Queueing Implications of New Security Procedures in Containerized Shipping

by

Jodi Nicole Beggs

Submitted to the Department of Electrical Engineering and Computer Science in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Electrical Engineering and Computer Science at the Massachusetts Institute of Technology

February 11, 2003

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Abstract

Transportation systems have historically been targets for terrorist activity. As a result of the September 11th terrorist attacks, concern over the vulnerability of the container shipping has vastly increased. Before September 11th, only about 2 percent of shipping containers were physically inspected for dangerous materials. More recently however, United States customs has put several plans in place to prevent shipping containers from being used to transport radioactive and other dangerous materials into the United States. Several of these initiatives involve raising the inspection rate of containers, and as a result they have a significant effect on the operations of the shipping system.

We developed several models to forecast the effect of increased security on the United States port system. First, we look at the current system from several perspectives- we develop an analytical model of the system and identify its shortcomings, and then we build a simulation model that overcomes many of these shortcomings. Furthermore, we extend the simulation model for both the case of increased cargo volume and increased inspection and monitor how the system is affected and what additional resources are needed to keep it running efficiently.

In addition, we discuss new technologies being used by U.S. Customs as an initial step in increasing security, and we provide an overview of several technologies being developed to supplement and/or replace the existing systems.

Thesis Supervisor: Richard C. Larson
Title: Professor, Department of Electrical Engineering and Computer Science and Director, Center for Advanced Educational Services
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1 Introduction

Transportation systems have always been popular targets for terrorist activity. There are numerous documented cases of airplane hijackings as well as sabotage to rail terminals and other systems. For example, there are many cases of airliners and boats being hijacked and exploited specifically for transportation to a particular destination, with the most common route being from the United States to Cuba in the 1960’s¹. [1] More recently, airplanes have even been used as weapons against the American people as well as some of the most notable structures in the country. Terrorists have even gone so far as to leverage the United States Postal Service as a means of transporting hazardous materials by sending envelopes of anthrax through the mail to various locations throughout the country. Given this history, it is reasonable to believe that transportation systems could again be exploited for attacks of great consequence, perhaps even surpassing that of the September 11th attacks.

The characteristics of transportation systems in general make them attractive to terrorists for a number of reasons. First, they usually contain large numbers of people and/or goods in confined spaces. Second, they are often moving quickly and as a result susceptible to a localized but well placed force. Third, transportation systems often contain elements that are symbolic and thus important to the country above and beyond their designated purpose. However, not all of these characteristics apply to the container

¹ The first wave of Cuban hijackings began in 1958, after Fidel Castro had taken control of Cuba. Those hijackings were primarily attempts by anti-Castro individuals to divert Cuban planes to the United States. (A number of Cuban boats were also hijacked to the United States. Immediately after the Bay of Pigs invasion in 1961, the direction of the hijackings reversed and there was a brief wave of diversions of U.S. planes to Cuba, many of these carried out by Cuban exiles. [1]
shipping system, and thus shipping has historically not been focused on as a system that is particularly susceptible to terrorist threat. Nevertheless, after the September 11th attacks, concern over the security of the container shipping process has risen dramatically.

Some people have speculated that the September 11th attacks had a purpose above and beyond mere terrorist activity. It has been postulated that the terrorists targeted the World Trade Center, the Pentagon, and other suspected targets not only to attack well-known landmarks and get the public's attention but also to fundamentally impede the country's economic system, its government, and the well being of its people. If that is true, then there are a whole new set of systems and structures that should be looked at as potential terrorist targets.

From this perspective, the container shipping system is a very attractive target for terrorist activity. First, seaports are strategically important, serving as key nodes in networks and corridors that handle the movement of a large number of goods into and out of the country. In addition, the shipping system is very international in scope and is intertwined in economics and social activities. Therefore, disruption to this system would have potentially far-reaching and long-lasting economic and social effects. Furthermore, shipping containers are highly mobile and are capable of being transported long distances in a short period of time, and also of traveling pretty much unnoticed throughout the country. These characteristics make shipping containers a ready means of delivering a wide range of terrorist weapons, from conventional explosives to extremely dangerous chemical, biological and radiological agents. [2]
As a result of the aforementioned concerns, the United States government, and more specifically the U.S. Customs Service, is undertaking significant measures in order to increase the security and safety of the shipping containers that are brought into the country. Two of these new initiatives, the Container Security Initiative and the Customs-Trade Partnership Against Terrorism, are described in detail, since they have direct ramifications for the operation of all U.S. ports.

In order to analyze the effect that these new security procedures will have on the container shipping industry and related business, we have developed a model to approximate the behavior of a single berth in a container shipping port in the United States. (We used the Port of Los Angeles as a basis for our model) This approximation can be multiplied and extended to model the behavior of an entire port if needed, thus making one able to look at the behavior of the port and determine what resources are needed in order to keep containers moving through in an efficient manner. We look at both an analytical solution and a simulation model in our examination of the current system, and we discuss the benefits and shortcomings of each. We then extend the simulation model to account for increased cargo volume and increased security (in the form of physical inspection as mandated by U.S. Customs) to see how the system responds. Next, we describe several new technologies that can be used to heighten security without severely slowing the movement of cargo. Finally, we outline the effects that these new technologies will have on the port system, both operationally and economically, and we discuss areas for further study in the shipping security realm.
2 Background and Statistics

In this section we present a general overview of the container shipping industry, highlighting the statistics that are most relevant from a security perspective. We then describe the security concerns that have arisen recently in regard to the shipping process, and we outline two important measures that U.S. Customs is implementing in an effort to effectively thwart attempts to use shipping containers as transporters of dangerous materials into the United States.

2.1 Container Shipping Overview

The term “container shipping” refers to the process developed about 40 years ago of moving various cargoes in large, uniformly sized, steel boxes (usually between 20 and 40 feet in length). The advantage of using these standardized containers is that they allow for mechanized and automated handling at ports, and they can be moved readily from one mode of transportation to another. In addition, because the goods being transported are never out in the open, container shipping is less susceptible to theft than traditional forms of cargo shipping. These advantages of container shipping have vastly improved the efficiency of ship, train, truck and terminal operations, reducing the time required for international shipping and enabling more businesses to reduce their warehouse and inventory costs through just-in-time logistics and manufacturing. [2]

However, despite the apparent appeal of container shipping in the United States, only a small number of ports have built a significant business around handling shipping
containers because of the large equipment investment required and the need for good connections with highway and rail services. Furthermore, there are significant economies of scale involved with warehousing and terminal operations that make it difficult to enter into the container-shipping realm. Most focus is placed on the ports of Newark-Elizabeth, Los Angeles and Long Beach since they handle about half of all containers entering and leaving the country. [2]

<table>
<thead>
<tr>
<th>Rank</th>
<th>Port City</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>New York (Newark-Elizabeth)</td>
</tr>
<tr>
<td>2</td>
<td>Los Angeles</td>
</tr>
<tr>
<td>3</td>
<td>Long Beach</td>
</tr>
<tr>
<td>4</td>
<td>Charleston</td>
</tr>
<tr>
<td>5</td>
<td>Seattle</td>
</tr>
<tr>
<td>6</td>
<td>Norfolk</td>
</tr>
<tr>
<td>7</td>
<td>Houston</td>
</tr>
<tr>
<td>8</td>
<td>Oakland</td>
</tr>
<tr>
<td>9</td>
<td>Savannah</td>
</tr>
<tr>
<td>10</td>
<td>Miami</td>
</tr>
</tbody>
</table>

Source: [3]

Despite the port limitations, container shipping is a vital link in global trade. Approximately 90 percent of the world’s cargo (by volume) moves by container, and there are about 200 million sea cargo container movements annually among the world’s top seaports. [3] More importantly, nearly 50 percent of all U.S. imports (by value) arrive via sea containers- in 2001, more than 5.7 million shipping containers arrived at U.S. ports in over 214,000 vessels. [3] These statistics are nearly double that for 1995 [3], and current growth predictions indicate that the amount of container cargo will quadruple over the next twenty years. [4]
As a result, the three megaports in the United States (Elizabeth-Newark, Los Angeles and Long Beach) can handle as many as 10,000 containers in a single day. [2]

Historically, United States ports have always had container inspection systems in place, but up until September 11th the focus was much more on identifying contraband than on preventing potentially destructive materials from entering the country. Inspection is handled by the U.S. Customs Service, which maintains inspectors at each port. Their main function is to classify and appraise goods and collect applicable customs duties, although other tasks may include the interception of contraband and assistance in enforcing the laws and regulations of numerous federal agencies. [2] It is also the Customs Service that provides the manpower for physical inspection of containers when necessary and performs the review of container documentation (which in most cases is just a list of container contents along with its travel history and itinerary).

---

2 Number of ships estimated based on historical data; concavity of forecast due to the assumption that new ships will be on average larger than existing ships.
2.2 Security Concerns in Container Shipping

The scenario that is most commonly considered from a security standpoint is the arrival of containers to the United States by ship and then the transfer to either truck or rail for transport to their ultimate destinations. Prior to September 11th, there were few practices to ensure the safety and security of shipping containers arriving on U.S. soil from various foreign lands. This was quite understandable, since at the time the primary focus of inter-modal transportation was the safe movement of cargo in a timely and efficient manner. Historically, in most cases shipping containers were cleared for entrance into the U.S. with a limited review of their documentation and contents. In addition, most known shippers were pre-cleared, and their shipments and documents may not be received and/or examined by Customs until up to 30 days after the cargo enters the United States. Only about two percent of containers were opened and physically inspected during the transportation process, since such inspection is very time consuming (taking 4 inspectors an average of 4 hours to inspect a 20 to 40 foot container [5], and in more thorough searches taking five inspectors up to eight hours [6]) and usually led to a delay of several days. This delay was clearly unacceptable to both shippers and receivers, who try to minimize their costs by relying on just-in-time service. [2] As a result, even though the concern over the vulnerability of container shipping has risen dramatically, the physical inspection rate has not risen to match.

The concerns over security and safety in the container shipping industry are not imaginary. The International Atomic Energy Agency has confirmed 181 cases of illicit trafficking in nuclear material since 1993. In addition, Russia has reported 500 incidents

3 This is no longer the case as a result of U.S. Customs’ Container Security Initiative. (See next section)
seized from one of Osama bin Laden’s top aides five years ago show how he apparently
planned to use shipping containers packed with sesame seeds as part of a plan to smuggle
high-grade radioactive material into the United States. [8] More recently, in October
2001 Italian law enforcement found a suspected al Qaida operative inside a shipping
container bound for Halifax, Nova Scotia. However, rather than being stowed amongst
normal cargo, the container was instead equipped with a bed and a bathroom, and the
stowaway was in possession of a mechanic’s license as well as airport security passes and
maps. [9] Clearly, the latter is a situation that could easily be averted with even a
rudimentary form of container scanning and inspection, but this would likely not be true
in most cases.

The terrorism problem in cargo presents four different types of threats:

1. Weapons of mass destruction
2. Small arms and explosives smuggling
3. Stowaways
4. Smuggling activities to fund operations

The first possibility, concealed weapons of mass destruction inside shipping containers, is
the most troubling concern and hence the immediate focus of authorities. [6] Therefore,
it is of paramount importance that procedures be implemented in order to detect these
dangerous materials, or the components needed to make such items, and prevent them
from entering the United States.


2.3 Government Response to Security Concerns

Due to increased terrorist threat, the United States has developed and is in the process of implementing a security regime that minimizes the possibility of a successful terrorist attack without slowing the movement of cargo. As a first step in better protecting the shipping system against terrorism, the U.S. Customs Service has put in place an eventual goal of increasing the physical inspection rate of containers gradually from 2 percent to 10 percent. [3] In addition, Customs is developing a comprehensive plan to identify suspicious containers and take the necessary actions to analyze their contents, in many cases before the containers ever arrive on U.S. soil. The two main parts of this plan are the Container Security Initiative and the Customs-Trade Partnership Against Terrorism. The Container Security Initiative established stricter security procedures at each step of the shipping process, and the Customs-Trade Partnership Against Terrorism joins Customs with various companies involved in the shipping process in order to maintain effective security procedures at each point in the supply chain.

2.3.1 Container Security Initiative

In response to the perceived need for increased security in container shipping, U.S. Customs launched the Container Security Initiative (CSI) in January 2002 to prevent global containerized cargo from being exploited by terrorists. The Container Security Initiative is a comprehensive anti-terrorism program, which consists of four core elements:

* Using automated information to identify and target high-risk containers
• Pre-screening containers identified as high-risk before they arrive at U.S. ports
• Using detection technology to quickly screen containers without having to conduct a physical inspection
• Using smarter, tamper-proof containers

The first component of the Container Security Initiative is the initial step in identifying potentially dangerous cargo. Using the products of increased intelligence activities, key indicators will be matched against available commercial information to intercept suspect containers. Customs is good at finding the “needle in the haystack” once appropriate criteria are identified. To support this component of the initiative, Customs introduced the 24-hour Advance Vessel Manifest Rule, which requires shippers to submit a cargo declaration a minimum of 24 hours before cargo is laden aboard a vessel at a foreign port for any vessel beginning its voyage on or after December 2, 2002.4 This will give Customs adequate opportunity to examine documentation and identify suspicious cargo before it ever has a chance to reach the United States. This mandatory advance manifest, entry and export information will certainly help Customs achieve its goal of increased security. [3]

The second core element of CSI involves placing U.S. Customs inspectors at major foreign seaports to pre-screen cargo containers before they are shipped to the United States. U.S. Customs officials, working with their foreign counterparts, will then be in a position to detect potential weapons of mass destruction as well as other dangerous materials in U.S.-bound containers at these foreign ports. The initial objective is to implement CSI at the ports (and with the governments) that send large volumes of

---

4 As noted earlier, prior to December 2002 it was common for container documentation to not reach U.S. Customs until up to 30 days after the container enters the United States.
shipping containers into the United States in a way that will facilitate the detection of potential security threats at the earliest possible opportunity. [3] Since nearly 70 percent of all U.S.-bound shipping containers pass through 20 major ports around the world, the Customs Service is initially focusing on these large ports. As of November 2002, 11 of the world’s top 20 ports (which account for over two-thirds of the containers shipped to the United States) have joined U.S. Customs in CSI to protect global commerce from a terrorist threat. [3]

<table>
<thead>
<tr>
<th>Port Location</th>
<th>Percent of U.S. Imports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong Kong</td>
<td>9.8%</td>
</tr>
<tr>
<td>Shanghai</td>
<td>5.8%</td>
</tr>
<tr>
<td>Singapore</td>
<td>5.8%</td>
</tr>
<tr>
<td>Kaohsiung</td>
<td>5.6%</td>
</tr>
<tr>
<td>Rotterdam</td>
<td>5.1%</td>
</tr>
<tr>
<td>Pusan</td>
<td>5.0%</td>
</tr>
<tr>
<td>Bremerhaven</td>
<td>4.5%</td>
</tr>
<tr>
<td>Tokyo</td>
<td>2.8%</td>
</tr>
<tr>
<td>Genoa</td>
<td>2.1%</td>
</tr>
<tr>
<td>Yantian</td>
<td>2.0%</td>
</tr>
<tr>
<td>Antwerp</td>
<td>2.0%</td>
</tr>
<tr>
<td>Nagoya</td>
<td>1.9%</td>
</tr>
<tr>
<td>Le Havre</td>
<td>1.9%</td>
</tr>
<tr>
<td>Hamburg</td>
<td>1.8%</td>
</tr>
<tr>
<td>La Spezia</td>
<td>1.7%</td>
</tr>
<tr>
<td>Felixstowe</td>
<td>1.7%</td>
</tr>
<tr>
<td>Algeciras</td>
<td>1.6%</td>
</tr>
<tr>
<td>Kobe</td>
<td>1.6%</td>
</tr>
<tr>
<td>Yokohama</td>
<td>1.5%</td>
</tr>
<tr>
<td>Laem Chabang</td>
<td>1.4%</td>
</tr>
</tbody>
</table>

Source: [3]
The third component of CSI involves using new technologies to efficiently examine those containers identified as containing potentially dangerous cargo. Advanced radiation detectors and container x-ray systems would be deployed to the big foreign ports to screen the high-risk containers. In addition, container inspection systems would also be maintained at U.S. ports to examine containers that had not been pre-cleared at a foreign port. (These systems will likely become obsolete once prescreening processes are implemented at all ports sending cargo to the United States.) We will examine several of these technologies in detail, and we will also examine the effects that they have on port efficiency both on U.S. soil and abroad.

Lastly, use of modern electronic seals at the origin of containers will greatly increase security. Currently, most containers never see a seal until after delivery to the carrier, when the carrier affixes a seal for insurance purposes. Tampering while in transit through the multiple steps of the supply chain would be minimized.

Together, these four steps should ensure strict enough security to effectively deter terrorist tampering in the shipping system and also thwart those terrorist attempts that may initially slip through the cracks.

2.3.2 Customs-Trade Partnership Against Terrorism

The Customs-Trade Partnership Against Terrorism (C-TPAT) is a joint initiative between government and businesses designed to increase the security of cargo entering the United States while improving the flow of trade. C-TPAT requires importers to take steps to assess, evolve and communicate new practices that ensure tighter security of cargo and enhanced security throughout the entire supply chain. In return, the goods
being shipped by these companies receive expedited processing during their journey into the United States. In addition, Customs will offer additional potential benefits to C-TPAT members, including dedicated commercial lanes (where infrastructure permits), an assigned Customs point of contact (or account manager), eligibility for account-based processes and billing, and reduced inspections. [10]

C-TPAT membership is available to importers, carriers, brokers, warehouse operators and manufacturers. These businesses must apply to participate in C-TPAT and agree to commit to a number of security procedures, including:

- Conducting a comprehensive self-assessment of supply chain security using the C-TPAT security guidelines jointly developed by U.S. Customs and the trade community
- Submitting a supply chain security questionnaire to Customs
- Developing and implementing a program to enhance security throughout the supply chain in accordance with C-TPAT guidelines
- Communicating C-TPAT guidelines to other companies in the supply chain and working toward building the guidelines into relationships with these companies

C-TPAT benefits can begin once Customs has completed a company risk assessment encompassing both security and trade compliance. Highly compliant importers who have already been evaluated for risk will be accepted into C-TPAT upon submission of a signed C-TPAT agreement. [10]

Seven companies- BP America, Daimler Chrysler, Ford Motor Company, General Motors Corporation, Motorola Inc., Sara Lee Corporation, and Target- helped to initiate
this program. In addition, as of November 2002, the C-TPAT program has been fully implemented and supports over 1000 members of the international trade community. [3]
3 A Model of the U.S. Port System

3.1 Description of Process

Much of the advantage of container shipping (as opposed to bulk shipping of goods) is in the standardized process by which the containers can be handled. A ship arrives at port carrying a number of containers. First, the containers are unloaded from the ship so that the ship is freed up to leave the port. The off-loaded containers are placed in a waiting area so that they are easily available when the next mode of transportation is available. Then the containers are placed on trucks in order to be transported to their ultimate destination. (Alternatively, the containers can be placed on trains or other forms of transportation, but this distinction doesn’t affect the process for the containers while in port, so will be overlooked for purposes of analysis.)

Most ports consist of several terminals, each of which contains multiple docking berths for ships. Furthermore, there are generally enough cranes and other facilities so that all of the berths can be used at the same time. This organization allows for parallel processing of many different ships (and thus many different containers). Hence, one can view each berth as its own system, which greatly simplifies the needed analysis. The current flow within a single berth could be summarized as follows:

---

5 In some cases, containers are unloaded from a ship and then reloaded due to the stacking structure of containers on the ship.

6 In reality, it is more likely that rather than using each of the berths at the same time, since ship arrival times are likely to be staggered, a shipper would have some empty berths and double up on the facilities at the berths that are occupied. However, we will make this simplifying assumption for our model.
We will use this general description of container flow to develop a model that describes the container flow within a port.

3.2 Model Formulation

We used the Port of Los Angeles as a basis for our model. This port was chosen largely because, as of year-end 2002, it was the busiest container port in the United States, and the 7th busiest in the world. [11] Six major shipping lines occupied 44 container berths in 2002, and the port is in the process of adding another terminal primarily focused on container shipping.
### Table 3-1: Port of Los Angeles Container Terminals, 2002

<table>
<thead>
<tr>
<th>Shipping Line</th>
<th>Number of Berths</th>
<th>Total Land Area (acres)</th>
<th>Mode of Operation</th>
<th>Number of Cranes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yang Ming Line</td>
<td>6</td>
<td>130</td>
<td>Grounded and Wheeled</td>
<td>5</td>
</tr>
<tr>
<td>Trans Pacific Container Service Corp.</td>
<td>5</td>
<td>125</td>
<td>Grounded and Wheeled</td>
<td>5</td>
</tr>
<tr>
<td>Stevedoring Services of America Terminals</td>
<td>4</td>
<td>91</td>
<td>Grounded and Chassis</td>
<td>4</td>
</tr>
<tr>
<td>Yusen Terminals Inc.</td>
<td>14</td>
<td>185</td>
<td>Grounded and Wheeled</td>
<td>10</td>
</tr>
<tr>
<td>Evergreen America Corp.</td>
<td>11</td>
<td>162</td>
<td>Grounded and Chassis</td>
<td>8</td>
</tr>
<tr>
<td>APL Limited</td>
<td>4 (Global Gateway South, Pier 300, Terminal Island)</td>
<td>262</td>
<td>Grounded and Wheeled</td>
<td>22</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>44</strong></td>
<td><strong>955</strong></td>
<td><strong>Grounded, Wheeled and Chassis</strong></td>
<td><strong>54</strong></td>
</tr>
</tbody>
</table>

Source: [11]

Given these data, we can use the totals for number of berths and number of cranes to estimate the structure of our model. We notice that there is approximately a one to one ratio of cranes to berths (as noted in the previous section). This implies that for our model we can assume that there is always a crane at a berth when it is needed and essentially have a series of one-server processes for normal processing. (Technically all of the processes would have to share cranes, which would limit their availability, but we take this into account by requiring a crane resource to be present at any step in our model that requires moving a container.) We can also envision the port as having separate queues for the various processes (normal, empty, and inspection), since it is not efficient.
for inspectors to wait to inspect a container until it reaches the front of a single queue, nor should it be logistically difficult to position 3 separate queues if necessary.

![Diagram of General Model Structure]

**Figure 3-2: General Model Structure**

### 3.2.1 Data and Data Issues

The data that we are using for our model are derived from a variety of sources. The most important data, the demand levels for the Port of Los Angeles and the description of facilities, comes directly from the port itself. In other cases, we looked for estimates for particular values in articles and other current publications. For example, the
manual inspection rate for containers comes from a number of specific articles, and we took a generally agreed upon middle estimate. Most sources agree that it takes a team of four inspectors an average of four hours to manually inspect a 20 to 40-foot shipping container. However, some sources quote that it takes a team of five inspectors up to eight hours to inspect a container [6]. In several instances we had to use logic to decide which statistics made sense given all of the information we had available. Since we will be dealing with Twenty Foot Equivalents (TEU’s) as a uniform container unit, it makes sense to estimate that it would take about 3 hours to inspect a container of this size.

To estimate demand levels, we first looked at yearly cargo volume data for the Port of Los Angeles. Given that we saw a steady increase in demand, we decided to use the most current volume as our estimate for cargo volume.

![Figure 3-3: Port of Los Angeles Yearly Historical Container Volume (TEU’s)](image)

Source: [11]
Again, for purposes of consistency, we will measure all aspects of our models in terms of twenty-foot equivalent units, or TEU's, as above.

Since we will most likely not run our model over an entire year, the next step was to look at how demand fluctuated from month to month. We looked at monthly data for the years 1999 to 2002, but saw no consistent seasonal trends. The 2002 data is shown below as an example.

![Graph showing monthly container volume at the Port of Los Angeles, 2002](image)

**Figure 3-4: Port of Los Angeles 2002 Monthly Container Volume (TEU’s)**

Source: [11]

Thus, we decided to use a middle value for our model, and we chose 300,000 containers per month as a reasonable estimate.7

---

7 This estimate also coincides well with the statistic that states that the large U.S. ports handle on the order of 10,000 containers per day. [2]
Despite the availability of data for a large number of our model components, we were not so fortunate as to obtain precise estimates for all aspects of our model. Overall, there are three main issues with the availability of data. First, because our data are pulled together from a large number of sources, certain statistics seem to be somewhat unintuitive. For example, we have estimates for number of containers in a year and number of ships in a year of 5.7 million and 214,000 respectively [3], but this translates to approximately 27 containers per ship, which seems like an unreasonably low number. However, we have found that container ships made approximately 51,000 port calls in 2001 [4], and though this statistic seems contradictory to the previous data, it does seem to provide a more accurate number of containers per ship (112). However, even this estimate seems quite low, since we have various data points that peg the number of containers on a ship at over 500. Second, we are unaware of the exact port structure in each of the berths. We make certain assumptions based on reading available material and using reason as a guide, but it is still unclear exactly what process each of the containers goes through while in port. Lastly, we don’t have particular estimates for how long each of the steps takes in the process that we designed. We can generate ranges to a certain degree of accuracy because we know that the port’s capacity is at least the maximum number of containers it has handled in the past.

Overall, our model is a good starting point for the analysis of new security procedures, and any changes that need to be made as more information becomes available should be able to be done with ease.

---

8 There is an additional statistic that quotes a total of 7,500 commercial vessels [4], which translates to 760 containers per ship, but this does not account for the fact that a ship can make more than one port call per year and is thus not used in our data gathering process. The apparent underestimation from using the port call number is likely due to the fact that not all of the port calls were made by container ships.
3.3 A Simple Analytical Solution

For an initial approach to analyzing this system, one might look to a traditional M/M/s queueing model. The advantage of this approach is that we only need values for three parameters— the container arrival rate, the container service rate and the number of servers. This seems like a reasonable preliminary approach for several reasons. First, one could argue that the container arrivals constitute a Poisson process because ships are arriving from a large number of different locations\(^9\) and, although their departures are likely to be scheduled in advance, the ships are subject to a number of unpredictable delays due to weather and tides and other factors that lead to the presence of nondeterminism in their arrival times. Furthermore, it makes sense for the service times to follow an exponential distribution since there are a number of conditions (container location, crane availability, and other unpredictable complications) that contribute to the memoryless nature of the service process.\(^{10}\)

---

\(^9\) According to the American Association of Port Authorities, each U.S. state receives goods from an average of 15 different ports each day. [12]

\(^{10}\) A memoryless distribution is one where the expected remaining service time for a process is the same as the expected service time at the beginning of the process— i.e. the process has no memory of how much time has gone by to change the expected remaining service time. For a more detailed explanation, see *Urban Operations Research* by Larson and Odoni. [13]
### Table 3-2: Analytical Model Parameters

<table>
<thead>
<tr>
<th>Model Parameter</th>
<th>Value</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container Arrival Rate ($\lambda$)</td>
<td>9.5 per hour</td>
<td>Based on L.A. cargo level estimate of 300,000 ships per month over 44 berths</td>
</tr>
<tr>
<td>Number of servers ($s$)</td>
<td>2</td>
<td>2 teams of workers, each of which can perform either container processing or inspection duties</td>
</tr>
<tr>
<td>Container Service Rate ($\mu$)</td>
<td>6.1 per hour</td>
<td>Weighted average of normal processing and inspection rates—assumes 2% inspection with 195 minute average inspection time (including regular processing), normal processing time of 6.08 minutes(^{11})</td>
</tr>
</tbody>
</table>

Based on these parameters (and also the fact that the system will reach steady state, i.e. $\lambda/s\mu<1$ – in this model it is 0.78), we can directly apply the theorems of classic queueing theory to analyze the behavior of the current port system.

\(^{11}\) For normal processing, 3 minute service time to get container off boat and 6 minute service time to get a single container to waiting area, though we put the average at 3 minutes since it is likely that 2 containers are moved in the 6 minutes; for inspection, 3 minute service time to get container off boat, 6 minute service time to get container to inspection area, 180 minutes to inspect, and 6 minutes to get container to waiting area
Table 3-3: Analytical Model Results

<table>
<thead>
<tr>
<th>System Characteristic</th>
<th>Formula</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability of System Being Empty</td>
<td>[ \rho_0 = \left( \frac{e^{-\lambda \mu^2} + 1}{s \mu} \frac{\lambda}{s \mu - \lambda} \right)^{-1} ]</td>
<td>0.12</td>
</tr>
<tr>
<td>Mean Number in Queue</td>
<td>[ L_q = \frac{(\lambda / \mu)^s \lambda \mu}{(s-1)(s \mu - \lambda)} \rho_0 ]</td>
<td>2.40</td>
</tr>
<tr>
<td>Mean Number in System</td>
<td>[ L = L_q + \frac{\lambda}{\mu} ]</td>
<td>3.96</td>
</tr>
<tr>
<td>Mean Waiting Time in Queue</td>
<td>[ W_q = \frac{(\lambda / \mu)^s \mu}{(s-1)(s \mu - \lambda)} \rho_0 ]</td>
<td>0.25 hours</td>
</tr>
<tr>
<td>Mean Waiting Time in System</td>
<td>[ W = W_q + \frac{1}{\mu} ]</td>
<td>0.42 hours</td>
</tr>
<tr>
<td>Proportion of Time Servers are Busy</td>
<td>[ 1 - \rho_0 ]</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Source: (for formulas) [13]

This model tells us several important things. First, it shows that if our estimates are valid then the system is not overloaded at this level of demand. Furthermore, we can see that on average the waiting time for a container is well below the 24-hour threshold that is generally accepted as the upper limit of acceptability in terms of turnaround time. Going further, we could tweak the model by increasing the inspection rate to the point where the system becomes overloaded. We can easily then see that the system becomes overloaded as the inspection rate rises above 3.4%. Since this is well below Customs' goal of increasing the inspection rate to 10%, our preliminary estimates show that a substantial increase in port resources will be necessary. In addition, we can see that the system becomes overloaded (at the 2% inspection rate) if the demand level exceeds approximately 385,000 containers for a sustained period of time. Thus, the system will
clearly not be able to handle the projected demand forecasts, even without increased inspection.

Though simple and easy to analyze (and beneficial in terms of getting an analytical solution), this method has a number of obvious drawbacks. First, there are other important metrics that are not easily to calculate within this model. For example, one would likely be interested in the number of containers that are held in the system for more then the 24-hour threshold, but this information is not easily attainable. Second, and more importantly, there are significant intricacies of the port system that are not taken into account with this approach. For example, this model fails to account for the fact that the containers actually arrive in batches since there are multiple containers on a ship being dropped off at a port. Also, the two-server configuration implies that the resources that inspect containers and the resources that take care of normal processing are interchangeable, which is certainly not the case. Clearly, a better model needs to be designed.

3.4 Using Simulation for a Better Model

One way to achieve a more accurate picture of the port operation in question is to abandon the analytical model and opt for a simulation model instead. While this approach is generally not considered as elegant, it is a very effective tool for examining a very specific model configuration. We will use the model that we described earlier for our simulation:
Now we can go through each component in turn and describe its structure, parameters, and resources required. (Note that pentagons denote work entry and exit points, ovals denote queues and rectangles denote work centers.)

### 3.4.1 Model Components

1. **Ship Arrives at Port**: This is a work entry point, which essentially just denotes the point at which objects enter the system. The unique aspect of this component is that containers leave this component in batches, thus accurately reflecting the fact that containers actually enter the port in batches, since they arrive on ships. Based
on the current statistics for number of containers (5.7 million) and number of port calls (51,000), we can estimate that there are approximately 112 containers per ship. For our model we can define the batch size as normally distributed with a mean of 130 and a standard deviation of 10. (We use a number slightly above the overall average to reflect the fact that the Port of Los Angeles handles a disproportionately large number of containers, and also to take into account the fact that when calculating average containers by ship by using the statistic for port calls, we don’t take into account the fact that not all port calls were made by container ships. Since we know that 90% of the world’s cargo moves by container, we assume that 90% of port calls are made by container ships.) The other characteristic of this component is the ship arrival rate. Using an estimate of 300,000 containers per month and 130 containers per ship, we model the arrival of ships as a Poisson process with an arrival rate of 0.073 ships per berth per hour.

2. Arrived Containers Still on Ship: This is a queue for containers that are waiting to be taken off of a ship. Since this queue is a simple storage area and we are assuming a first come first served discipline, it doesn’t have any specific parameters.

3. Containers are Taken Off Ship: Once containers are taken off the ship, they are directed to one of three queues- Normal Queue, Empty Queue, or Inspection Queue. In our model, we need to specify how containers are directed to these queues. First, we know that our baseline inspection rate is 2%; therefore we send 2% of containers to the inspection queue. (It is important to note that even empty
containers can be inspected, since there is a possibility of hiding dangerous material in a seemingly vacant container.) According to the Port of Los Angeles cargo volume data, in 2002 an average of 4 percent of containers were empty when they arrived in the United States. Thus we will direct 4 percent of remaining containers to the empty queue. The remaining containers will go to the normal queue. We will assume that the containers are not arranged in any particular fashion\(^\text{12}\), and thus containers will randomly be sent to queues such that the above percentages are satisfied. In addition, we need to specify a service time distribution for containers being taken off the ship. We will use a log normal distribution\(^\text{13}\) with a mean of 3 minutes and a standard deviation of 0.5 minutes. (For purposes of simplicity we are not taking into account the fact that cranes could process more than one container at a time- we assume this is taken into account in the service time mean.) Furthermore, we require that a crane resource be present to take the containers off of a ship. This resource is separate from the forklift resource that will do the other moving of containers.

4. Normal Queue: This is a queue for containers that are waiting normal processing-\(\text{i.e. they are not empty and not scheduled for inspection, so they simply are waiting to be moved to an area where they wait to be placed on trucks. Since this queue is a simple storage area and we are assuming a first come first served discipline, it doesn’t have any specific parameters.}

---

\(^{12}\) Though much work in Operations Research has been centered on ideal container configuration within a ship, we will not assume that any particular efficiency algorithm is used in the arriving ships.

\(^{13}\) A log normal distribution is commonly used for service times, and is similar to a normal distribution but skewed to the left and not resulting in values less than zero. This distribution is appropriate since we expect most service times to be in close proximity on either side of the mean, but a few times may be much greater due to complications in the process.
5. Empty Queue: This is a queue for containers that were empty when they arrived at port. Since this queue is a simple storage area and we are assuming a first come first served discipline, it doesn’t have any specific parameters.

6. Inspection Queue: This is a queue for containers that have been scheduled for inspection. Since this queue is a simple storage area and we are assuming a first come first served discipline, it doesn’t have any specific parameters.

7. Normal Processing: This is a work center, so we need to define the service time distribution. Essentially the work process here involves taking a container that has been recently taken off a ship and moving it to an area to await pickup by the appropriate truck. Since this is likely to involve more distance than the process of taking containers off ships, we will assume that the service time is log normal with a mean of 6 minutes and a standard deviation of 0.5 minutes. (Again we are not taking batching into account here) We will require a forklift resource to be present for this work to be done, and we will assume that the work could happen with 2 containers in parallel if the needed resources are available.

8. Empty Processing: This is a work center, so we need to define the service time distribution. The process for empty containers is very similar to that for full containers, but since empty containers are lighter (and perhaps better balanced and being moved to a different location), we are going to assume a slightly shorter service time and use a log normal distribution with a mean of 5 minutes and a standard deviation of 0.5 minutes. We will require a forklift resource to be present to do this work.
9. Inspection: This is a work center that has multiple components. The process for containers being inspected is threefold—first containers are moved to an inspection area, then they are inspected, and finally they are moved to the area where they can await truck pickup. Given that we know that the average time to inspect a TEU is 3 hours, we can model this process as three consecutive work centers with queues between them. First, we have a process of moving the container to an inspection area, which will have a log normal service time distribution with a mean of 6 minutes and a standard deviation of 0.5 minutes, and will require a forklift resource. Next, we have the inspection process, which is log normal with a mean of 180 minutes and standard deviation of 30 minutes, and requires an inspection team resource.\textsuperscript{14} Finally, the container is moved to the waiting area, and this process is also log normal with mean 6 minutes and standard deviation 0.5 minutes, and requires a forklift resource. Thus, we can state the total time needed for this process as having a mean of $3+180+3=186$ minutes. There are several simplifying assumptions that we made to arrive at these parameters. The first is that there will be a set of customs inspectors available at each berth at all times. While this may not be entirely accurate, making the assumption and then analyzing the percentage of time that the inspectors would be busy gives us good insight into the port system and how many overall resources would be needed. The second assumption is that there is an inspection area at each berth. This assumption seems reasonable, and is also easy to modify for the case of a more central inspection location— one could correct the model by changing the times

\textsuperscript{14} We define an inspection team resource to be a set of four inspectors.
needed to move the container to and from the inspection area. (In some port examples we have seen that the presence of a centralized inspection location is a definite possibility, but it is not clear whether time taken to move the container to this area is taken into account in the inspection time statistics.)

10. Ready to Leave Port: This is a work exit point, which means that the containers that pass through here are now ready to leave the port by being placed on trucks. By monitoring the throughput of this component we can measure the overall throughput of the system.

This information is summarized below:

| Table 3-4: Summary of Model Components and Parameters |
|---------------------------------|-----------------|---------------------------------|-----------------|
| Model Component                 | Type            | Parameters                      | Resources       |
| Ship Arrives at Port            | Work Entry Point| Ship arrival rate: Poisson process with mean of 0.073 per hour; Batches normally distributed with mean 130 and st. dev. 10 |                  |
| Arrived Containers Still on Ship| Storage (Queue) | FCFS, no specific parameters     |                  |
| Containers are Taken Off Ship   | Work Center     | Service time log normal with mean 3 minutes and st. dev. 0.5; 2% of containers (randomly) directed to inspection queue, 3.92% to empty queue, and rest to normal queue | Crane           |
| Normal Queue                    | Storage (Queue) | FCFS, no specific parameters     |                  |
### 3.4.2 Building the Model

In order to run our model, we employed a simulation software package called Simul8. This program allows the user to define various components of logistical processes and then run Monte Carlo type simulations over a specified period of time and analyze the results. When we build the model using the program, we get the following structure:

<table>
<thead>
<tr>
<th>Component</th>
<th>Location</th>
<th>Service Time</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty Queue Storage</td>
<td>FCFS, no specific parameters</td>
<td>Forklift</td>
<td></td>
</tr>
<tr>
<td>Inspection Queue Storage</td>
<td>FCFS, no specific parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal Processing Work Center</td>
<td>Service time log normal with mean 6 minutes and st. dev. 0.5; 2 work centers</td>
<td>Forklift</td>
<td></td>
</tr>
<tr>
<td>Empty Processing Work Center</td>
<td>Service time log normal with mean 5 minutes and st. dev. 0.5</td>
<td>Forklift</td>
<td></td>
</tr>
<tr>
<td>Inspection</td>
<td>Three work points with queues between and log normal service times, first with mean 3 minutes and st. dev. 0.5, second with mean 180 minutes and st. dev. 30 and third with mean 6 minutes and st. dev. 0.5</td>
<td>Forklift, Inspectors, Forklift</td>
<td></td>
</tr>
<tr>
<td>Ready to Leave Port</td>
<td>No specific parameters</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Within this simulation are exactly the parameters that we described earlier. An important feature to note is the definition of resources. For example, based on our estimates there is only about one crane to handle all of the moving of containers off a ship, we have one crane resource. Similarly, we determined to model one set of inspectors for each berth, so we have one inspector team resource available. We define a forklift resource that is a general device to move containers within the port, and we assume that two of these will be available for each berth and that they are different from the crane resource.
3.4.3 Running the Model

In order to run the simulation that we just described, we need to make a few more design decisions. The first is regarding how we want to arrange the port's hours of operation. Given the uncertainty in the arrival time of ships (as well as the global nature of the industry), and also the cost effectiveness of utilizing resources as fully as possible, it is reasonable to assume that the port is in operation 24 hours a day, 7 days a week. Fluctuations in demand will most likely occur, but they are not likely to be significantly different from the fluctuations created by the Poisson arrival process in the first place.

The second decision is twofold. The first part of the decision involves choosing an overall time frame over which to analyze the model. Because our demand estimates were based on monthly statistics, it makes sense to choose 30 days as our period of observation. The second part of the decision involves choosing general runtime techniques. We chose both to have a warm up period of one week before the results collection period, because we don't want to assume that our model starts with an empty port, and we will run multiple trials of our simulation in order to correct for outlying results due to randomness.

3.4.4 Model Results

Once we've made all of the design decisions for the model, the next step is to run the model and analyze the results. We will run five trials of the simulation and record the results of each trial, and then calculate the average and the 95 percent confidence interval (based on calculating 2 standard deviations above and below the mean). We will look at
the overall performance of the system, and we will also look at characteristics of individual components within the system.

Since we are primarily concerned with system throughput and waiting time, the relevant statistics to look at for the overall system have to do with these measures. In addition, we will look at the proportion of containers that are ready to leave the port within 24 hours of arrival, since that is a generally accepted standard for in port turnaround time. The results are summarized as follows:

Table 3-5: Overall System Results

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
<th>Trial 5</th>
<th>Average</th>
<th>-95%</th>
<th>+95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number Completed</td>
<td>7072</td>
<td>7706</td>
<td>6535</td>
<td>7580</td>
<td>5804</td>
<td>6939</td>
<td>5964</td>
<td>7915</td>
</tr>
<tr>
<td>Minimum Time in System (minutes)</td>
<td>10.5</td>
<td>9.6</td>
<td>10.0</td>
<td>10.4</td>
<td>9.7</td>
<td>10.0</td>
<td>9.5</td>
<td>10.6</td>
</tr>
<tr>
<td>Average Time in System (minutes)</td>
<td>422.2</td>
<td>398.8</td>
<td>497.2</td>
<td>341.4</td>
<td>362.5</td>
<td>404.4</td>
<td>329.2</td>
<td>479.7</td>
</tr>
<tr>
<td>Maximum Time in System (minutes)</td>
<td>2287.2</td>
<td>3762.9</td>
<td>2540.9</td>
<td>2169.5</td>
<td>3404.4</td>
<td>2833.0</td>
<td>1951.9</td>
<td>3714.1</td>
</tr>
<tr>
<td>Standard Deviation of Time in System (minutes)</td>
<td>301.4</td>
<td>328.8</td>
<td>406.9</td>
<td>233.8</td>
<td>316.4</td>
<td>317.5</td>
<td>240.5</td>
<td>394.4</td>
</tr>
<tr>
<td>% in system less than 24 hours</td>
<td>99.6</td>
<td>99.1</td>
<td>95.5</td>
<td>99.6</td>
<td>99.4</td>
<td>98.6</td>
<td>96.4</td>
<td>100</td>
</tr>
</tbody>
</table>
The first measure, number completed, is roughly equal to the number of containers that arrived to the port during the specified results calculation period. This is because, although there are containers left in the system when the time period ends, there were containers that exited the system during the results collection period that entered the system during the warm up period. The next four measures specify the distribution of the turnaround time for a container going through the port. From our model, it appears that on average, it takes containers about seven hours to go through the port system. (This does not necessarily mean that they will leave the port seven hours later however- there is an additional waiting time for the truck that the container goes on to arrive at the port.) However, the time to go through the system varies widely, ranging from very little time to in some cases over a full day. Thus, it follows logically that the vast majority of containers are ready to leave the port less than 24 hours after they arrive on a ship.

Next, we will examine the different paths that a container can take- normal processing, empty processing and inspection- in turn. The main focus of the process is on the containers being inspected, so we will analyze those statistics first. For the work center, there are only a couple of relevant numbers, but for the queue leading to the work center there are a good deal more measures of interest.

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
<th>Trial 5</th>
<th>Average</th>
<th>-95%</th>
<th>+95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number Completed</td>
<td>127</td>
<td>154</td>
<td>129</td>
<td>165</td>
<td>122</td>
<td>139</td>
<td>116</td>
<td>163</td>
</tr>
<tr>
<td>% of Time Working</td>
<td>53.8</td>
<td>64.0</td>
<td>53.5</td>
<td>70.2</td>
<td>50.5</td>
<td>58.4</td>
<td>48.1</td>
<td>68.8</td>
</tr>
<tr>
<td>Performance Measure</td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Trial 3</td>
<td>Trial 4</td>
<td>Trial 5</td>
<td>Average</td>
<td>-95%</td>
<td>+95%</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Minimum Queue Size</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Average Queue Size</td>
<td>1.23</td>
<td>3.59</td>
<td>1.29</td>
<td>1.62</td>
<td>1.54</td>
<td>1.85</td>
<td>0.63</td>
<td>3.07</td>
</tr>
<tr>
<td>Maximum Queue Size</td>
<td>9</td>
<td>17</td>
<td>12</td>
<td>8</td>
<td>12</td>
<td>12</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>Minimum Queueing Time (minutes)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Average Queueing Time (minutes)</td>
<td>411.7</td>
<td>1004.7</td>
<td>422.9</td>
<td>416.8</td>
<td>545.6</td>
<td>560.3</td>
<td>244.3</td>
<td>876.4</td>
</tr>
<tr>
<td>Maximum Queueing Time (minutes)</td>
<td>1497.5</td>
<td>2973.6</td>
<td>1929.9</td>
<td>1311.2</td>
<td>2092.3</td>
<td>1960.9</td>
<td>1156.2</td>
<td>2765.6</td>
</tr>
<tr>
<td>Standard Deviation of Queueing Time (minutes)</td>
<td>406.4</td>
<td>969.7</td>
<td>435.5</td>
<td>366.5</td>
<td>533.2</td>
<td>542.3</td>
<td>236.0</td>
<td>848.6</td>
</tr>
</tbody>
</table>

The number of containers inspected follows from the fact that we would expect the amount to be approximately 2 percent of the containers entering the port. In addition, we observe that the inspectors for a given berth are busy only a little over half of the time. As we noted before, this implies that if there were to be a general pool of inspectors that serve the entire port, there would only need to be a little over one team of inspectors for every two berths. (Although, while the system will reach steady state as long as inspector service rate is greater than container arrival rate, if utilization is too high then too many containers will be held in excess of the 24-hour period) In fact, the
general pool configuration could lead to a slightly more efficient system, since if there were two containers to be inspected in one berth and zero in another, they would both be able to be inspected at the same time, which is not possible in the existing configuration.

As for the characteristics of the inspection queue itself, we first notice that the minimum queue length (and therefore wait time) is zero in all cases. This follows logically from the above, since the queue would have to be empty in order for the inspectors to not be working. We can also see that, although on average containers wait about 7 hours to be inspected (ignoring the outlier in trial 2), in some cases they wait several days, which is a significant detriment to the system.

In addition to the inspection process itself, there are two more components to this part of the port system. As we stated before, containers must be moved to an inspection area to be inspected and then out of the inspection area when they are deemed safe to enter the country.

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
<th>Trial 5</th>
<th>Average</th>
<th>-95%</th>
<th>+95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of Time Working</td>
<td>1.81</td>
<td>2.17</td>
<td>1.84</td>
<td>2.32</td>
<td>1.72</td>
<td>1.97</td>
<td>1.65</td>
<td>2.29</td>
</tr>
</tbody>
</table>
We notice that the process of moving containers to an inspection area does not put a large burden on port resources, not does it add significantly to the time in the port system for containers. We would expect the same to be true of the process that moves containers from the inspection area to the waiting area, and that assumption is correct based on the following statistics:
The processes of moving containers to and from the inspection area doesn't create a lot of overhead simply because so few containers are being inspected. (In other words, we would expect overhead to increase slightly as the inspection rate increases.) Now we can turn our attention to the non-inspection pathways in the port system.
We can see from the above data that the port is not running at capacity. In addition, it is clear that in general that waiting time for normal processing is not an overwhelming bottleneck in the port system - the maximum waiting time for a container
being processed normally is much less than the expected time it takes for a container to go through the inspection part of the system.

Lastly, we can look at the system that handles the processing of empty containers that arrive at the port.

Table 3-14: Empty Container Work Center Statistics

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
<th>Trial 5</th>
<th>Average</th>
<th>-95%</th>
<th>+95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of Time Working</td>
<td>3.67</td>
<td>3.59</td>
<td>3.11</td>
<td>3.64</td>
<td>2.74</td>
<td>3.35</td>
<td>2.84</td>
<td>3.86</td>
</tr>
</tbody>
</table>

Table 3-15: Empty Processing Queue Statistics

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
<th>Trial 5</th>
<th>Average</th>
<th>-95%</th>
<th>+95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Queue Size</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Average Queue Size</td>
<td>0.0013</td>
<td>0.0009</td>
<td>0.0012</td>
<td>0.0019</td>
<td>0.0012</td>
<td>0.0013</td>
<td>0.0008</td>
<td>0.0017</td>
</tr>
<tr>
<td>Maximum Queue Size</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Minimum Queueing Time (minutes)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Average Queueing Time (minutes)</td>
<td>0.14</td>
<td>0.14</td>
<td>0.15</td>
<td>0.21</td>
<td>0.12</td>
<td>0.15</td>
<td>0.11</td>
<td>0.20</td>
</tr>
<tr>
<td>Maximum Queueing Time (minutes)</td>
<td>4.29</td>
<td>5.52</td>
<td>4.15</td>
<td>5.07</td>
<td>4.64</td>
<td>4.73</td>
<td>4.03</td>
<td>5.44</td>
</tr>
<tr>
<td>Standard Deviation of Queueing Time (minutes)</td>
<td>0.56</td>
<td>0.61</td>
<td>0.58</td>
<td>0.72</td>
<td>0.54</td>
<td>0.60</td>
<td>0.51</td>
<td>0.69</td>
</tr>
</tbody>
</table>
It is shown very clearly here that the processing of empty containers does not place a heavy burden on the resources allocated to perform those tasks. Given that the empty processing resources are utilized less than 4 percent of the time, perhaps a more accurate model would assume that empty and normal processing are handled by the same work center. To implement this, we could view the normal processing and empty processing queues as a single queue with the service time being a weighted average of the two separate times. However, if getting the empty containers off the ship and into a position where they can be picked up and taken to be filled very quickly is a high priority for the shipping line, perhaps the existing model is perfectly satisfactory.

The last components of interest in our model are the work center for taking containers off of a ship and the arrived containers queue leading up to the work center.

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
<th>Trial 5</th>
<th>Average</th>
<th>-95%</th>
<th>+95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of Time Working</td>
<td>49.1</td>
<td>53.7</td>
<td>45.5</td>
<td>52.8</td>
<td>40.3</td>
<td>48.3</td>
<td>41.4</td>
<td>55.1</td>
</tr>
</tbody>
</table>

Table 3-16: Taking Containers off Ships Work Center Statistics
### Table 3-17: Arrived Containers Queue Statistics

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
<th>Trial 5</th>
<th>Average</th>
<th>-95%</th>
<th>+95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Queue Size</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Average Queue Size</td>
<td>65.2</td>
<td>64.7</td>
<td>74.6</td>
<td>55.3</td>
<td>45.1</td>
<td>61.0</td>
<td>47.1</td>
<td>74.9</td>
</tr>
<tr>
<td>Maximum Queue Size</td>
<td>410</td>
<td>453</td>
<td>683</td>
<td>359</td>
<td>474</td>
<td>476</td>
<td>322</td>
<td>630</td>
</tr>
<tr>
<td>Minimum Queueing Time (minutes)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Average Queueing Time (minutes)</td>
<td>398.3</td>
<td>362.1</td>
<td>474.9</td>
<td>315.6</td>
<td>333.8</td>
<td>376.9</td>
<td>298.7</td>
<td>455.2</td>
</tr>
<tr>
<td>Maximum Queueing Time (minutes)</td>
<td>1223.3</td>
<td>1350.1</td>
<td>1878.4</td>
<td>1080.3</td>
<td>1424.8</td>
<td>1391.4</td>
<td>1016.4</td>
<td>1766.4</td>
</tr>
<tr>
<td>Standard Deviation of Queueing Time</td>
<td>284.2</td>
<td>244.4</td>
<td>398.6</td>
<td>206.1</td>
<td>277.4</td>
<td>282.2</td>
<td>192.6</td>
<td>371.7</td>
</tr>
</tbody>
</table>

While these components are not central to our analysis of security procedures specifically, it is important to note that although containers are being taken off ships less than half of the time, there can be backlog times of over a day in some cases. This is a result of the batching of the container arrival process. Thus, if the ships were scheduled to arrive such that the time between arrivals was enough to get all of the containers off of a ship before the next one arrives, this delay could in theory be avoided.

The above statistics give us a pretty comprehensive picture of how a berth in the port system operated prior to September 11th (and to a certain degree afterwards, since
many initiatives were not put into place until late 2002). The next step in a thorough analysis is to examine how changes in both demand and inspection affect the port system and container delays.
4 Modeling Forecasted Demand and Security

An important component of our analysis is to examine how changes in demand and inspection affect the system. First, we will look at how increasing the number of containers (and therefore ships) affects the different parts of our system. Next, we will model how changing the container inspection rate will impact container delays.

In each of the following analyses, it is important not only to perturb the model the maximum amount that is reasonable in order to give a worst case delay scenario, but also to find the break point levels at which the system produces delays of unacceptable length (in our case over 24 hours). Both of these actions are outlined for the demand and the inspection case.

4.1 Increased Demand

As stated earlier, the number of containers arriving at U.S. ports is expected to approximately quadruple over the next twenty years. This has the effect of both increasing the number of ships coming into U.S. ports, and also most likely increasing the number of containers on each ship. Although many U.S. ports have expansion in the works, or will be implementing such plans in the near future, it is extremely doubtful that port resources will quadruple by the year 2020. Nevertheless, there are two ways in which ports will expand in order to be able to handle increased capacity. The first is that the number of berths in each port will increase. Therefore, a portion of the increased volume will be absorbed by the new berths, and the existing berths will not be subjected
to the full brunt of the increase. The second is that the facilities at the port in general will improve. For example, ports might increase the number of cranes in order to process the increasing number of containers. In addition, Customs would likely also increase the number of inspectors present at each port in order to keep up with busier conditions.

We can use this information to make appropriate changes to our model in order to approximate the future operations of the system. First, we change the average number of containers per ship from 130 to 180 (to take into account both larger ships and more heavily loaded ships). Therefore, since we are assuming that container volume will quadruple, the number of ships should increase by a factor of less than 4. Next, we estimate that the number of berths will increase by 50 percent. Then we can estimate also that the number of cranes and forklifts will be augmented, so there will be two cranes and three forklifts available per berth on average. Thus, the normal processing queue will now lead to three servers, each of which will require a forklift resource (of which there will be three total) to operate. (We do not increase the number of servers for the other moving processes since they have very low utilization) We also assume that the number of inspectors increases by 50 percent, so there are 1.5 sets of 4 inspectors each per berth.\(^{15}\)

Putting this all together, we have the following inputs to our model:

- Ship arrival rate: Given \(44 \times 1.5 = 66\) berths, \(1,200,000\) containers per month for port, and 180 containers per ship, we estimate a ship arrival rate of 0.14 ships per hour.

\(^{15}\) We account for this in the model by having the inspection work center require an inspection resource, where an inspection resource is a set of 4 inspectors. We approximate 1.5 resources by making one set of resources only available for 12 hours out of each 24-hour period. (We alternate 1 hour shifts of 1 and 2 sets of inspectors to approximate this characteristic without artificially inflating queueing times)
- Batch size normally distributed with mean 180 and standard deviation 10

The other parameters stay the same from the original model. Furthermore, the structure of our model changes to reflect the new system:

![Diagram of Forecasted Demand](image)

**Figure 4-1: Model for Forecasted Demand**

As with our original model, a lot of the parameters are rough estimates, yet they can easily be changed once more accurate data becomes available. The overall system performance is as follows:
<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
<th>Trial 5</th>
<th>Average</th>
<th>-95%</th>
<th>+95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number Completed</td>
<td>16924</td>
<td>20240</td>
<td>19345</td>
<td>17800</td>
<td>16993</td>
<td>18260</td>
<td>16430</td>
<td>20091</td>
</tr>
<tr>
<td>Minimum Time in System (minutes)</td>
<td>9.7</td>
<td>9.1</td>
<td>10.0</td>
<td>9.8</td>
<td>9.4</td>
<td>9.6</td>
<td>9.2</td>
<td>10.0</td>
</tr>
<tr>
<td>Average Time in System (minutes)</td>
<td>743.1</td>
<td>1037.1</td>
<td>1371.1</td>
<td>681.9</td>
<td>587.9</td>
<td>884.2</td>
<td>487.2</td>
<td>1281.3</td>
</tr>
<tr>
<td>Maximum Time in System (minutes)</td>
<td>2410.9</td>
<td>3225.0</td>
<td>5562.8</td>
<td>3069.5</td>
<td>2615.9</td>
<td>3376.8</td>
<td>1805.5</td>
<td>4948.2</td>
</tr>
<tr>
<td>Standard Deviation of Time in System (minutes)</td>
<td>529.9</td>
<td>715.7</td>
<td>1114.3</td>
<td>552.6</td>
<td>437.6</td>
<td>670.0</td>
<td>337.5</td>
<td>1002.5</td>
</tr>
<tr>
<td>% in system less than 24 hours</td>
<td>88.1</td>
<td>68.9</td>
<td>59.0</td>
<td>87.8</td>
<td>95.3</td>
<td>79.8</td>
<td>61.0</td>
<td>98.7</td>
</tr>
</tbody>
</table>

We can see from this that the percentage of containers getting through the system in an acceptable length of time is much lower. Given that it would most likely unacceptable to have less than two-thirds of containers on average leaving the port within 24 hours, it is clear that more port resources (beyond the projected increase in resources) would be needed to maintain efficiency. In order to best identify where more resources are needed, we will look at the utilization of each of the components in our model:
From this data, it seems as though the backlog in the system is in the process of processing containers once they come off the ships. This makes sense because, even though we doubled the resources for taking containers off of ships, we only increased the number of resources to move containers from 2 to 3. (We can also see that the inspection process is somewhat of a bottleneck, but we give normal processing higher priority since it affects a much larger number of containers.) However, we can easily add a forklift resource and observe how it affects the system. We find that with four forklifts, containers are ready to leave the port within 24 hours about 96% of the time, which is a huge improvement.

Next, we would like to return to our original model to determine at what demand level it will be necessary to supply additional resources, and what resources these should be. In order to determine this break point, we will say that more resources are needed.

<table>
<thead>
<tr>
<th>Component</th>
<th>Utilization (%)</th>
<th>Average Wait in Queue (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taking Containers off Ships</td>
<td>63.7</td>
<td>418.5</td>
</tr>
<tr>
<td>Normal Processing</td>
<td>79.5</td>
<td>462.0</td>
</tr>
<tr>
<td>Empty Processing</td>
<td>8.6</td>
<td>0.28</td>
</tr>
<tr>
<td>Moving Containers to Inspection</td>
<td>5.2</td>
<td>0.21</td>
</tr>
<tr>
<td>Inspection</td>
<td>80.7</td>
<td>595.7</td>
</tr>
<tr>
<td>Moving Containers from Inspection</td>
<td>5.5</td>
<td>0.10</td>
</tr>
</tbody>
</table>
when less than 90 percent of containers are able to leave the port within 24 hours of entering. Therefore, we increase the arrival rate of ships (we will not worry about increasing ship size for this analysis) until this point is reached.

<table>
<thead>
<tr>
<th>Cargo Volume (containers per month for port)</th>
<th>% of Containers Processed Within 24 Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>300,000 (current level)</td>
<td>98.6</td>
</tr>
<tr>
<td>350,000</td>
<td>96.6</td>
</tr>
<tr>
<td>400,000</td>
<td>92.9</td>
</tr>
<tr>
<td>450,000</td>
<td>88.2</td>
</tr>
</tbody>
</table>

Therefore, the port must start adding additional resources when monthly demand is between 400,000 and 450,000 containers per month. According to our historical and projected growth, this is likely to be only a short time into the future. In addition, from our model it is clear that at this level of demand, both additional moving and inspection resources are necessary. Admittedly, the inspection process creates more of a bottleneck, with an average queueing time of almost 24 hours (1405 minutes to be exact) in itself, but this component only affects 2 percent of containers. Thus, we must also look toward the process of taking containers off ships, with a maximum queueing time of almost two days (2368 minutes), to alleviate the efficiency problem.
4.2 Increased Security

To model the effects of increased security (in this case an increase in the physical inspection rate of containers), we can again take our original model and make a few changes to the parameters and the structure. Unlike the previous scenario, we would first like to consider the breakpoint where the system becomes unreasonably saturated. This is a hard quantity to define because our overall statistics are somewhat misleading. For example, at a 4 percent inspection rate, it is generally the case that 96% percent of containers are ready to leave the port within 24 hours, which seems okay, but when we examine the inspection part of the system in itself, we see that the system cannot keep up with the number of containers to be inspected, and it results in an average inspection queueing time of over 3 days (4738 minutes) and a final inspection backlog of 41 containers. Clearly the system is going to have to adapt in order to meet the goal of significant increased inspection.

In order to find a break point with current inspection resources, we will look at how much the inspection rate can increase before more than half of containers being inspected have to wait more than 24 hours (1440 minutes) in the inspection queue.
Table 4-4: Inspection Rate vs. Inspection Efficiency

<table>
<thead>
<tr>
<th>Inspection Rate</th>
<th>% Waiting More Than 24 Hours in Queue</th>
</tr>
</thead>
<tbody>
<tr>
<td>2%</td>
<td>9.5</td>
</tr>
<tr>
<td>2.5%</td>
<td>27.8</td>
</tr>
<tr>
<td>3%</td>
<td>47.0</td>
</tr>
<tr>
<td>3.5%</td>
<td>71.5</td>
</tr>
<tr>
<td>4%</td>
<td>88.4</td>
</tr>
</tbody>
</table>

We can see that the increase needed to cause unacceptable delays in the system is not large- the inspection rate only has to be increased to a little over 3%. Since this is nowhere near the 10% physical inspection goal that Customs has set, we need to look at how many additional resources will be necessary to efficiently accomplish this goal.

To do so, we have developed a general model for handling increased inspection rates.
We now have the ability to have more than one team of inspectors per berth, and more importantly, we have the ability to easily increase the number of inspection work centers as needed, as long as we supply the needed resources to handle the inspections. Therefore, we will set the rate of inspection at 10 percent and determine how many inspection resources will be needed to keep the system moving efficiently.

Since we know from the preceding analysis that an increase in inspection resources will be necessary, we will start with 2 teams of inspectors per berth and increase our estimates from there.
Table 4-5: Inspection Resources vs. Efficiency

<table>
<thead>
<tr>
<th>Teams of Inspectors Per Berth</th>
<th>% of Containers in Inspection Queue Less Than 24 Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.8</td>
</tr>
<tr>
<td>3</td>
<td>31.7</td>
</tr>
<tr>
<td>4</td>
<td>83.7</td>
</tr>
<tr>
<td>5</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Therefore, in order to maintain an acceptable standard of efficiency, we would need to significantly increase the number of inspection resources present. Since we know that the non-inspection processing is not a bottleneck in the system, it is safe to say that in this case of the model the only containers being detained over 24 hours are the ones that are to be inspected. Thus, in the case of 4 teams of inspectors, it is estimated that about 20% of the containers being inspected, and therefore about 2% of overall containers, are held over 24 hours in port.\(^\text{16}\) The actual increase in inspection resources will depend heavily on the efficiency standards of an individual port, but it is clear that the increase will have to be significant for all ports if the 10 percent physical inspection rate goal is to be reached.

\(^{16}\) In our estimation we must account for overhead in non-inspection activities.
4.3 Conclusions

In the preceding sections we have looked at how the port system responds to increased demand and the need for increased security. In both cases, we have found that significant additional resources will be necessary if port efficiency is to be maintained. In reality, it is not the case that these two scenarios will happen independently of each other. Instead, both of these scenarios (the increasing of volume and the increase in inspection rate) will happen simultaneously, and they will start to happen in the near future. Thus, the impending need for resources (both for transportation and inspection, but more importantly for inspection) is actually based on the multiplied effect of the previous two cases. We do not go into detail on this scenario because either situation by itself makes a clear case for developing alternative security and processing procedures.
5 Alternative Methods for Increasing Security

As mentioned earlier, U.S. Customs has an eventual goal of increasing the number of containers being physically inspected from 2 percent to 10 percent. Since we have shown with a few models of the port system that raising the physical inspection rate has severe consequences for the efficiency of the port shipping system (and we know that even raising the inspection rate to 10% may still not be enough to reliably detect dangerous cargo should it exist), it is clear that new technologies must be utilized in order to identify dangerous cargo in shipping containers and protect containers from tampering.

5.1 Government Initiatives

Currently, U.S. Customs officials are trying out a wallet-sized radiation pager device that it says can reliably detect radioactive material in a shipping container. Customs officials say that this state-of-the-art system can detect even a small, shielded, low-level amount of radioactive material. [8] In addition, Customs employs a second screening device, a wheeled x-ray scanning machine, which can be used on suspect containers to detect suspicious items. The idea behind the system is that inspectors would then be able to detect radiation as well as unusual objects and then physically inspect the containers that appear suspicious based on these screenings.

However, these devices are not yet perfect. For example, in an experiment performed by ABC news, Customs failed to detect 15 pounds of depleted uranium shielded by a steel pipe with a lead lining in a suitcase on a shipping container brought to
the United States. In fact, it went through seven countries in 25 days without ever being detected. [8] This uranium was the kind of substance that, if highly enriched, would by some estimates provide about half of the material required for a crude nuclear device and more than enough for a “dirty bomb”, which would certainly have devastating consequences for the United States. Furthermore, though this particular material was not highly enriched and therefore not dangerous, it was similar enough in many key respects that, to the human eye or an x-ray scanner, the depleted uranium would look the same as an actual dangerous radioactive shipment. In other words, the planted substance replicated everything about the dangerous material except for the capability to explode. [8]

An opposite, yet still frustrating scenario, can show the disastrous effects of a false positive reading by these new devices. In September 2002, a vessel coming into the Port of New York with properly documented cargo was detained by the Coast Guard and quarantined for several days at sea outside the port because it set off the radiation detectors used by U.S. Customs. However, there was no dangerous material aboard the container, only ceramic tiles that emitted a very low level of naturally occurring radiation. [14] While Customs is very proud of the fact that their devices are sensitive enough to be set off by something as minor as a person who has undergone chemotherapy, this example shows the need for further testing and development of radiation level thresholds.

The errors associated with these devices clearly highlight the fact that, even with advanced technology, there is a largely human component to the security process. Furthermore, there are bugs to still be worked out in the devices being used- for example,
the radiation pagers used by Customs are essentially useless unless placed directly on top of the radioactive material. \[8\]

5.2 Emerging Technologies

There are many companies that are trying to improve upon and develop new technologies that will improve Customs' ability to screen containers and detect dangerous materials, and we will discuss a sampling of them in the following sections. The most common solutions for the container security problem are in the form of high-powered scanning devices. Some of these devices are intended to view the contents of a shipping container, while other are designed to simply detect potentially dangerous radioactive material. Both of these types of systems are extremely important in a comprehensive security program, and we will discuss a few examples of each type of device in detail.

Currently, freight containers are equipped with physical or electrical seals on the outside of their doors. While these seals can protect the freight from theft, the containers are still extremely vulnerable to calculating terrorists because the visibility of the seals allows the terrorists to study the seal mechanisms and prepare for an attack. We will also discuss some high tech seals being developed that can help to combat this problem.

5.2.1 General Defense Systems

General Defense Systems is an integrated security and surveillance company that deploys and implements large-scale security applications for agencies of the U.S. government and other clients from both the public and private sector. In June 2002 it introduced the Shipping Container Inspection System (SCIS), an advanced chemical,
biological and radioactive inspection system for shipping containers. SCIS was designed to be an integral component of a comprehensive plan to intensify security, and thus would fit in nicely with Customs’ CSI undertakings. General Defense Systems’ SCIS system deploys highly sensitive and accurate\textsuperscript{17} detection devices on the cranes and lift trucks that move shipping containers in and out of ports, and thus it can enable inspection of up to 100\% of the shipping containers moving through a port without impeding the movement of containers. [12]

5.2.2 ScanTech Sciences, Inc.

ScanTech Sciences Inc., a member company of Georgia Tech’s Advanced Technology Development Center, has developed an electron beam/x-ray system that can enable looking into steel shipping containers and other large receptacles without physical inspection. The device works by generating some of the highest intensity security inspection x-rays in the world, which can penetrate 14-15 inches of steel or the equivalent, and is thus ideal for shipping container inspection.

ScanTech uses two basic technologies in its systems, both of which employ a powerful 10 million volt electron beam. For container inspection, a dual beam, dual energy system uses x-rays of different spectrums to peer through thick steel walls. Next, ScanTech’s software uses the energy beams to determine the characteristics of a material in a shipping container and then calculates what type of material it is. Finally, the system tells the user whether the container contents are legitimate cargo or something more dangerous, such as a dirty bomb or nuclear device.

\textsuperscript{17} According to company representatives
The ScanTech system, which has been successfully beta-tested in the laboratory, resembles a giant car wash. Shipping containers, pallets and vehicles are scanned as they pass through.

![Figure 5-1: Schematic of ScanTech Inspection System](source: [15])

ScanTech is currently in talks with several federal government agencies that are interested in using its container-scanning technology for homeland defense applications. [15]

### 5.2.3 American Science and Engineering

American Science and Engineering has fielded several x-ray based systems that can be used to protect U.S. port operations as well as various other military forces. The most relevant for shipping are the MobileSearch™ and IsoSearch™ systems, which are extremely mobile and flexible x-ray inspection systems that are capable of inspecting large packages, vehicles and shipping containers to find car bombs, small arms,
contraband and hidden passengers. An AS&E inspection system can inspect a 40-foot container for weapons, explosives and contraband in just three minutes. In addition, MobileSearch™ systems can be deployed to quickly scan multiple containers, up to three high, for stowaway detection at ports. [6]

![MobileSearch™ System](image)

**Figure 5-2: MobileSearch™ System**
Source: [16]

MobileSearch™ is used to patrol threat areas and inspect vehicles and their contents. It houses all components within a truck chassis, is totally self contained and can be transported by C-17 aircraft. All AS&E systems use Z*Backscatter technology to provide precise images of the contents inside each container.
Z*Backscatter displays organic materials with photo-like clarity, and can also detect low-density organic materials in complex cargo. The photo-like image is very important to operators for the purpose of quick identification of cargoes in order to confirm that they match the provided documentation. This technology can be used to image a wide variety of materials, which allows for the same system to quickly identify plastics, explosives and drugs as well as small arms, contraband and cargo discrepancies.

IsoSearch™ provides a similar type of imaging, and is capable of scanning cargo from both sides.

Figure 5-3: Z*Backscatter Image of a Shipping Container
Source: [6]
IsoSearch™ houses all scanning components in two 40-foot ISO containers that can be shipped using conventional shipping methods. The system utilizes two 450keV x-ray sources—transmission detectors are mounted externally to the containers when imaging, and relative motion of the target vehicle is achieved using an Automated Guided Vehicle and a dolly. [16]

5.2.4 Lawrence Livermore National Laboratories

Lawrence Livermore National Laboratories, which had been known for developing defense technologies during the Cold War, is now focusing its attention on making devices to support anti-terrorism strategies. LLNL’s primary mission has been (for the last decade or so) to ensure the safety and security of the nation’s nuclear stockpile as well as to prevent the spread and use of nuclear weapons worldwide. Defending the nation against weapons of mass destruction and terrorist activities has always been a secondary mission, but has been increasing in priority as a result of the recent terrorist attacks on the United States. [17]

In some cases, LLNL is updating technologies that have already been developed to adjust to the current concerns of the nation. For example, scientists in the National Atmospheric Release Advisory Center had used sophisticated computer models to track fires or nuclear accidents. Now, the models are being used to simulate chemical or biological attacks on U.S. cities. However, there are completely new devices that are being developed as well. For example, a high-purity germanium detector being developed at Lawrence Livermore National Laboratory scientists will hopefully help port
inspectors to better detect smuggled nuclear material. LLNL is hoping that this and other prototype detectors will be able to screen 100 percent of the containers that arrive at U.S. ports.

LLNL is improving on the devices currently used by Customs by developing a new generation of hand held devices. These devices would be able to give a more sophisticated reading of a radioactive element’s isotopes so that inspectors would then know whether they were dealing with a potentially dangerous discovery or a naturally occurring form of radiation. So far, no one was signed on to produce the radiation detector. However, LLNL has a hand-held anthrax detector that is being produced, but there is no current plan in place as to who should have access to this device. [17]

5.2.5 Osram Sylvania

Osram Sylvania is currently working with the U.S. Coast Guard to test a high-tech system that can tell shippers instantly if a cargo container has been compromised. This system, if implemented correctly and paired with foreign port prescreening, would eliminate the need for time-consuming border checks in the United States.

The overall process is fairly simple. First, a shipment of auto lamps is packed into a sea container at Osram’s plant in Slovakia. Once the container is inspected, it is tagged by officials from the U.S. Department of Transportation with a special tracking device that allows Osram to monitor the container’s whereabouts. More importantly, this device will also detect any effort to tamper with the container, such as a terrorist trying to plant explosives or nuclear material. [18] The containers are now allowed to speed across the U.S. border without inspection or delay to their final destination, where the
containers will be carefully examined to see if the tracking devices have detected any tampering. Assuming that the examination shows no signs of foul play, then the containers are unloaded and the product is distributed.

However, there are two main drawbacks to this system that must be resolved if it is going to become mainstream in the shipping industry. The first is a matter of cost- at $2,000 apiece for a tracking device, as opposed to $1.50 for a traditional mechanical seal [18], this new technology threatens to greatly escalate the cost of container shipping, though presumably the price of the new devices would drop with mass production. The second is a matter of security- if the devices are not examined for tampering until they reach their final destinations, then it may be too late at that point to prevent the dangerous materials from having disastrous consequences.

5.2.6 Hagoromo Project

The Hagoromo Project is an initiative of OMRON Technology Ventures Group. Hagoromo is a self-organized network consisting of many wireless communication nodes equipped with various sensing abilities. Each node of Hagoromo automatically learns the characteristics of the direct links with nodes around it, and passes the information on to all of the other nodes. Thus, each node knows the entire network structure, and it can detect any geometric or topological change in the structure. As a result, Hagoromo can achieve a high level of security by creating an invisible seal inside of a shipping container. This seal is invisible and inaccessible for tapping, tampering, or attacking, and

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18 It is unclear how many times a single tracking device would be able to be used.
it can detect any movement in the contents of the container. In addition, it has a large advantage over conventional sensors being developed today.

![Figure 5-5: Conventional Sensor Schematic](source: [19])

With conventional sensors, each sensor requires adjustment and calibration on its location, orientation, amplification level and threshold level based on the surface conditions of the freight and enclosures and the distance between the two.

![Figure 5-6: Schematic of Hagoromo e-seal](source: [19])

Hagoromo is an inside “e-seal” which can be deployed inside of freight containers. This seal concept is a potential breakthrough for cargo container security. The innovative architecture of Hagoromo realizes sensing and identification capability.
and anti-manipulation characteristics all together, and additional sensors can be attached to each node to increase functionality. The topological structure of the Hagoromo seal is independent of the conditions of the freight and its enclosures, and therefore there is no need for sensor adjustment or configuration. However, The Hagoromo Project is at very early stages of development, and thus there are not yet real application products that utilize the concepts. [19]
6 Effect on Port Operations and Economics

In the wake of September 11th, the container shipping process has suddenly increased in complexity, thus threatening to increase the cost and slow the efficiency of much U.S. manufacturing. Big delays in shipping have been regularly cropping up at U.S. ports, as officials insist on carefully inspecting containers for potential terrorist-related problems. International shippers are already operating at serious financial losses, especially those with significant trans-Pacific services. [14] Furthermore, the inspection of containers which turn out to pose no security threat to the United States results in huge losses both for the carriers\(^{19}\) and for the companies that rely on the prompt delivery of these shipments, often in the hundreds of thousands of dollars. This has created problems for a number of manufacturers, including General Motors and Ford Motor Company. To keep the shippers in business, rates must increase, and this will have a further negative impact on those businesses that rely on container shipping for their supply chain, and will ultimately have a negative impact on consumers in terms of price increases. [14] It is clear that something must be done to restore the efficiency of this system while at the same time increasing security.

Altogether, U.S. Customs employs 19,764 people and has an annual budget of $3.1 billion. [7] Implementing a system that would achieve the 10 percent physical inspection goal would require hiring thousands of additional inspectors, at a total cost in the hundreds of millions of dollars. Similarly, the cost of new inspection equipment as

\(^{19}\) Importers are charged about $200 if a container has to be x-rayed [20], and another fee on the order of several thousand dollars for a manual inspection. [14]
described above could have a huge impact on port costs as well, especially given Customs’ plan for inspection both at foreign ports and on U.S. soil if necessary. These costs would be huge in comparison to the existing budget, so it is most likely that the costs would be passed on to shippers in the form of increased port charges.\textsuperscript{20} In addition, shippers would most likely have to invest in container seal technology in order to avoid having their cargo being consistently delayed at port, and this too does not come cheap—at an estimated $100 per box \textsuperscript{21} for the best technology, it is yet another cost that shippers will either have to absorb or pass along to manufacturers and consumers.

Although these costs may seem to place a significant burden on both ports and shippers, they are small when compared to the negative consequences a shutdown in the port system would have on the U.S. economy. An example of a similar disruption came in 1999, when the nation’s Western rail system slowed dramatically as it adjusted to a merger of two railroads, a booming economy and other factors. The slowdown created havoc for weeks—Christmas items did not arrive to stores on time, perishable goods rotted, and factories closed because needed parts were delayed. \textsuperscript{22} It has been estimated that a shutdown of the U.S. port system would cost the country on the order of billions of dollars per day.\textsuperscript{22} That cost, especially when coupled with the possible destruction that a successful smuggling could cause, seems to more than justify the added expense in manpower and technology in order to create a secure system.

\textsuperscript{20} AAPA Chairman Dick Steinke, executive director of the Port of Long Beach, California, told Congress in March 2002 that more than twice the monies allocated for Port Security Grants will be needed to help ports meet new federal mandates for increased security. Congress appropriated $93.3 million for the program, but Steinke said more than $222 million will be needed. \textsuperscript{23}

\textsuperscript{21} This does not include devices with tracking capabilities

\textsuperscript{22} The West Coast dockworkers strike in October 2002 demonstrated the high cost of a port shutdown—the work stoppage cost the U.S. economy an estimated $1 Billion a day and closed some factories as supplies ran out. \textsuperscript{20}
It is important to remember that no system will ever be completely foolproof, but just about any new system would be a vast improvement to the security measures in place before September 11th. Thus, these systems would be a large deterrent to potential terrorist attacks using shipping containers. It is not an immediate need to have a foolproof system, but rather to have a security program that is good enough to make shipping containers disproportionately unattractive as a means for smuggling dangerous materials into the country. As a result, one can examine the economic costs in terms of tolerance for failure in the system and make an allocation of resources that will match this tolerance.
7 Areas for Further Study

There are two main areas for further study on the topic of container shipping security. The first undertaking would involve more thorough research on the actual structure of port operations. Given that this information is not readily accessible (otherwise it would have been taken into account in this research), it is likely that one would have to speak to a port manager or a U.S. Customs official in order to get a detailed description of the exact resources at the port and the amount of time it takes to perform each of the necessary steps to transfer a container from an incoming ship to an outgoing truck or train. At the time of writing, this is not an available option due to residual security concerns from the September 11th attacks. However, if this becomes an option in the future, there are several refinements to the model that could be made:

- One could incorporate resource costs, resource downtime and travel time into the model in order to more accurately mimic system operation. This would be quite simple to do with our current simulation, since that functionality is readily available with the tools we are using.

- One could develop a model of an entire terminal or an entire port in order to examine how the sharing of resources across port berths affects the efficiency of the system.
  o Does the fact that a resource not assigned to a berth could be used in that berth if it was not in use elsewhere significantly improve port efficiency?
  o How would resource travel time affect this change in efficiency?
  o How should priority for resources be determined?
• One could examine how the nondeterminism in the system (or at least in the model of the system) affects the efficiency or truck and train pickup
  
  o What happens to the system if ships have strategically scheduled arrival times?
  
  o How does variation in port service times change based on changes in inspection procedures? What should the maximum tolerance for variation be? How scheduled are the pickups by trucks and trains?

  The second potential analysis that could be done on the system is to learn more about the prescreening process being carried out in foreign ports and the priority rules for pre-cleared containers. With that information, one could fairly simply use the existing model structures to analyze the service times in the port for various different categories of containers and determine whether the priority system should be modified in order to provide efficiency and equitable treatment (to the degree reasonable) for all incoming cargo.
References


[7] http://www.marketnewzealand.com/home/index/0,1455,SectionID%253D4558%2526ContentID%253D3068,00.html


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