to this question.

The arrival rate is 75 trucks/hr and the average IR under the current High Level of Security with 10 sec differential between security levels is 40 trucks/hr at the first stage and 20 trucks/hr at the second stage based on section 4.11.

The utilization rate at both the first and second stages needs to be less than 1 to maintain a stable system, $(\rho_{1s} = \lambda / c_{1s}\mu_1) < 1$ and $\rho_{2s}(= \lambda / c_{2s}\mu_2) < 1$. So, $c_{1s} = 1$ is not acceptable because the utilization rate is greater than 1. The only cases to be considered are $c_{1s} = 2$ and 3. If $c_{1s} = 2$, the utilization rate at the second stage is 0.938 and 0.625 when $c_{1s} = 3$.

At the second stage, $c_{2s} = 1$, 2 and 3 are not acceptable. The only cases to be considered are $c_{2s} = 4$ and 5. If $c_{2s} = 4$, the utilization rate at second stage is 0.938 and 0.750 when $c_{2s} = 5$.

When a MMM is considered at both the first and second stages the formulations of the MCMSM-MM model need to be used.

The additional truck turnaround time at the first stage inspection station is:

$$ATTT_{1s,MCMSM} = \frac{\sum_{n=c}^{\infty}(n-c)P_n}{\lambda} + \frac{1}{\mu_1} = \frac{\frac{(c\rho_{1s})^c}{c!} * \frac{\rho_{1s}}{(1-\rho_{1s})^2} P_0}{\lambda} + \frac{1}{\mu_1} = \frac{\frac{\rho_{1s}}{(1-\rho_{1s})^2} P_c}{\lambda} + \frac{1}{\mu_1}$$

The additional truck turnaround time at the second stage inspection station is:

$$ATTT_{2s,MCMSM-MM} = \frac{\sum_{n=c}^{\infty}(n-c)P_n}{\lambda} + \frac{1}{\mu_2} = \frac{\frac{(c\rho_{2s})^c}{c!} * \frac{\rho_{2s}}{(1-\rho_{2s})^2} P_0}{\lambda} + \frac{1}{\mu_2} = \frac{\frac{\rho_{2s}}{(1-\rho_{2s})^2} P_c}{\lambda} + \frac{1}{\mu_2}$$

The results are summarized in Table 5.3. The total delay is 0.048 (at first stage) + 0.094 (at second stage) = 0.142 hr (total) or 8.52 min (total). In this case, three equipment are used at the first stage and five equipment at the second stage to maintain a less than 10 minute delay time.

Table 5.3 Result of Number of Inspection Equipment

	First Stage		Second Stage	
Number of Equipment	2	**3**	4	**5**
Utilization Rate	0.938	0.625	0.938	0.750
Delay Time (hr)	0.271	**0.048**	0.303	**0.094**

CHAPTER 6

PROCEDURE FOR INDENTIFYING INSPECTION NEEDS

The goal of this dissertation is to obtain the minimal number of inspection equipment needed to keep the a queue delay time to an acceptable level (10 to 15 minutes). The procedure used to accomplish this goal is.

Step 1. Determine the actual arrival rate coming into the inspection station denoted by λ (containers/hr) and the inspection rate μ (containers/hr).

$$\lambda = \Lambda - \gamma \tag{6.1}$$

where, λ = actual arrival rate coming into the first stage (containers/hr)
Λ = total container arrival rate (containers/hr)
γ = usage rate of Green Lane (containers/hr)

and,

$$\mu = f(e, s, \mu_1 \text{ and } t_f \text{ (or } t_w)) \tag{6.2}$$

where , μ = actual inspection rate (containers/hr)
e_{1s} = equipment factor at first stage, s = security factor (1 to 5),
t_{f1s} = fixed time interval between level of security, and
t_{w2s} = weighted time interval between level of security.

Step 2. Given the actual arrival rate (λ) and the inspection rate (μ), determine the offered rate or utilization rate if there is only one inspection equipment ($a = \lambda / \mu$) at the first stage and the offered rate ($a_{2s} = \lambda_{2s} / \mu_{2s}$) at the second stage including $\lambda, \lambda_{2s}, \mu and \mu_{2s}$. The offered rate is defined as the utilization rate with one inspection equipment only. The actual arrival rate (Λ_{2s}) coming into the second stage is:

$$\lambda_{2s} = \lambda * \theta \tag{6.3}$$

where, λ_{2s} = arrival rate coming into second stage (containers/hr), and

θ = specific percentage going from the first stage to the second stage (containers/hr)

and, the actual inspection rate at the second stage (μ_{2s}) is.

$$\mu_{2s} = f(e_{2s}, s, \mu_2 \text{ and } t_{f2s} \text{ (or } t_{w2s}\text{))} \tag{6.4}$$

where, μ_{2s} = actual inspection rate at second stage (containers/hr)

e_{2s} = equipment factor at second stage, s = security factor,

t_{f2s} = fixed time interval between level of security at second stage, and

t_{w2s} = weighted time interval between level of security at second stage.

Step 3. From step 1 and step 2, obtain the minimal number of inspection equipment at each stage by using the offered rate and including the actual arrival rate and inspection rate into the formulation of the delay time and the number of container trucks in a single M/M/1 model (SMM) or multiple M/M/c model to keep the delay below a specified maximum level.

Step 4. Obtain the best layout and inspection station model among Single Channel and Multiple Stages (SCMSM), Multiple Channel and Multiple Stage - Single and Multiple (MCMSM-SM), Multiple Channel and Multiple Stage – Multiple and Single (MCMSM-MS), Multiple Channel and Multiple Stage – Multiple and Multiple (MCMSM-MM) are found. Best layout means the layout out of the six models with the minimal number of inspection equipment.

The flow diagram of this procedure is shown in Figure 6.1.

Total Arrival Rate (Λ); Season, Year, Market trend, Weather, Fuel Price, Port Condition, Level of security, and Political Issue etc.

Green Lane Usage Rate (γ); Percentage of trusted shippers adopted by Customs-Trade Partnership Against Terrorism (C-TPAT)

Offered Rate (a)

$\dfrac{\lambda}{\mu}$

Inspection Rate (M_1)

Equipment Factor (e_{1s})

Security Factor (s)

Time interval Fixed and/or Weighted $t_{f_{1s}}(ort_{w1s})$

IF $a < 1$

IF $a >= 1$

Formulation of SMM

Formulation of MMM

If No (If delay > targeting delay)

SMM (If Yes) If delay <= targeting delay

Second Stage

MMM (If Yes)

Arrival Rate ($\lambda_{2s} = \lambda * \theta$)

$\dfrac{\lambda_{2s}}{\mu_{2s}}$

Inspection Rate at second stage (M_2, e_{2s}, s, and $t_{f_{2s}}(ort_{w2s})$)

$\dfrac{\lambda_{2s}}{\mu_{2s}}$

Arrival Rate ($\lambda_{2s} = \lambda * \theta$)

If $a_{2s} < 1$

If $a_{2s} >= 1$

If $a_{2s} < 1$

If $a_{2s} >= 1$

Formulation of SMM

Formulation of MMM

If No

Formulation of SMM

Formulation of MMM

If No

SCMSM (If Yes) 1st: Single 2nd: Single

MCMSM-SM 1st: Single 2nd: Multiple

MCMSM-MS (If Yes) 1st: Multiple 2nd: Single

MCMSM-MM 1st: Multiple 2nd: Multiple

Figure 6.1 Flow Diagram: Procedure for Identifying Inspection Needs.

Top of Figure 6.1 shows the inputs to the process, which include actual arrival rate (λ) (the total arrival rate minus the Green Lane usage rate) the actual inspection rate (μ), which depends on the type of equipment used, the level of security, and whether fixed or weighted time interval is used between security levels. The actual arrival rate over the inspection rate becomes the offered rate (OR). If the offered rate (OR) is greater than 1, the use of a multiple M/M/c model (MMM) is required. If the offered rate (OR) is less than 1, or single M/M/1 model (SMM) will be used.

After determining the number of inspection equipment and using either the SMM or MMM model at first stage, the percentage (θ) of containers to be inspected at the second stage is used to determine the actual arrival rate at that stage. The equipment factor for X-ray/Gamma-ray inspection equipment, security factor, and fixed and/or weighted time interval are used to determine the actual arrival rate (λ_{2s}) and inspection rate (μ_{2s}) at the Second Stage. If there is a SMM at the first stage, the procedure follows the left hand side at the second stage in Figure 6.1. If there is a MMM at the first stage, the procedure follows the right hand side. If the offered rate (OR) at the second stage is greater than 1, the MMM formulation will be used to obtain the minimum number of inspection equipment needed at the Second Stage. If the offered rate is less than 1, the SMM formulation will be used.

The bottom at Figure 6.1 shows the final procedure for determining the best layout and model including SCMSM (if there are SMM models used at both first and second stages), MCMSM-Single and Multiple (if there is a SMM model at the first stage and a MMM model at the second stage), MCMSM-Multiple and Single (if MMM is used at the first stage and SMM at the second stage), and MCMSM-Multiple and Multiple (if MMM is used at both stages). Best layout means the layout out of the minimal number of inspection equipment.

6.1 Best Layout and Models

Best layout means the layout out of the six models with the minimal number of inspection equipment. The methodology presented in the flow chart of Figure 6.1 can be used to determine the minimum number of inspection equipment needed to maintain delay to an acceptable level. Assume that the inspection rates are 120 trucks/hr at the first stage, 30 trucks/hr at the second stage. Ten percent of the containers passing the first stage proceed to the second stage, and the maximum acceptable delay is 10 min. The methodology can be used to generate, the results contained in Table 6.1. As the arrival rate increases, so does the offered rate and the associated delay. As the system becomes increasingly loaded, there is a need for adding inspection equipment both at the first and second stages.

The best layout for the inspection station in this case is a SCMSM system when the offered rate is less than 0.94 (first stage) and 0.38 (second stage), a MCMSM-MS system when the offered rate is between 0.95 and 1.81 (first stage) and 0.38 and 0.72 (second stage), and a MCMSM-MM system when the offered rate is more than 2.00 (first stage) and 0.8 (second stage).

The Table 6.2 shows similar results when the inspection rate is 90 trucks/hr at the first stage and 12 trucks/hr at the second stage. Since the inspection rates are lower, as expected, the switching to a higher capacity model (SCMSM to MCMSM-MS and MCMSM-MS to MCMSM-MM) takes place now at lower offered rates than it did in Table 6.1.

Table 6.1 Best Layout and Models with IR=120, 30

Offered Rate			Offered Rate			Offered Rate		
First Stage (IR=120)	Second Stage (IR=30)	Best Model	First Stage (IR=120)	Second Stage (IR=30)	Best Model	First Stage (IR=120)	Second Stage (IR=30)	Best Model
0.02	0.01	SCMSM	0.89	0.36	SCMSM	1.76	0.70	MCMSM-MS
0.03	0.01	SCMSM	0.90	0.36	SCMSM	1.77	0.71	MCMSM-MS
0.04	0.02	SCMSM	0.91	0.36	SCMSM	1.78	0.71	MCMSM-MS
0.05	0.02	SCMSM	0.92	0.37	SCMSM	1.79	0.72	MCMSM-MS
0.06	0.02	SCMSM	0.93	0.37	SCMSM	1.80	0.72	MCMSM-MS
0.07	0.03	SCMSM	0.94	0.38	SCMSM	1.81	0.72	MCMSM-MS
0.08	0.03	SCMSM	0.95	0.38	MCMSM-MS	1.82	0.73	MCMSM-MS
0.09	0.04	SCMSM	0.96	0.38	MCMSM-MS	1.83	0.73	MCMSM-MS
0.10	0.04	SCMSM	0.97	0.39	MCMSM-MS	1.84	0.74	MCMSM-MS
0.11	0.04	SCMSM	0.98	0.39	MCMSM-MS	1.85	0.74	MCMSM-MS
0.12	0.05	SCMSM	0.99	0.40	MCMSM-MS	1.86	0.74	MCMSM-MS
0.13	0.05	SCMSM	1.00	0.40	MCMSM-MS	1.87	0.75	MCMSM-MS
0.14	0.06	SCMSM	1.01	0.40	MCMSM-MS	1.88	0.75	MCMSM-MS
0.15	0.06	SCMSM	1.02	0.41	MCMSM-MS	1.89	0.76	MCMSM-MS
0.16	0.06	SCMSM	1.03	0.41	MCMSM-MS	1.90	0.76	MCMSM-MS
0.17	0.07	SCMSM	1.04	0.42	MCMSM-MS	1.91	0.76	MCMSM-MS
0.18	0.07	SCMSM	1.05	0.42	MCMSM-MS	1.92	0.77	MCMSM-MS
0.19	0.08	SCMSM	1.06	0.42	MCMSM-MS	1.93	0.77	MCMSM-MS
0.20	0.08	SCMSM	1.07	0.43	MCMSM-MS	1.94	0.78	MCMSM-MS
0.21	0.08	SCMSM	1.08	0.43	MCMSM-MS	1.95	0.78	MCMSM-MS
0.22	0.09	SCMSM	1.09	0.44	MCMSM-MS	1.96	0.78	MCMSM-MS
0.23	0.09	SCMSM	1.10	0.44	MCMSM-MS	1.97	0.79	MCMSM-MS
0.24	0.10	SCMSM	1.11	0.44	MCMSM-MS	1.98	0.79	MCMSM-MS
0.25	0.10	SCMSM	1.12	0.45	MCMSM-MS	1.99	0.80	MCMSM-MS
0.26	0.10	SCMSM	1.13	0.45	MCMSM-MS	2.00	0.80	MCMSM-MM
0.27	0.11	SCMSM	1.14	0.46	MCMSM-MS	2.01	0.80	MCMSM-MM
0.28	0.11	SCMSM	1.15	0.46	MCMSM-MS	2.02	0.81	MCMSM-MM
0.29	0.12	SCMSM	1.16	0.46	MCMSM-MS	2.03	0.81	MCMSM-MM
0.30	0.12	SCMSM	1.17	0.47	MCMSM-MS	2.03	0.82	MCMSM-MM
0.31	0.12	SCMSM	1.18	0.47	MCMSM-MS	2.04	0.82	MCMSM-MM
0.32	0.13	SCMSM	1.19	0.48	MCMSM-MS	2.05	0.82	MCMSM-MM
0.33	0.13	SCMSM	1.20	0.48	MCMSM-MS	2.06	0.83	MCMSM-MM
0.78	0.31	SCMSM	1.64	0.66	MCMSM-MS	2.07	0.83	MCMSM-MM
0.78	0.31	SCMSM	1.65	0.66	MCMSM-MS	2.07	0.84	MCMSM-MM
0.79	0.32	SCMSM	1.66	0.66	MCMSM-MS	2.08	0.84	MCMSM-MM
0.80	0.32	SCMSM	1.67	0.67	MCMSM-MS	2.09	0.84	MCMSM-MM
0.81	0.32	SCMSM	1.68	0.67	MCMSM-MS	2.10	0.85	MCMSM-MM
0.82	0.33	SCMSM	1.69	0.68	MCMSM-MS	2.11	0.85	MCMSM-MM
0.83	0.33	SCMSM	1.70	0.68	MCMSM-MS	2.11	0.86	MCMSM-MM
0.84	0.34	SCMSM	1.71	0.68	MCMSM-MS	2.12	0.86	MCMSM-MM
0.85	0.34	SCMSM	1.72	0.69	MCMSM-MS	2.13	0.86	MCMSM-MM
0.86	0.34	SCMSM	1.73	0.69	MCMSM-MS	2.14	0.87	MCMSM-MM
0.87	0.35	SCMSM	1.74	0.70	MCMSM-MS	2.15	0.87	MCMSM-MM
0.88	0.35	SCMSM	1.75	0.70	MCMSM-MS	2.15	0.88	MCMSM-MM

Table 6.2 Best Layout and Models with IR=90, 12

Offered Rate			Offered Rate			Offered Rate		
First Stage (IR=90)	Second Stage (IR=12)	Best Model	First Stage (IR=90)	Second Stage (IR=12)	Best Model	First Stage (IR=90)	Second Stage (IR=12)	Best Model
0.01	0.01	SCMSM	0.50	0.38	SCMSM	0.99	0.74	MCMSM-MM
0.02	0.02	SCMSM	0.51	0.38	SCMSM	1.00	0.75	MCMSM-MM
0.03	0.03	SCMSM	0.52	0.39	SCMSM	1.01	0.76	MCMSM-MM
0.04	0.03	SCMSM	0.53	0.40	SCMSM	1.02	0.77	MCMSM-MM
0.06	0.04	SCMSM	0.54	0.41	SCMSM	1.03	0.78	MCMSM-MM
0.07	0.05	SCMSM	0.56	0.42	SCMSM	1.04	0.78	MCMSM-MM
0.08	0.06	SCMSM	0.57	0.43	SCMSM	1.06	0.79	MCMSM-MM
0.09	0.07	SCMSM	0.58	0.43	SCMSM	1.07	0.80	MCMSM-MM
0.10	0.08	SCMSM	0.59	0.44	SCMSM	1.08	0.81	MCMSM-MM
0.11	0.08	SCMSM	0.60	0.45	SCMSM	1.09	0.82	MCMSM-MM
0.12	0.09	SCMSM	0.61	0.46	SCMSM	1.10	0.83	MCMSM-MM
0.13	0.10	SCMSM	0.62	0.47	SCMSM	1.11	0.83	MCMSM-MM
0.14	0.11	SCMSM	0.63	0.48	SCMSM	1.12	0.84	MCMSM-MM
0.16	0.12	SCMSM	0.64	0.48	SCMSM	1.13	0.85	MCMSM-MM
0.17	0.13	SCMSM	0.66	0.49	SCMSM	1.14	0.85	MCMSM-MM
0.18	0.13	SCMSM	0.67	0.50	MCMSM-SM	1.16	0.86	MCMSM-MM
0.19	0.14	SCMSM	0.68	0.51	MCMSM-SM	1.17	0.87	MCMSM-MM
0.20	0.15	SCMSM	0.69	0.52	MCMSM-SM	1.18	0.88	MCMSM-MM
0.21	0.16	SCMSM	0.70	0.53	MCMSM-SM	1.19	0.88	MCMSM-MM
0.22	0.17	SCMSM	0.71	0.53	MCMSM-SM	1.20	0.89	MCMSM-MM
0.23	0.18	SCMSM	0.72	0.54	MCMSM-SM	1.21	0.90	MCMSM-MM
0.24	0.18	SCMSM	0.73	0.55	MCMSM-SM	1.22	0.90	MCMSM-MM
0.26	0.19	SCMSM	0.74	0.56	MCMSM-SM	1.23	0.91	MCMSM-MM
0.27	0.20	SCMSM	0.76	0.57	MCMSM-SM	1.24	0.92	MCMSM-MM
0.28	0.21	SCMSM	0.77	0.58	MCMSM-SM	1.25	0.92	MCMSM-MM
0.29	0.22	SCMSM	0.78	0.58	MCMSM-SM	1.27	0.93	MCMSM-MM
0.30	0.23	SCMSM	0.79	0.59	MCMSM-SM	1.28	0.94	MCMSM-MM
0.31	0.23	SCMSM	0.80	0.60	MCMSM-SM	1.29	0.95	MCMSM-MM
0.32	0.24	SCMSM	0.81	0.61	MCMSM-SM	1.30	0.95	MCMSM-MM
0.33	0.25	SCMSM	0.82	0.62	MCMSM-SM	1.31	0.96	MCMSM-MM
0.34	0.26	SCMSM	0.83	0.63	MCMSM-SM	1.32	0.97	MCMSM-MM
0.36	0.27	SCMSM	0.84	0.63	MCMSM-SM	1.33	0.97	MCMSM-MM
0.37	0.28	SCMSM	0.86	0.64	MCMSM-SM	1.34	0.98	MCMSM-MM
0.38	0.28	SCMSM	0.87	0.65	MCMSM-SM	1.35	0.99	MCMSM-MM
0.39	0.29	SCMSM	0.88	0.66	MCMSM-SM	1.36	0.99	MCMSM-MM
0.40	0.30	SCMSM	0.89	0.67	MCMSM-SM	1.38	1.00	MCMSM-MM
0.41	0.31	SCMSM	0.90	0.68	MCMSM-SM	1.39	1.01	MCMSM-MM
0.42	0.32	SCMSM	0.91	0.68	MCMSM-SM	1.40	1.02	MCMSM-MM
0.43	0.33	SCMSM	0.92	0.69	MCMSM-SM	1.41	1.02	MCMSM-MM
0.44	0.33	SCMSM	0.93	0.70	MCMSM-MM	1.42	1.03	MCMSM-MM
0.46	0.34	SCMSM	0.94	0.71	MCMSM-MM	1.43	1.04	MCMSM-MM
0.47	0.35	SCMSM	0.96	0.72	MCMSM-MM	1.44	1.04	MCMSM-MM
0.48	0.36	SCMSM	0.97	0.73	MCMSM-MM	1.45	1.05	MCMSM-MM
0.49	0.37	SCMSM	0.98	0.73	MCMSM-MM	1.46	1.06	MCMSM-MM

6.2 Best Model for Delay Time

The results of Table 6.1, are shown graphically in the second part of Figure 6.2, where the applicable models are indicated as a function of the offered rate at the first stage. The remaining three sections of the figure reproduce the results when the maximum acceptable delay is 5, 15 and 20 minute.

Best Layout for Delay Time (15min)

Best Layout for Delay Time (20min)
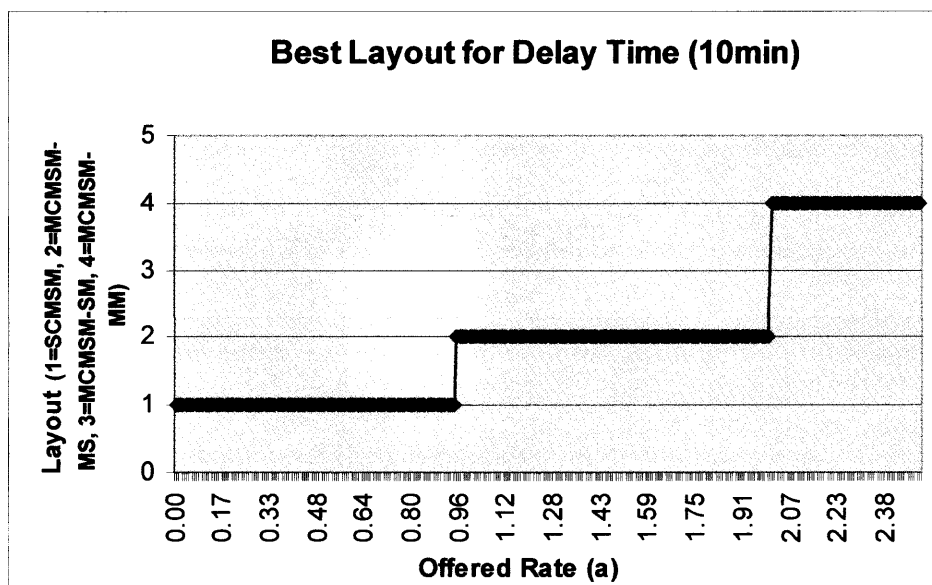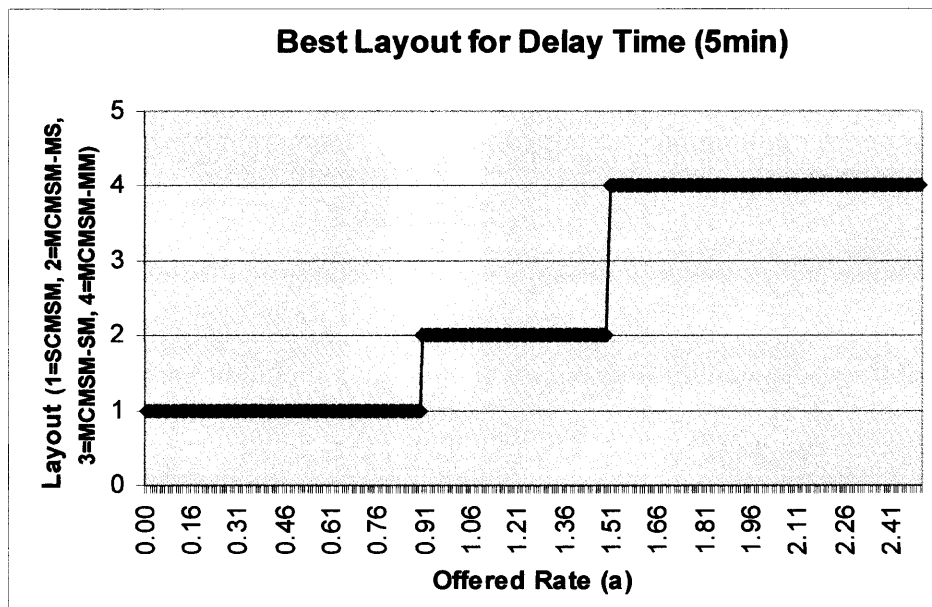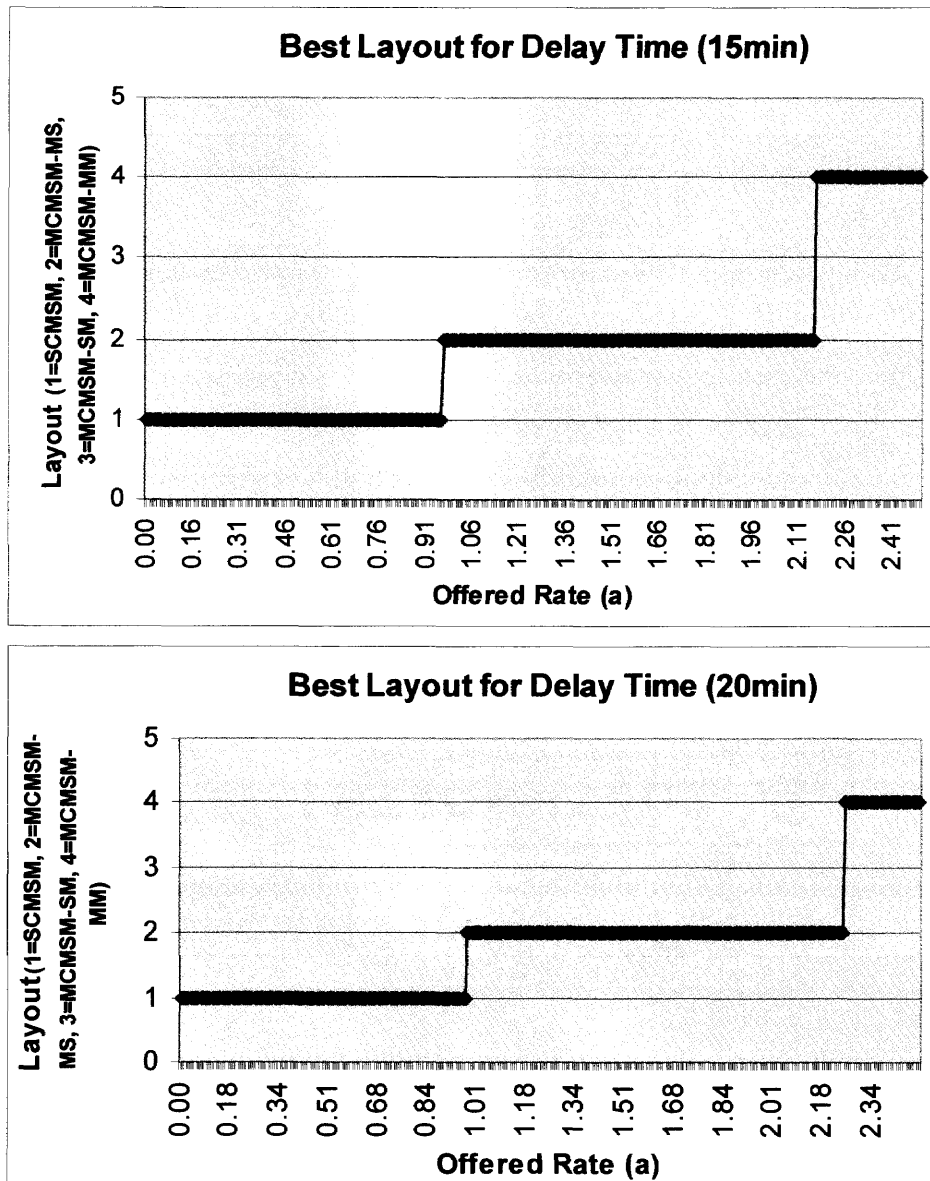
Figure 6.2 Best Layout for Delay Time, if IR=120 (1st stage) and IR=30 (2nd stage), 10% inspection at second stage.

The first point of Figure 6.2 shows that if the tolerable delay is 5 min, the best layout of the inspection station is SCMSM up to an offered rate of 0.9, MCMSM-MS for an offered rate between 0.91 and 1.5 and MCMSM-MM when the offered rate is greater than 1.5. As expected, when the acceptable delay time increases, additional equipment are added at higher offered rates.

CHAPTER 7

CONCLUSION AND RECOMMENDATION

After September 11, 2001, special attention has been given to vulnerability of containers to terrorist activities. This fact necessitated installation of inspection station at seaport container terminals. This practice resulted in additional truck turnaround time at the terminals.

In this study, queuing models are used to analyze the truck turnaround time at inspection stations. Six base models were developed and used including a single M/M/1 model (SMM), a multiple M/M/c model (MMM), a single channel with multiple stages model (SCMSM), and three multiple channels and multiple stages models (MCMSM) for predicting the additional truck turnaround time and determine the number of inspection equipment needed.

As a result of the analysis of the additional truck turnaround time (ATTT) at seaport inspection stations, the following conclusions and recommendations can be drawn and made.

* The average additional delay time in the inspection station is very dependent inspection rate of the lower stage.

* If utilization rate of the equipment is close to 1, a small increase in the arrival rate (or a small decrease in the inspection rate) will allow the delay time at the inspection equipment to increase dramatically.

* Increasing the Green Lane usage (GR) rate will decrease the arrival rate, and improvement the inspection equipment efficiency.

* The higher weighted inspection time based on raising security level allows less number of trucks to be inspected, which will derive high delay in the inspection station.

* A procedure for identifying inspection needs was used to obtain minimum number of inspection equipment needed to keep the total delay is the inspection system at acceptable levels.

U.S Coast Guard, homeland security, CBP, seaport terminal officers, truck and marine carriers and international freight shippers may use the results at this dissertation to design terminal security inspection systems in a way that does not generate excessive delays due to inspections

The models at this dissertation can be used for analyzing the additional truck turnaround time (ATTT) at seaport terminals not only in the United States, but in other foreign terminals as well. However, in this cases, the models will have to be adjusted properly considering the specific parameters associated with security levels, inspection equipment and number of stages etc that may be applicable in a particular location.

REFERENCES

Andel, Tom, and R. Cooper. Network Planning: Plug into Powerful Resources. *Transportation and Distribution.* Vol. 33, No. 5. May 1992, pp. 26-29.

Andrea, E. R., F. Nicoletta, and M. G. Luca. A Simulation Tool for Combined Rail/Road Transport in Intermodal Terminals. *Journal of Mathematics and Computers in Simulation.* Vol. 59, Issue 1. 2002.

Aron, L. P&G's Logistics Strategy: Simplify and Standardize. Inbound Logistics. Vol. 14, No. 4. April, 1994. pp. 24-29.

Asokan, T. et al., Optimum Positioning of an Underwater Intervention Robot to Maximize Workspace Manipulability. *Science Direct, Mechatronics,* Vol. 15, 2005, pp. 747-766.

Backer, R. D. and A. H. Christer. Review of Delay-Time or Modeling of Engineering Aspects of Maintenance. *European Journal of Operation Research.* Vol. 73, 1994, pp. 407-422.

Bailey, N.T.J. On Queueing Process with Bulk Service. *Journal of the Royal Statistical Society,* Series B, Vol. 16, 1954, pp. 80-87.

Baskett, F., K. M. Chandy, and R. R. Muntz. Open, Closed and Mixed Networks of Queues with Different Classes of Customers. *Journal of the Association for Computing Machinery.* Vol. 22. Issue 2. 1975, pp. 248-260.

Bharucha-Reid, A.T. Elements of the Theory of Markov Process and their Application. McGraw-Hill, New York, 1960.

Bjorkholm, P. and L. D. Boeh. The Economics of Cargo Screening, *Customs and Security,* PT31-39_2, 2002.

Bjorkholm, P. Optimising a Layered Port Security System. *Customs and Security,* PT26-01/3, 2003.

Bonner, R.C. Bonus C-TPAT Include Green Lane. *American Shipper,* Jan 17, 2005.

Bowser, G.F. and R.C. Husemann. Full Cargo Inspection Possible through Recent Technology Advances, Port Technology International. September 27, 2004.

Bruell, S.C. Computational Algorithms for Closed Queueing Networks, Elsevier/North-Holland Pub. Co., New York, 1980.

Bukowski J. V. Modeling and Analyzing the Effects of Periodic Inspection on the Performance of Safety Critical Systems. *IEEE Trans Reliable.* Vol. 50, 2001, pp. 321-329.

Burke, P. J. The Output of a Queueing System. Operation Research. Vol. 4, Issue 6. 1956, pp. 699-704.

Buxbaum, P. Timberland's New Spin on Global Logistics. *Transportation and Distribution.* Vol. 93, No. 5. May, 1994. pp. 32-36.

Cargo container X-ray inspection systems, *Hitachi Review,* Vol. 53, No. 2, 2005, pp. 97-102.

Chandy, K.M. and C.H. Sauer. Computational Algorithms for Product-form Queuing Networks. Commcations of ACM. Vol. 23, No. 10, 1980, pp. 573-583

Chatterjee, A. An Overview of Security Issues Involving Marine Containers and Ports, 82th Annual Meeting, Conference Papers. CD-ROM. Transportation Research Board, National Research Council, Washington, D.C., 2003, pp. 12-16.

Cheng, Y.L., H.C. Sen, K. Natarajan, and C.P. Teo. Dispatching Automated Guided Vehicles in a Container Terminal. PSA Corporation. Feb. 16, 2005.

Chao, X. and M. Pinedo. On Generalized Networks of Queues with Positive and Negative Arrivals. Probability in Engineering and Information Sciences, Vol. 7, 1993, pp. 301-334.

Collins, S.M., C. Levin, and D.D. John. Container Security; *A Flexible Staffing Model and Minimum Equipment Requirements Would Improve Overseas Expecting and Inspection Efforts,* Publication GAO-05-557. GAO, U.S. Government Accountability Office, Apr. 2005.

Conyers, J.C., and C.C. Kilpatrick. Customs and INS; Information on Inspection, Infrastructure, Traffic Flow, and Security Matters at the Detroit Port of Entry. Publication GAO-02-595R. GAO, U.S. Government Accountability Office, Apr 22, 2002

Cosmetatos, G. P. Some Approximate Equilibrium Results for the Multi-Server Queue (M/G/r). *Operational Research,* U.K., 27, 1976, pp 615–620.

Cox, D.R. The Analysis of Non-Markovian Stochastic Processes by the Inclusion of Supplementary Variables. *Proceedings of the Cambridge Philosophical Society,* Vol. 51, 1955, pp. 433-441.

Daganzo, C. F. The Crane Scheduling Problem. *Transportation Research Part B:* Vol. 23, Issue 3, 1989, pp. 159–175.

Dekker, R., N.P. Dellaert, M.B. Duinkerken, J.A. Ottjes, J.J.M. Evers, S.T.G.L. Kurstjens. Planning of Inter Terminal Transport at the Maasvlakte, TRAIL Proceedings, 2nd TRAIL Congress, 1996.

Department of Homeland Security. Homeland Security Advisory System. http://www.dhs.gov/xinfoshare/programs/Copy_of_press_release_0046.shtm. Accessed by September 12. 2006

Evers, J.J.M and S.A.J. Koppers , Automated Guided Vehicle Traffic Control at a Container Terminal. *Transportation Research A,* Vol. 30, Issue 1, 1996, pp. 21–34.

Feeney, K.T., R. Bentley, and D. Houde. *Programmatic Environmental Assessment for Gamma Imaging Inspection Systems*. US Customs Border Protection, July, 2004.

Fekpe, K., S. Edward, and A. M. Clayton. Aspects of Performance of Truck Weigh Stations. *Canadian Journal of Civil Engineering*. Vol. 20, 1993, pp 380-385.

Feldman, R. M. Optimal Replacement with Semi-Markov Shock Models. Journal of Applied Probability. Vol. 13. 1976. pp. 108-117.

Feller, W. An Introduction to Probability Theory and Its Applications. Vol. I, 2nd Edition, John Wiley & Sons, New York. 1968.

Fossen T. I. Guidance and Control of Ocean Vehicles. Chichester, England. Wiley. 1991.

Green, L. A Limit Theorem on Subintervals of Inter-renewal Times. *Operation Research*. Vol. 30, No. 1, 1982, pp. 210-216.

Gross, D. and C. M. Harris. Fundamentals of Queueing Theory. Second Edition. *Wiley Series in Probability and Mathematical Statistics*. John Wiley and Sons, Inc., New York, 1997

Goedvolk, E. J., H. Bob, J. Wil, and M. P. Piet. Risk Analysis of Container Import Processes. https://doc.telin.nl/dscgi/ds.py/Get/File-19007/riskanalysisVH.pdf. Accessed by October 4, 2005

Hall, G., J. Rosenthal and J. Wade. How to Make Reengineering Really Work. Harvard Business Review. Vol. 71, No. 6. November, 1993. pp. 119-131.

Hall, R. W., and C.F. Daganzo. Tandem Toll Booths for the Golden Gate Bridge. *Transportation Research Record: Journal of the Transportation Research Board, No. 905*, TRB, National Research Council, Washington, 1983, pp. 7-14.

Hamid, B., A. Amitrajeet, and A. A. Batabyal. International Trade and Biological Invasions: A Queuing Theoretic Analysis of the Prevention Problem. *European Journal of Operational Research*, Vol. 170, Issue 3, May 2006. pp. 758-770.

Hammer, M. and J. Champy. Reengineering the Corporation. Harper Business, New York. 1993.

Heyman, D.P. and S. Stidham Jr. The Relation Between Customer and Time Average in Queues. Operation Research. Vol. 28, 1980, pp. 983-993

Huynn, N., C.M. Walton, and J. Davis. Finding the Number of Yard Cranes Needed to Achieve Desired Truck Turn Time at Marine Container Terminals. *Transportation Research Record: Journal of the Transportation Research Board, No. 1873*, TRB, National Research Council, Washington, 2004, pp. 99-108.

Hultin, J.M. et al.. Securing The Port of New York and New Jersey: Network-Centric Operations Applied to the Campaign Against Terrorism. Stevens Institute of Technology, Sep. 2004.

Imai, A., Nagaiwa, K., Tat, C.W. The Dynamic Berth Allocation Problem for a Container Port, Transportation Research Part B: Methodological, Vol. 35, Issue 4, May 2001, pp. 401-417.

Jackson, J. R. Networks of Waiting Lines. Operation Research. Vol. 5. 1957, pp. 518-527.

Johnson, E. Cargo is Reviewed Several Times. Long Beach Press Telegram. July 11, 2004.

Juran, S. M. and Gryna, F. M. Quality Planning and Analysis, New York, McGraw Hill Book Co. 1980.

Kacker, R. N. Off-line Quality Control, Parameter Design, and the Taguchi Method, with Discussion. *Journal of Quality Technology*. Vol. 17. 1985. pp. 175-209.

Keane, A.G. Security in the Green Lane. *Traffic World*, Vol. 269, No. 4, Jan 24, 2005.

Keller, J. B. Optimum Checking Schedules for System Subject to Random Failure. *Management Science*. Vol. 21. 1974, pp. 256-260.

Khattak, A.J. Transportation Security: Identifying Vulnerabilities Through Spatial Analysis of Risk Perceptions. *Southeastern Transportation Center; Issues in Transportation Security*. 2002, pp. 37-49.

Khoong, C.M. and W.S. Shen. A DSS for Empty Container Distribution Planning. *Decision Support Systems.*Vol. 15. 1995, pp. 75–82.

Kim, J. O. and K. P. Khosla. Dexterity Measures for Design and Control of Manipulators. *International Workshop on Intelligent Robot and Systems*. 1991, pp. 758-763.

Kim, K.H. and H.B. Kim , Segregating Space Allocation Models for Container Inventories in Port Container Terminals. *International Journal of Production Economics*. Vol. 59, Issue 1–3, 1999, pp. 415–423.

Kleinrock, L. Queuing Systems. Vol. 1. Theory. Wiley, New York. 1975.

Kozan, E. Increasing the Operational Efficiency of Container Terminals in Australia. *Journal of the Operational Research Society*. Vol. 48. Issue 2, 1997, pp. 151–161.

Krikorian, G. Ports Called "Enormous Target": About 12000 Containers Arrive Daily in L.A. On Average, 43 of Them are Inspected by Hand under the Layered System of Homeland Security. LA Times. November 26, 2004.

Lacasse, B. B. Pannetion, and F. Fournier. Terminal Speed and Size Sorting of Insect Eggs. *Biocontrol Science and Technology*, Vol. 16, 2006, pp. 953-969.

Lee, A.M. Applied Queueing Theory, St. Martin's Press, Montreal, 1966.

Lee, H. W. *Queuing Theory*, Sigma Press, Seoul, 2006

Lee, H.W., S.H. Yoon, and S.S. Lee. Continuous Approximations of the Machine Repair System. *Applied Mathematical Modeling*, Vol. 19, No. 9, 1995, pp. 550-559.

Lewis, B. M., A. L. Erera and C. C. White III, Optimization Approaches for Efficient Container Security Operations at Transshipment Seaports, *Transportation Research Record: Journal of the Transportation Research Board, No. 1822*, TRB, National Research Council, Washington, 2003, pp. 1-8.

Lin, F. B., and M. W. Lin. Modeling Traffic Delays at Northern New York Border Crossings. *Journal of Transportation Engineering*, Vol. 127, No. 6, Nov/Dec, 2001.

Liu, C.I., H. Jula, and P. A. Ioannou. Design, Simulation, and Evaluation of Automated Container Terminals. *IEEE Transactions on Intelligent Transportation Systems,* Vol. 3, No. 1, Mar. 2002.

Modeling Toll Plaza Behavior Using Queuing Theory, Feb 7, 2005.

Munford, A. G. and A. K. Shahani. An Inspection Policy for the Weibull Case. Operational Research Quarterly. Vol. 24. 1973. pp. 453-458.

Nakagawa, T. On a Replacement Problem of a Cumulative Damage Model. *Journal Operational Research Society*. Vol. 2. 1976. pp. 895-900.

Nakagawa, T. and K. Yasui. Approximate Calculation of Optimal Inspection Times. *Journal of Operational Research Society*. Vol. 31. 1980, pp. 851-853.

Newell, G.F. Application to Queuing Theory. Chapman and Hall, London. 1971.

Orphan, V., M. Ernie, J. Gormley and R. Richardson. Advanced Cargo Container Scanning Technology Development. http://trb.org/Conferences/MTS/3A%20Orphan%20Paper.pdf. Accessed on October 3, 2005.

Osaki, S. A note on Optimum Checking Procedures. *Trans IECE Japan*. Vol. 60. 1977. pp. 764-765.

Osaki, S. An Optimum Checking Policy with Delay. *Trans IECE Japan*. Vol. 63. 1980. pp. 463-464.

Painton, L. and J. Campbell. Genetic Algorithms in Optimization of System Reliability. *IEEE Trans Reliability*. Vol. 44. Issue 2. 1995, pp. 172-178.

Peterkofsky, R. I. and C.F. Daganzo , A Branch and Bound Solution Method for The Crane Scheduling Problem. *Transportation Research Part B*, Vol. 24, Issue 3, 1990, pp. 159–172.

Phadke, M. S. Quality Engineering Using Robust Design. Prentice-Hall. Englewood Cliffs, New Jersey, 1989.

Polzin, S. Security Considerations in Transportation Planning. *Southeastern Transportation Center; Issues in Transportation Security*, 2002, pp. 12-36.

Randhawa, S.U., Y.G. Chung and E.D. Mcdowell , A Simulation Analysis for a Transtainer-Based Container Handling Facility. *Computers and Industrial Engineering.* Vol. 14. Issue 2, 1988, pp. 113–125.

Ravichandran. N. and I.V. Subba Rao. A Process oriented Approach to Waiting Line Management in a Large Pilgrimage Center in India: A Case Study, The Smart Manager, Vol 5, Issue 1, 2005, pp. 69-76.

Reich, E. Waiting Times when Queues are in Tandem. Ann. Math. Stat. Vol. 28. 1957, pp. 768-773.

Ronen. D. LSD-Logistic System Design Simulation Model. In Proceedings of the 18th Annual Transportation and Logistics Educators Conference. The Ohio State University, 1988.

Rountree, C. D. and M. J. Demetsky. A Framework for Analysis of Security Measures within On-airport Cargo Facilities. CD-ROM. Transportation Research Board, National Research Council, Washington, D.C., 2006.

Sawaragi, Y., H. Nakayama, and T. Tanino. Theory of Multi-Objective Optimization. Orlando, FL. Academic Press. 1985.

Salisbury J. K., and J. J. Craig. Articulated Hands: Force Control and Kinematic Issues. International J rob Research. Vol. 1. Issue 1, 1982, pp. 4-7.

Schiesel, S. Their Mission: Intercepting Deadly Cargo. New York Times. March, 20. 2003.

Schoenberg, J. J. and O. Shisha. In Inequalities. Academic Press. New York. 1967, pp. 255-291.

Sgouris, P. S., M. Dimitrios, and C. A. Demos. Simulation Analysis for Midterm Yard Planning in Container Terminal. *Journal of Waterway, Port, Coastal, and Ocean Engineering.* Vol. 129, Issue 4. 2003, pp. 178-187.

Shabayek, A.A. and W.W. Yeung. Effect of Seasonal Factors on Performance of Container Terminals. *Journal of Waterway, Port, Coastal, and Ocean Engineeri*ng, Vol. 127, No. 3, 2001, pp. 135-140.

Srinivasan, K. Transportation Network Vulnerability Assessment: A Quantative Framework. Southeastern Transportation Center; Issues in Transportation Security. 2002, pp. 60-79.

Stana, R.M. Homeland Security; Preliminary Observations on Efforts to Target Security Inspections of Cargo Containers. Publication GAO-04-325T. GAO, U.S. Government Accountability Office, Dec 16, 2003

Steenken, D., S. Vob, and R. Stahlbock. Container Terminal Operation and Operations Research-A Classification and Literature Review. *OR Spectrum*, Vol.26, 2004, pp. 3-49.

Stock, J. R. and D. M. Lambert. Becoming a 'World Class' Company with Logistics Service Quality. International Journal of Logistics Management. Vol. 3. No. 1. 1992. pp. 73-81.

Solberg, J. J. A mathematical Model of Computerized Manufacturing Systems. *Working Paper*, Purdue University, U.S.A.

Suri, R. An Overview of Evaluative Models for Flexible Manufacturing System. *Proceedings, First ORSA/TIMS Special Interest Conference on Flexible Manufacturing Systems.* August. 1984. pp. 15-17.

Taguchi, G. Taguchi on Robust Technology Development, ASME, New York, 1993.

Takacs, L. A single-server Queue with Feedback. *The Bell System Technical Journal*, March. 1963, pp. 505-519.

Tapiero, C. S. Quality Control by the Optimal Control of a Discrete-state Stochastic Process. *International Journal of Production Research*, Vol.24, 1986, pp. 927-937.

Tapiero, C. S. and L. Hsu. Quality Control of the M/M/1 Queue. *International Journal of Production Research*, Vol. 25, Issue 3, March 1987, pp. 447-455.

Tersine and J. Richard. Principles of Inventory and Materials Management. North-Holland, New York, 1988.

U.S. Customs Border Protection (US CBP). U.S. *Customs Trade Symposium 2002*. November 21, 2002

U.S. Customs Border Protection (US CBP). Automated Targeting System. http://www.cbp.gov/xp/cgov/newsroom/highlights/cbp_responds/facts_automated_targeting_sy s.xml. Accessed on December. 25, 2006

U.S. Customs Border Protection (US CBP). CSI Fact Sheet. http://www.cbp.gov/xp/cgov/border_security/international_activities/csi/csi_in_brief.xml. Accessed on July 15, 2006.

U.S. Customs Border Protection (US CBP). C-TPAT Fact Sheet. http://www.cbp.gov/xp/cgov/import/commercial_enforcement/ctpat/ctpat_validation/validation _fact_sheet.xml. Accessed on April 20, 2006.

U.S. Customs Border Protection (US CBP). Radiation Portal Monitor Systems. Jan. 2004.

U.S. Customs Border Protection (US CBP). Border Wait Time at http://apps.cbp.gov/bwt/ Accessed on February 8, 2007.

Vis, I.F.A., and De Koster, R. Transshipment of Containers at a Container Terminal: An Overview, *European Journal of Operational Research*, Vol. 147, 2003, pp 1-16.

Woo, T. H., and L. A. Hoel. Toll Plaza Capacity and Level of Service. *Transportation Research Record: Journal of the Transportation Research Board, No. 1320*, TRB, National Research Council, Washington, 1991, pp. 119-127.