4-30-2011

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Recommended Citation

Meng, Si, "Simulation framework of port operation and recovery planning" (2011). *Theses and Dissertations*. 3947.
https://scholarsjunction.msstate.edu/td/3947

SIMULATION FRAMEWORK OF PORT OPERATION AND RECOVERY PLANNING

By

Si Meng

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Industrial Engineering
in the Department of Industrial and Systems Engineering

Mississippi State, Mississippi

April 2011

SIMULATION FRAMEWORK OF PORT OPERATION AND RECOVERY PLANNING

By

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Pages in Study: 78

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This study proposes a framework of simulation tool suites for ports to evaluate their response to disaster crisis and port security policies. The focus is containerized cargos that are imported through ports in the U.S. with final destinations also in the U.S. A crisis, such as a man-made or natural disaster, may cause a delay at the seaport. The down time of ports may result in severe economic losses. Thus, when a seaport cannot normally operate, it is important to minimize the impact caused by the disrupted freight flow. Port security policies also have a significant impact on the port operation efficiency. This model developed in this study evaluates the performance of re-routing strategies under different crisis scenarios and can help the user to find an effective re-routing decision and analyze security policies of a port. This model also analyzes security policies of the simulation port.

DEDICATION

I would like to dedicate this research to my parents, grandparents, and my cat.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the people who have given assistance in this research. I would like to thank my major professors, Dr. Mingzhou Jin, for providing his endless guidance in this research. Special thanks are also given to Dr. Kari Babski-Reeves and Dr. Lesley Strawderman for their invaluable suggestions in completing this research. I especially appreciate Dr. Allen G. Greenwood and Flexsim Software Products Inc.’s help with providing the research software. Additionally, I would like to thank the Port of New Olreans or providing the research data.

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Q_1 — Anchoring queue. Incoming ships join the anchoring queue to gain access to the port.

Q_2 — Entering queue. Incoming ships join the entering queue to gain access to the unloading berth.

Q_3 — Transportation queue. Unloaded containers join Q3 to wait for an available transporter (trailer, straddle carrier, or automatic guided vehicle (AGV)) that will transport them to the screening machine or stacking yard.

N — The set of containers which pass through the port and get to their inland destination, $n \in N$.

I — The set of imported ports, including the original port and its neighbor re-routing ports, $i \in I$.

J — The set of destination of containers, including the area of imported ports and other inland destination, $j \in J$.

T_{ij}^{n} — The time that the nth container spends from the imported port *i* to its destination *j*, $n \in N$, $i \in I$ and $j \in J$.

T_{ijp}^{n}— The time that the nth container spends at the imported port *i* when it goes from this port *i* to its destination *j*, $n \in N$, $i \in I$ and $j \in J$.

T_{ijt}^{n} — The time that the nth container spends on highway or railway transportation when it goes from the imported port *i* to its destination *j*, $n \in N$, $i \in I$ and $j \in J$.

$\overline{T}$ — The average time of all of the containers (*N*) spend in the system.

X_{ijR}^{n}– Binary variable that describes whether the *n*th container is transported by railway, $n \in N$, $i \in I$ and $j \in J$.

$F_{railcar}$ – Fix cost of using a railcar.

D_{ij}^{r} –Distance from imported port *i* to destination *j* by railway transportation, $i \in I$, $j \in J$.

C_r – Variable cost per mile of railway transportation.

$C_{blocking}$ – Cost of block handling.

X_{ijT}^{n} – Binary variable that describes whether the n^{th} container is transported by railway, $n \in N$, $i \in I$ and $j \in J$.

F_{truck} – Fix cost of using a truck.

D_{ij}^{t} – Distance from imported port i to destination j by highway transportation, $i \in I$, $j \in J$.

C_h – Variable cost per mile of highway transportation.

X_{ij}^{r} – Binary variable that describes whether there will be a blocking process from the imported port i to destination j if this route includes railway transportation, ,$i \in I$ and $j \in J$.

$C_{\text{depreciation}}$ – Depreciation cost of container.

X_{s}^{n} – Binary variable that describes whether the n^{th} container need pre-screening to enter the port, $n \in N$.

$C_{\text{screening}}$ – Cost of screening a container.

C^n – Transportation cost of the n^{th} containers.

$\overline{C}$ – Average transportation cost of containers.

CHAPTER I

INTRODUCTION

Port Operations

The world's healthy economy depends on efficient and reliable global freight transportation (American Association of Port Authorities 2008) [3]. The marine transportation system is one of the major lifeline systems in modern society and its reliable operation is crucial for national and regional economies [2]. In many cases, as in international commerce, there is no alternative to moving goods by water. Marine transportation is more fuel-efficient than other transportation modes, and it can relieve congestion in other transportation modes [54].

As reported by American Association of Port Authority (AAPA), there are more than 2 billion tons of domestic and import/export cargo transported through US ports annually [3]. Much of total domestic production of basic commodities and finished products are shipped by water. Eighty percent of the cargos (measured by value) moved by ocean are transported in containers [1]. More than 4 million cars, vans, SUVs and light trucks were imported/exported through North American seaports in 2008 [3]. Summarized by AAPA (2008), the total container trade transported through US ports exceeded 42.83million TEUs (Twenty-foot Equivalent Units), an increase of 2/3 in ten years compared to of 26.1 million TEUs in 1998 [4]. Figure 1 shows the total trade in short tons of the top 30 US ports in 2008 (ranked in 2010 by AAPA) [3, 4]. Figure 2 shows the turnover for the ten main seaport terminals in the US from 1998 to 2008 [3, 4].

As can be seen, TEU turnovers at the top 30 ports (Los Angeles, Long Beach, NY/NJ) increased dramatically through 2003 and decreased slightly through 2008.

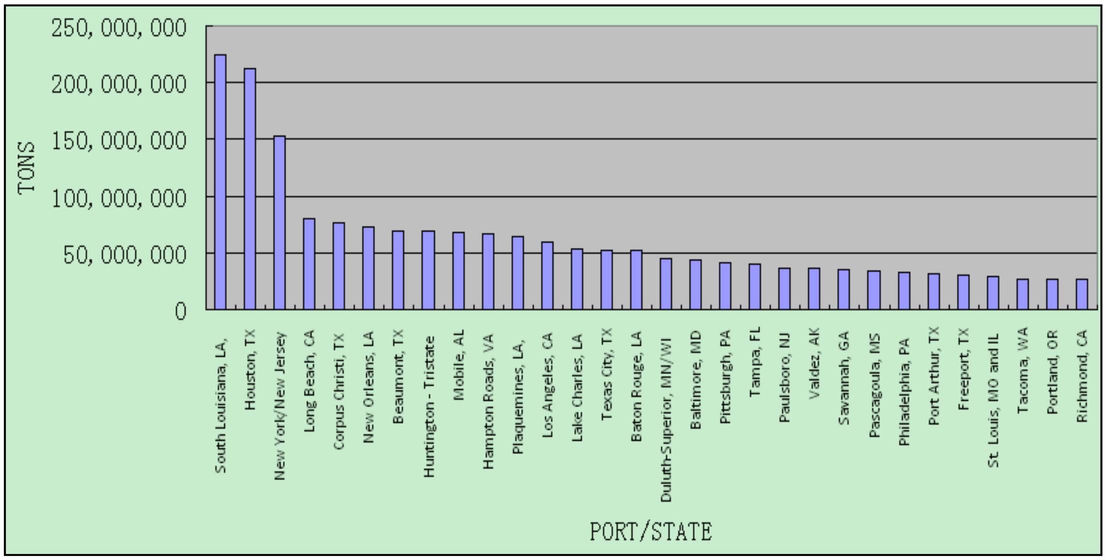


Figure 1 Total Trade of 30 Main Ports of US in 2008 [3,4]

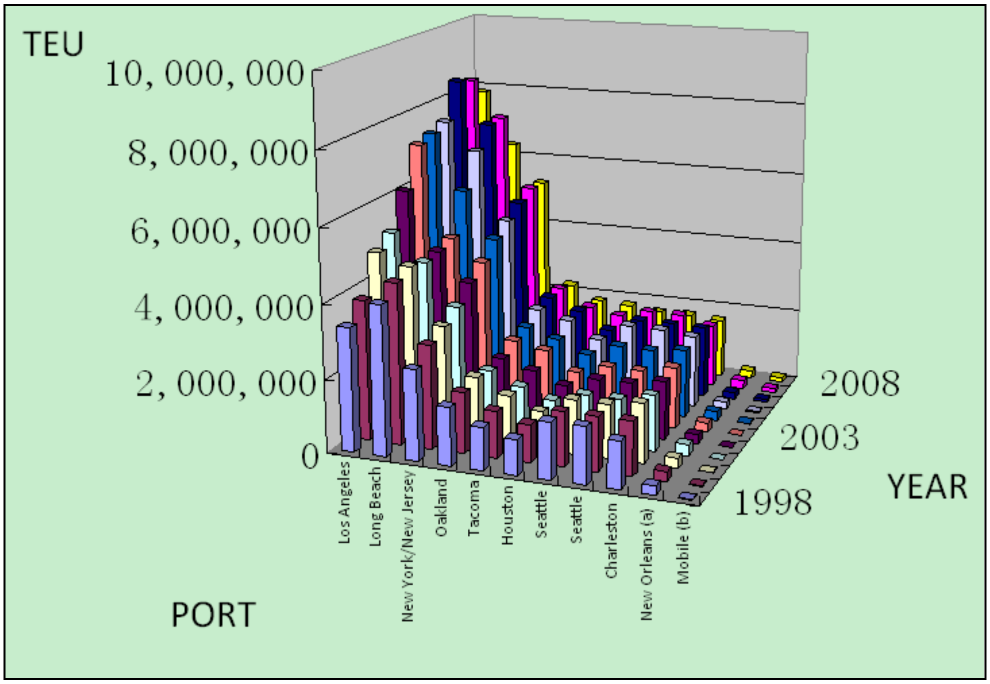


Figure 2 Container Turnovers of Ten Seaports in the US from 1998 to 2008 [3,4]

Port Securities

Ports are often regional economic centers and important components of national and global transportation lifeline systems. A wide variety of industries rely on efficient port operations to receive the raw materials [56]. Therefore, the downtime of ports due to catastrophes (e.g. earthquakes, hurricanes) or man-made disruptions (e.g. terrorist attacks, fires) will result in delays in the flow of materials through the affected port, consequently cause severe economic losses. Recent events, such as the Hurricane Katrina in New Orleans, have heightened concerns that the U.S. maritime transportation system is vulnerable to exploitation or disruption by natural or man-made disasters.

The recovery of the Port of New Orleans after hurricane Katrina provides an example of the issues critical to consider when a seaport is under crisis. Hurricane Katrina hit Louisiana on August 29, 2005. Before Katrina, each day the port had 1,000 truck drivers hauling 1,500 loads. By September 12, 70% of the Port of New Orleans' railroad lines and interchanges were operable, and the first commercial cargo vessel entered the port the following day. By October 3, 90% of the port's railroad lines and interchanges were operable. The port's trucking industry, however, was operating at only 25% to 50% of its normal capacity. Nine ships, including four container vessels, called on the port during that week. By this time, the port's truck capacity was still at only 40% of pre-storm levels. One month later, the port was still struggling to fill a shortage of truck drivers. Handling approximately 70% of cargo that moves through the port, trucks are a vital component of the port. By November 10, there were 150 drivers hauling 450 truckloads per day. The storm's impact on fuel prices, along with increased construction and debris clearing efforts, greatly exacerbated the demand of truck drivers. In addition, many truckers lost their homes and rigs during the storm. Despite the shortage of trucks, port operations achieved nearly 45% of pre-storm levels during the week of November 10. By January 20, port activity reached 65% of pre-Katrina levels. Container cargo levels were over 80% of pre-storm levels. The port continued its recovery in the following months, and its cargo tonnage levels during the first five months of 2006 were higher than that period's average over the previous four years.

For the concerns of seaport securities, the US government has institutionalized a number of acts to enhance port security. For example, the Container Security Initiative (2002) requires the containers to be pre-screened at the departure ports before they enter U.S. The port security relative acts will be studied in the Section 2.2.

Statement of the Problem

There are approximately 150 mainly commercial seas and river ports serving the US [24]. In 2008, container trade exceeded 42.83 million Twenty-foot Equivalent Units (TEUs) (a 30% increase from 2002 and 61.5% increase from 1998) [4, 24]. With more than 90% of world trade moved by maritime transportation [25], waterway transportation has become a crucial link within supply chains. Ports also serve as shore-side facilities for intermodal transfer of cargo among ships, barges, trucks, and railroads [6]. Most US maritime transportation involves multiple transportation modes (e.g., rail, plane and truck) to transport cargo to final destinations [25].

Most studies evaluating port security policies have ignored intermodal port functions. Increased security coverage, adoptions of advanced security technologies, and enhanced vigilance contribute to delays and congestion at ports [28] and therefore hinder maritime supply chain efficiency [29]. The operation delay and disruptions caused by natural disasters at ports result in severe economic losses. Terrorists could also attack

U.S. ports. It is warned that U.S. seaports could be tempting targets for terrorists bent on killing large numbers of people (Flynn 2006), grabbing media attention, and disrupting the U.S. economy. Port, ferry, and cruise-ship terminals are often located in highly congested areas where large numbers of people live and work. Liquefied natural gas terminals and refineries that produce highly volatile petrochemicals and convert crude oil into gasoline and heating oil are also often nearby. Given the importance of foreign trade to the U.S. economy, an attack that shut down a major American port for even a few days could devastate the regional economy served by that port. Hence, it is important to utilize various port security measures and maintain port recovery plans for a variety of scenarios [26-27].

However, ports are hard to protect. They're often large and busy, offering multiple opportunities for terrorists to get in and attack. The port of Houston, for example, is twenty-six miles long, and thousands of trucks enter and exit its major terminals every day. Moreover, ships often traverse narrow channels; a sunken ship in such a channel could close the port for weeks or months and cause economic chaos.

Research Objective

This project is the first step in the development of a decision support system based on simulations to aid ports in evaluating recovery plans and security. The objective of this project is to provide port operators the capability of evaluating their local security policies and recovery planning through simulating various scenarios of crisis over their ports. The objective also includes the assessment of economic and operational impacts on port operations due to different re-routing strategies toward the crisis. The purpose of this study is achieved by constructing a framework for port operation simulation that can assist port operators to evaluate the performance of a terminal and the local security policies. This study defines procedures to ensure that after inputting port characteristics, scenario information, security policies and recovery planning. Based on the given information, the simulation tool suite will provide port operators corresponding intermodal freight flow management after port disruption (e.g., rerouting to other ports or other transportation modes).

As a pilot study, the framework will be realized by a small-sized simulation model. The simulation model will be used to investigate different recovery plans under various scenarios (natural disasters and terrorist attacks) and security policies. The pilot simulation model is expected to include the performance criteria and model parameters defined in the framework and to study an operational case.

CHAPTER II

LITERATURE REVIEW

Port Operations

The major operations in a typical container port include berth operation, yard operation, and gate and intermodal connection operation. The berth operation concerns the schedules of arriving ships and the allocation of wharf space and quay or gantry crane resources to discharge or load containers onboard ships. The key concerns are the turn-around time of ships (waiting time for ships to receive berth space) and crane rates (number of containers moved per hour). The planner has to optimize the crane working sequence (a detailed list of crane moves) so that there would not be any crash involving neighboring cranes and at the same time ensure a smooth feed rate of prime movers, tractor, or trucks (all called vessels) to cart away (discharge) and send (load) containers to the quay cranes. The yard operation typically involves discharging of containers from the vessels, loading of containers onto vessels, shuffling of containers that are out of sequence, redistribution of containers to other blocks (yard shifting) for more efficient loading onto the second vessels and inter-terminal haulage where containers are moved to other yards in another terminal. The gate operation deals with external freight forwarders. Two activities are usually involved, namely export delivery where the freight forwarders bring in export containers to the yard or wharf to be loaded onto the vessels, and import receiving, where the freight forwarders receive containers from the yard or wharf. In the ports with railroad connection, the containers may be transported by intermodal transportation. A challenge in developing a simulation methodology for the port is to model the appropriate level of detail from all of this activity.

In general, ports act as buffers between the incoming and outgoing vessel traffic (Dahal 2003), there are many individual components that play an important role in terminal operation (Na 2009). Basically, seaport terminal consists of gate, yard, berth, ware house (including container freight station (CFS) for container transportation), and cargo handling equipments. Na (2009) and Yun (1999) summarize the basic operations in a seaport terminal as receiving (for export), delivering (for import), loading, and unloading different kinds of cargos. These operations occur simultaneously and interactively in the terminal. Container cargos are managed within a seaport terminal by means of three parts operations: quay cranes operations, container yard operations, and shuttle truck operations (Biell, Boulmakoul and Rida 2006).

Ports are important points within supply chain systems. They are vulnerable to natural or man-made disasters. As mentioned in Biederman (2007)'s report, the U.S. Government Accountability Office (GAO) investigated 17 ports in the U.S., and 12 out of these 17 ports were subjected to at least one hurricane or earthquake since 1998. Stephen Flynn (2006) stated that maritime transportation is one of our nation's most serious vulnerabilities (Flynn 2006). At current staffing and funding levels, U.S. Coast Guard personnel and Customs agents can thoroughly inspect only about 5 percent of the 9 million shipping containers that arrive at U.S. ports every year.

Cargoes through ports include bulk cargo, break bulk cargo, and container cargo. Bulk cargoes are classified as being in a liquid or dry freight, that is not packaged such as minerals (oil, coal, and iron ore) and grains, and can usually be dropped or poured during loading, such as salt, oil, tallow, and scrap metal [46-47]. Bulk cargo often requires the use of specialized ships as well as transshipment and storage facilities [55]. Break bulk cargo refers to general cargo that has been packaged in some way with the use of bags, boxes or drums, and it is lifted into and out of a vessel individually by cranes [46-47, 55]. Container cargo, which can be defined as a kind of break bulk cargo, is a reusable transport and storage unit for moving products and raw material between locations. Containerized cargo includes everything from auto parts and machinery to shoes, toys, and frozen meat [46- 47].

Various cargoes are imported, exported, or transshipped within a seaport daily generally by the assistance of handling equipment, such as quay crane, yard crane, trailer, yard tractor, and forklift [31-32].

General Idea of Handling Equipment

Figure 3 Aerial View of the Port of Rotterdam

The quay cranes (QCs) are equipped with trolleys that can move along the crane arm to transport the cargo from the ship to the transport vehicle and vice versa. The cargoes are picked with a spreader, a pick up device attached to the trolley. The QCs move horizontally on rails to the different holds to take/put containers off/on the deck and holds [9]. Quay cranes can work in parallel on the same ship at the same time. Some quay cranes may have only a fixed gantry [33]. The technical performance of a crane is in the range of 50-60 boxes per hour, while the operational performance is typically in the range of 22-30 boxes per hour [33]. Whenever a crane breaks down, work is interrupted until it is repaired or until another crane is positioned in place of the broken one.

Stacking cranes (SCs) are equipped on stacking line, where the export and import cargo can be stored for a certain period. These cranes are used for both the stacking of incoming cargo and the removal of outgoing cargo. All movements of these cranes are considered constant (no acceleration or deceleration). There are three types of stacking cranes: rail mounted gantry cranes (RMG), rubber tired gantries (RTG), and overhead bridge cranes (OBC). An example of rail mounted gantry cranes is shown in Figures 4-5. Furthermore, the stacking process can also be done automatically by automated stacking cranes (ASCs). Similar cranes could be used for loading and unloading trains; they could span several rail tracks.

Figure 4 Quay Crane (Dual-Trolley)

Figure 5 Stacking Crane

The first class of horizontal transport means is “passive”, which is in some vehicle in a sense not able to transport cargo by them. Trailers (Figure 6 and 7), multi-trailers (Figure 8) and automatic guided vehicles (AGV, Figure 9) belong to this class [33-34].

Figure 6 Container Trailer [33]

Figure 7 Trailer [33]

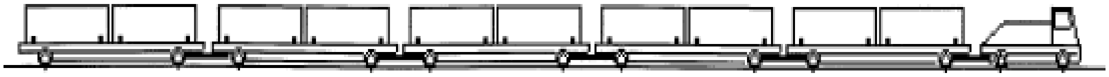


Figure 8 Multi-Trailer System [33]

Figure 9 Automatic Guided Vehicles (AGVs) [34]

The second class of transport vehicles is “positive” vehicles, which are able to lift or transport cargo by themselves. Straddle carriers (see Figure 10), forklifts (see Figure 11), and reach-stackers (see Figure 12) belong to this class [33-34].

Figure 10 Straddle Carrier [33]

Figure 11 Electronic Forklift Truck [34]

Figure 12 Container Reach-Stacker [34]

The comparison table of operational capacities of handling equipment's is shown in the following table [35].

Table 1 Epitome of Features of Handling Equipment's at A Port [35]

		Features		Speed (Container)
Cranes	Quay crane	Single trolley	• Engaged at container terminals • Move containers from ships to quay or vehicle • Man driven	50-60 boxes/h (technical performance) 22-30 boxes/h (in operation)
		Dual trolley	• Main trolley moves container from ship to platform • Second trolley moves container from platform to shore • Main trolley-man driven; second trolley-automatic	
	Stacking crane	Rail mounted gantry cranes (RMG)	• Stable • Two RMG often employed at one stack area (block)	20 moves/h Span up 8-12 rows Stacking 4-10containers high
		Rubber tired gantries (RTG)	• Flexible	
		Overhead bridge cranes (OBC)	• Mounted on concrete or steel pillars	
Vehicles	Passive vehicles	Truck with trailers	• Loading and unloading are done by cranes	Depends on transport vehicle
		Multiple trailers		
		Automatic guided vehicles(AGV)	• Robotics • High investment	Load one 40'/45' or two 20' containers
	Positive vehicles	Straddle carriers (SC)	• Transport/stack containers • Regarded as cranes • Automatic SC with GPS (transport only)	Load 2-3 containers Stack 3-4 containers high
		Forklifts	• move and stack light containers • Especially empty ones	
		Reach-stackers		

Operations in a Seaport Terminal

In general, ports act as buffers between incoming and outgoing vessel traffic [7]. There are many individual components of a seaport that play an important role in terminal operation [18]. A seaport terminal consists of a gate, yard, berth, warehouse (including container freight station (CFS) for container transportation), and cargo handling equipment. Na [18] and Yun [32] summarize the basic operations in a seaport terminal as receiving (for export), delivering (for import), loading, and unloading different kinds of cargo. These operations occur simultaneously and interactively in the terminal. Na and Shinozuka [18] illustrate the general operations within a container terminal in Figure 13. Yun and Choi [32] state that a terminal operation consists of berth allocation and yard, stowage and logistics planning. Berth allocation controls of the loading and unloading of a ship cargo. Yard planning aims to provide optimal and efficient allocation of storage area for import, export and transshipment cargo. Stowage planning is a process that assigns each cargo by its location in the ship, including hold, between-deck, and deck space. Logistics planning coordinates the operations of the facilities, such as quay cranes, yard cranes, straddle carriers, and trailers for transporting cargo between the ship's bay and the yard [32]. Results have showed in Ng's [20] study that vessel traffic interference results in a considerable reduction of the terminals' capacities. The result facilitates the estimation of the benefits of improved movement coordination in the terminal basin.

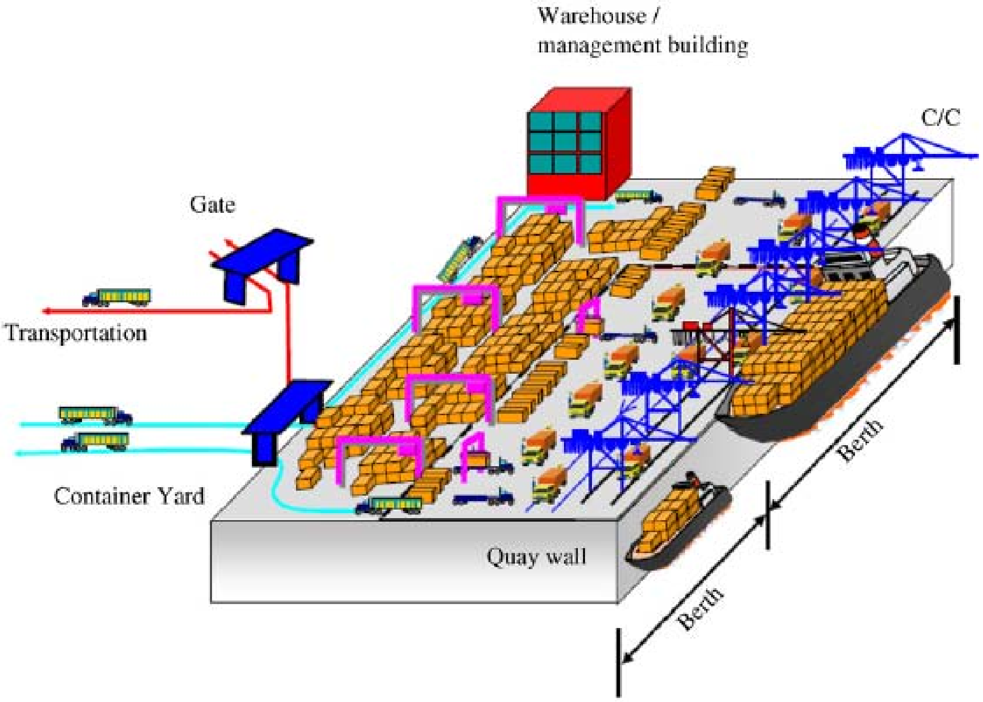


Figure 13 General Operations in a Container Terminal System [18]

Bulk cargo is received, stored, processed, and dispatched using port components such as an unloader, loader, conveyor, transfer station, stacker etc. Break bulk cargo can be delivered straight from a truck or a train onto a ship, however, the most common way is for break cargo to be delivered to the dock in advance of the arrival of the ship and then to be lifted by quay crane on board when the ship is ready to receive cargo [43]. Container cargo is managed within a seaport terminal by means of three part operations: quay crane operations, container yard operations, and shuttle truck operations [6].

Freight Flow Management during Crisis Conditions

Ship routing and scheduling under normal conditions have been studied for more than three decades. A recent comprehensive review on maritime ship routing and scheduling was provided by. Optimization models are usually used to minimize the operating and layup costs by determining the optimal routes, schedules, and deployment of the fleet. However, there are few papers discussing the routing decision under emergency scenarios or when some ports are not available. For example, the Port of Kobe in Japan lost about 57% of cargo in 1995 and 34% in 1996 compared to 1994 after the 1995 earthquake in the Hanshin region of western Japan. A lot of transshipment traffic was re-routed to other ports such as the ports of Osak, Nagoya, and Busan.

Though economic loss and recovery analysis for natural disasters have been well studied for network systems such as highways, power supply, and water distribution networks [18], there are less research on economic losses for port system.

Port transportation systems have its relatively long restoration times in comparison with other urban lifeline systems. In 1995 Kobe earthquake, port transportation systems required a much longer restoration period than other urban lifeline systems such as electric power, telecommunication, highways, and railways. Electric power and telecommunications were restored with a few weeks, water and natural gas within 3-4 months, and port transportation systems required 26 months to complete repairs [18, 50-52]. Na [18] also states that among various components of port facilities, the quay wall is the one of most expensive structural components. The permanent displacement of the quay wall determines the usefulness of the terminal, and the length of restoration period required for damaged structural quay wall is critical in relation to the recovery schedule. Therefore, the state of damage of structural quay wall is considered as a main component representing the state of terminal damage.

Port Security

Recently, more advanced technologies are available for port operators to inspect cargo containers, such as Non-Intrusive Inspection (NII), Advanced Spectroscopic

Portals (ASP), Tagged Neutron Inspection System (TNIS), Passport Systems (PS), Pulsed Photonuclear Assessment (PPA) inspection technology, MicroSearch, Muon radiography (MR), and Neutron Elemental Inspection System (NELIS) (Qi and Wang 2010).

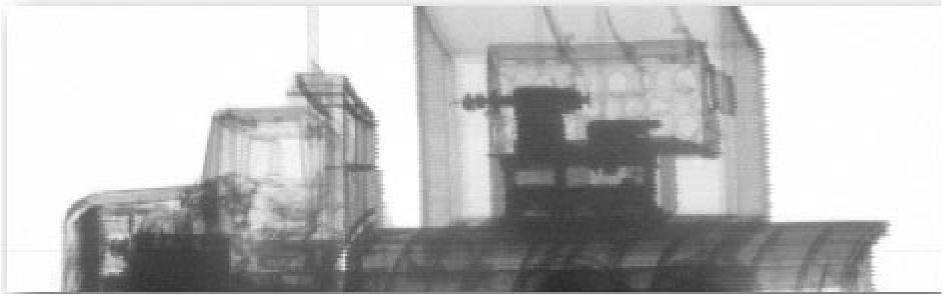


Figure 14 Gamma-Ray Image of a Truck with Cargo Container

In terms of the cost, function, inspect time and false rate of each technology, previous and advanced ones are discussed and compared in Table 2 (Qi and Wang 2010), the advanced technologies are shown with shadow. The operational and economic impacts of those security technologies on one port or a regional intermodal transportation system could be evaluated by simulations.

Security is considered critical to a high-performance maritime supply chain, so various maritime security measures are conducted at ports in addition to transportation operational procedures SAFE Port Act enacted in 2006 requires all containers entering the United States through all U.S. ports should be scanned for radiation before being loaded at a foreign port or upon entry at a U.S. port. In the U.S., there are 19 major programs regarding overall port security, port facility security, and container securities. They are Area Maritime Security Committees, Interagency Operational Centers, Port security operations, Area Maritime Security Plans, port security exercises, evaluations of security at foreign ports, port facility security plan, port facility security compliance monitoring, Transportation Worker Identification Credential, background checks, Automated Targeting System, Customer In-Bond System, Container Security Initiative, Customs-Trade Partnership Against Terrorism, Promoting Global Standards, Domestic Nuclear Detection Office, Megaports Initiative, Secure Freight initiative, and 100 Percent Container Scanning at Foreign Ports. Increased security coverage with enhanced vigilance at ports contributes to delays and congestion at ports and therefore hinders maritime supply chain efficiency A Sandia National Laboratories groups developed models to evaluate the impact of port security policies applied to container cargo on shipping times, to identify conditions under which there infrastructure disruptions may happen and how those disruptions affect port operations, and to estimate the potential long-term economic impacts of increased security costs. So far, most studies to evaluate security policy focus on the local port operations without considering intermodal features and the possible interactions among ports.

Port security has become increasingly important to the public economy and welfare. Port security problems, such as natural disasters and terrorist attacks, can and could cause severe economy loss. The US Department of Homeland Security launched the Container Security Initiative (CSI) in 2002, which requires other governments to pre-screening those containers at the ports of origin before they are shipped to the US and identify high-risk cargo containers [48]. Banomyong [15], Bichou et al. [16] and Tsai [17] analyzed the impact of the US Container Security Initiative (CSI) on maritime supply chain management, it was stated that the security initiatives will theoretically facilitate access to major international markets through the use of secure hub centers and interface points.

Inspection technologies are used for closed cargo, like containers, at the seaport points of entry. Qi and Wang [10] reviewed newly available non-intrusive inspection (NII) technologies for ports, including new radiation detection technologies, new image based detection technologies, and illegal stowaways' detection technology. Compared with the current function-limited NII technologies; e.g., conventional x-ray and gamma-ray imaging technology, more advanced NII technologies are available for port operators to inspect cargo containers, such as Non-Intrusive Inspection (NII), Advanced Spectroscopic Portals (ASP), Tagged Neutron Inspection System (TNIS), Pulsed Photonuclear Assessment (PPA) inspection technology, and Neutron Elemental Inspection System (NELIS). This review provided and compared the capabilities, costs and applicable situation of advanced NII technologies and aimed to help select appropriate devices for port cargo inspection [10].

Table 2 Comparison of Security Technologies [10]

Category	NII technologies	Cost	Screen for	Inspection time	False alarm rate	Material description	Installation
Detecting Nuclear Materials	Radiation Portal Monitors (RPMs)	$55,000	Nuclear materials (unshielded only)	In seconds	2%	No	Fixed
	Radioisotope Identification Device (RIID)	~$20,000	Nuclear materials (unshielded only)	5- 15mins	<0.1%	Yes	Handheld
	Advanced Spectroscopic Portals (ASP)	$377,000	Nuclear materials (unshielded only)	<10s	< 0.1%	Yes	Mobile by vans or SUVs
	Pulsed Photonuclear Assessment (PPA)	Relatively low	Nuclear materials (shielded/unshielded)	< 60s	~0%	No	Mobile by truck
	Muon Radiography (MR)	$1 million	Nuclear materials (shielded/unshielded)	20-60 s	<3%	No	Mobile by a tractor trailers
Elemental Composition and Imaging Based Detection.	X-ray systems	$1 - 10 million	WMD, explosives, nuclear materials, drugs	2-5 mins	<2%	No	Fixed or mobile by vans or SUVs
	Tagged Neutron Inspection System (TNIS)	< $1,000	Explosives, illicit drugs	10 mins	Low	Yes	Portable as a small brief case
	Neutron Elemental Inspection System (NELIS)	Relatively low	Explosives, Illicit drugs	<5 mins	Low	Yes	Mobile by truck
	Passport Systems (PS)	Relatively low	WMD, explosives, nuclear materials, drugs, etc.	<15s generate alarm; < 2 mins locate material	<1%	Yes	NA
Detecting Stowaways	Micro-Search	Relatively low	Stowaways	In seconds	~0%	Yes	Portable as a small brief case

Port Simulation

An object-oriented simulation (OOS) consists of objects interacting with each other during the execution of the simulation. OOS views the world as a set of autonomous agents that interact or work together to solve some complex tasks. Simulation development has two main phases: modeling and programming. The programming style can be procedural or object-oriented. Procedural programming consists of repetition of some logical procedures, functions and/or subprograms. The procedure of the code follows a flowchart-like structure. For simulation models that require complicated interactions and messaging between entities, the procedural approach will be inefficient because the only means of communication and messaging is through global data exchange or function calls. These communication mechanisms are inefficient, vulnerable to inappropriate use, and too visible to end users. Furthermore, the procedural approach lacks "extensibility". The only way to extend the simulation is to add "structural functionality", which does not alter any of its basic properties. For example, when a new crane or berth is added into a simulation, it has to be completely re-programmed. OOS achieves efficiency and extensibility through providing encapsulation, object communication, object formation, and inheritance. OOS allows for "encapsulation" (i.e., templates, sub-networks etc.). Objects in OOS gain independence of actions, hide their implementation details, and yet provide a friendly interface. Under encapsulation, each entity encapsulates the properties of the object which are set within the definition of the object. When multiple instances of the object (i.e., entities in simulation) are created they will automatically be embedded with all the properties of the object. In OOS, objects communicate through message passing, including direct reference, data methods or functions, and pointers. The term “class” is used to provide a “pattern” for creating objects and to define its type (i.e., properties). Objects can be initiated from a class without special instructions. Constructors and destructors are used if special procedures are needed when an object is created (arrival) or destroyed (departure). One of the main advantages of the OOS is the ability to make other objects from existing ones by inheritance, where a parent-child relation is set between classes. Under inheritance, the child class inherits the public properties of the parent class. For example a port simulation model may define a class for “ships” destined to a port and child classes along with it specifying the type of the ship: container ship, bulk carrier, cruise liner, etc. OOS provide outstanding extensibility through full data abstraction. With the help of inheritance, the designer does not have to anticipate every type of entity/event. Users can define their own entities/events provided that they inherit from an existing class.

There are quite a few OOS tools that can interact with other applications in a computational environment. A significant number of the OOS tools have been built using C++ or Java. Other languages include ADA, Self (exploratory programming by Sun), Smalltalk, CLOS, Eiffel, and Modula 3. In recent years, an open-source programming language, Python, and its applications have become quite popular for object-oriented programming and simulation. Some commercial and open-source tools built based on C++, Java, and Python are discussed below.

For analysis of complex systems, simulation is often used prior to the operation of the real world system for a dynamic situation [32, 53]. Therefore, simulation methodology has been recommended and chosen to analyze seaport terminal systems [35].

Analytical Methodology

Related to the theory and methodology of evaluating a ports' performance, Dahal and Hopkins [7] applied a discrete event simulation model together with a Genetic Algorithm-based evolutionary approach for simulating a port system. Radmilovic [11] and Kozan [12] analyzed the port's operation by means of queuing theory. Noritake and Kimura [13] applied this queuing theory to estimate the optimum size of a seaport as well. Lewis et al. [44] formulated a best-first optimal search procedure (A*) to model two problems, one is the problem of moving containers from in-bound ships to staging areas (areas where security inspections can occur) and to out-bound ships, the other one is the problem of moving containers from staging areas and areas where security inspections have been completed to out-bound ships. Load planning for incoming and outgoing vessels was assumed to be known, and the containers to be inspected have been determined by agencies prior to ship arrival. Bielli et al. [6] presented the analysis of a dynamic container terminal system by using an object-oriented simulation approach. Shabayek [14] stated that safety issues, like safety traveling distance, must be considered affecting the arrival pattern of the incoming vessels; because of the complexity caused by the safety issue, the operation of terminal operation is a combination of a number of queues rather than a single queue.

Simulation Methodology

Analytical queuing models are valid for seaport terminal operations, however，they require the probability distributions for various of times, such as arrival times and service times of ships [32]. A large number of stochastic processes are involved in port operations. The arrivals and operational throughput at a seaport vary greatly in practice as well. Because it is hard for analytical models to calculate the overall performance with so many interdependent processes, simulation tool is an effective alternative for a seaport terminal system analysis [32].

In general, simulation studies are widely used for applications in manufacturing, materials handling, and transportation. These simulation applications are usually accomplished with the aid of specially developed simulation software, such as GPSS/H, GPSS/World, SIMAN, SIMSCRIPT, and ARENA, which can be conveniently used for most discrete-event simulation problems [37-39].

The most popular port simulation models are the UNCTAD port model, PORTSIM, and the MIT port simulator [40-41], and their functions are listed in Table 3. However, modern terminals are equipped with modern sophisticated handling equipment and involve various security measures. Recovery planning is also of great interest in addition to regular port operation simulations. Complexity of port layouts and operations, and large variability across ports limit the applicability of those existing port simulation software packages. Further, those packages are not scalable to various port sizes. This study will develop a framework that targets an object-oriented generic port simulation tool box for various port designs and for analyzing security measures and recovery planning beyond regular operation.

Table 3 Comparison of Simulation Software Packages

Simulation Model	Year of developed	Feature
ARENA	N/A	A simulation software with predefined modules (for example, Arrive, Depart, Process, and Hold) [18].
UNCTAD	1969	Used to analyze port operations dealing with conventional loose cargo
PORTSIM	1970's	Intended as a project appraisal tool; useful for evaluating the cost and benefits of changing a port configuration
MIT port simulator	Early 1980's	A refinement of the earlier models, analysis a multipurpose port entailing break-bulk cargo, bulk cargo, refrigerated cargo and containers.

Simulation has been well used by researchers for analyzing operations sea port terminals. Bielli et al.'s [6] simulator could be used to evaluate management policies and to estimate cost functions and other performance measures that could not be easily obtained by analytical computation. Simulation tools contribute to the improvement of internal operations of container terminals. For those port terminals equipped with coastal rail, Kia et al. [8] investigated a computer simulation for evaluating performance of the ship-to-rail direct loading method. By comparing these two systems statistically via a simulation model, the study demonstrated the positive impact of the ship-to-rail direct loading on the capacity of a container terminal, saving in port expansion costs, ship's time at port, and inventory cost on cargo. Lewis, Erera, White [44] describe an approach for aiding the management of a container transshipment seaport in understanding the balance between the number of containers to undergo security inspection and two alternative objectives: the vessel cost as measured by the concomitant departure delays of out-bound vessels and the port cost as measured by the total number of container moves.

A group of authors demonstrate the usage of simulation for seaport operation and security operation, and evaluate their simulation models by comparing and discussing different scenarios and systems. Lewis, Erera, White [44] discussed several ways in which the base case, where a known subset of containers much complete a time-deterministic inspection, can be realistically extended to decide on the balance between the percentage of containers to undergo security inspection and the concomitant departure delays of out-bound vessels and port costs as measured by the number of container moves.

Kia, Shayan and Ghotb [8] investigate two different operational systems. One was the current system in which containers would stay in the terminal for 3~6 days after unloading and then a small portion of containers would be transported by rail to a rail terminal while a large portion (85%) would be taken by trucks. The other one was the proposed system in which a large portion of import containers were taken by rail directly to inland distribution centers, using ship-to-rail loading method. Ship-to-rail direct loading is recommended based on the comparison of the simulation model.

Vis [45] presents a simulation study for the evaluation and comparison of different terminal systems with manned stacking cranes (SCs) and rail mounted gantry cranes (RMGs) in terms of costs and performances. Vis' [45] task was to perform a fixed number of storage and retrieval requests. The performance criterion is the (average) total travel time including empty and full travel distances, average hoisting times as well as average reshuffle times. Characteristics of each container, such as its location in the stack, the type of operation, or origin/destination are randomly generated. A sensitivity analysis is performed for obtaining fair results. The results show advantages for RMGs for a width of the stack up to nine containers.

Duinkerken et al. [22] proposed a simulation model for the comparison of three systems with trucks and multi-trailers, Automatic Guided Vehicles (AGVs), and Automatic Locating Vehicles (ALVs) for overland transport between terminals within a large port area with several terminals, such as Rotterdam's Maasvlakte complex. The model incorporates a rule-based control system and an advanced planning algorithm. Numerical results, such as the utilization of vehicles or cost characteristics, for a realistic scenario for Rotterdam helped in gaining insight into different characteristics of the transport systems and their particular interaction with the handling equipment.

Economic Performance based on Simulation

Selecting port security measures should also be based on the estimation of the economic loss of disasters. Na and Shinozuka [18] estimate the economic loss by analyzing four parts: direct physical damage loss, induced physical damage loss, direct economic/social loss, and indirect economic/social loss [18, 49]. Physical damage loss means replacement and repair cost for structural damage and induced physical damage represents the damage caused by other events related to the disaster, for example, inundation and fire. Direct economic loss is associated economic loss to direct physical damage, such as business interruption and income loss. For example, buildings, roads, and production facilities may be disrupted or closed by the physical damage. Indirect economic loss is the economic impact that is driven by the damage in other sectors by the disaster. For example, if port facilities experienced severe damage so that international trade is interrupted, this will affect some manufacturing sectors that are dependent on the imported sources and the export of their products.

Efforts at estimating loss for specific natural disasters have been completed. For example, Pachakis and Kiremidjian [19] studied seismic revenue loss of seaports considering the damaged states of container cranes using seismic risk assessment (SRA) methodology for the evaluation of the post-earthquake performance of the lifeline system. Na and Shinozuka [18] provided a methodology for estimating the effects of the earthquake on the performance of a container terminal operation system. An analytical framework integrating the models and the curves was proposed to provide a systematic solution.

Simulation models are also used by a group of authors to estimate the economic performance of seaport terminal systems. Na and Shinozuka [18] built a simulation model that was verified by actual terminal operation records, and the system fragility curves that were developed based on the analytical procedure were used to assess the seismic performance of the terminal.

Veenstra et al. [23] analyzed economic aspects of a container terminal with simulation. The simulation results helped to show the interdependence of different decisions. The approach is useful for gaining insight into the decisions' influence on the overall performance of a terminal.

Dahal and Hopkins [7] applied a discrete event simulation model together with a Genetic Algorithm-based evolutionary approach for two real-world port systems and demonstrated a significant improvement in the operational and economic performance. Shabayek [14] performed a cost analysis and estimated the improvements of the terminal operators when their handling capacities varied.

CHAPTER III

METHODOLOGY

Simulation Model

System Description

Port Operation System

Containerized cargos pass through a port terminal in three ways: import, export and transshipment. This study focuses on the operations of imported containers. Imported containers arrive by ships and leave the terminal via trucks or trains. First, an imported container is unloaded by a quay crane. The crane puts the container onto an available transporter (trailer, straddle carrier, or Automatic Guided Vehicle (AGV)). There are two types of containers based on the security policy. One is the pre-screened containers. These containers are from Container Security Initiative (CSI) agreed ports and will go to the container yard directly without going to the screening machine. The other type is the containers not from Container Security Initiative (CSI) agreed ports. A certain percentage (0%-100%) of these containers needs to go to the screening machine for security checking. Further inspection will be needed if the screening result is positive (means the inspected cargo need additional tests). The transporter (trailer, straddle carrier, or automatic guided vehicle (AGV)) then transports the cargo to a container yard. A yard crane picks the container off the transporter and places the container in a stack. The container dwells at the container yard until the dispatch by a truck or train. The yard crane retrieves the container from the container yard and places it onto an external truck or train. Under crisis condition, re-routing will be necessary to keep the freight flow. The operations of re-routing ports are the same as the original ports. Figure 15 provides an overall view of the port operations.

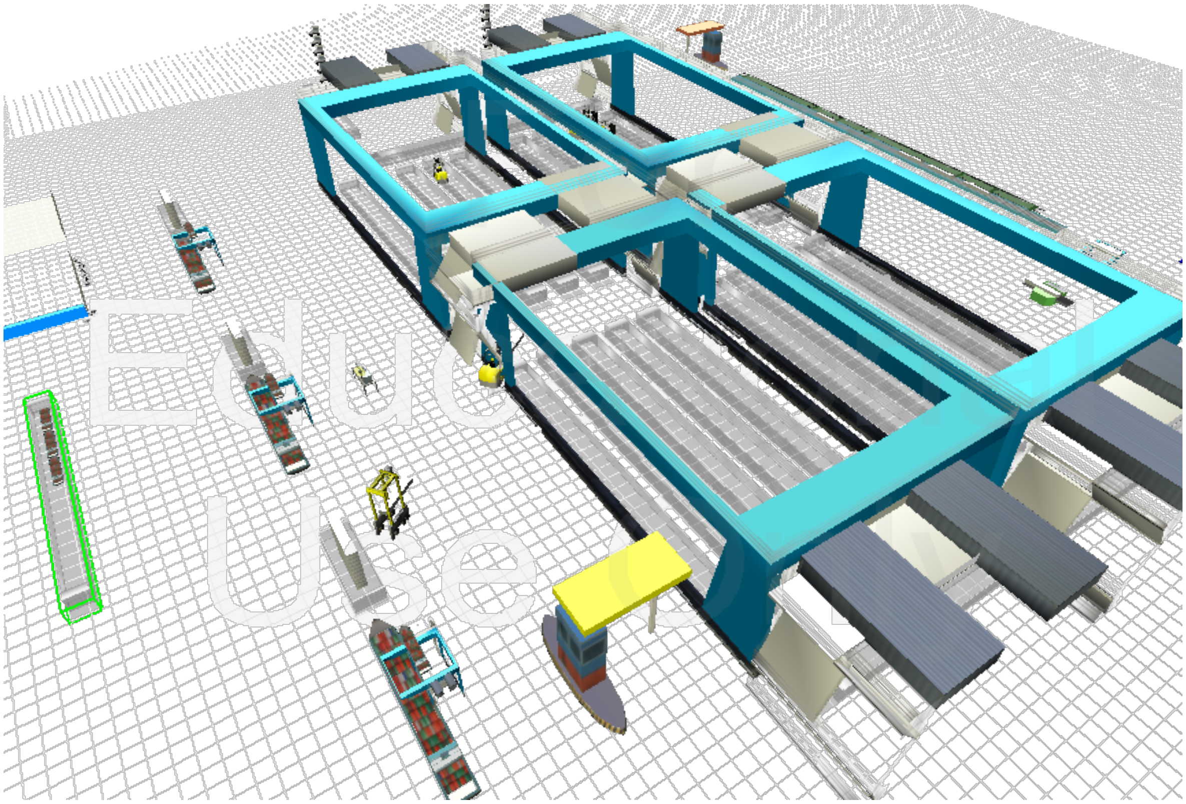


Figure 15 Model View of Port Operation

Transportation System

Once leaving the port, imported containers go to their inland destinations by trucks or trains. Figure 16 is an example of the operation sketch map of an intermodal transportation system. This chart shows inland destinations of containerized cargos, in which the annual throughputs are represented by the size of yellow squares at destinations under study. The chart also shows the transportation mode from the unloading port to the destinations. The red arrow represents the incoming ships. The red circle is its unloading port. Highway routes are showed in dotted lines and arrows while railway routes are showed in solid lines and arrows. The mode of transportation is chosen based on the distance between the unloading port and the inland destination.

Under crisis condition, re-routing will be necessary for keeping the freight flow. Grey circles represent re-routing ports. The incoming ships will be re-routed on the sea. Ships go to re-routing ports based on the current remaining capacity of the ports. After the containers are unloaded at the original port, they go to their inland destinations by trucks or trains. The same as the re-rouging ports' transportation system, highways are showed in dotted lines and arrows while railways are showed in solid lines and arrows. The railways used from a re-routing port to a destination may not be the same as those used for the original port.

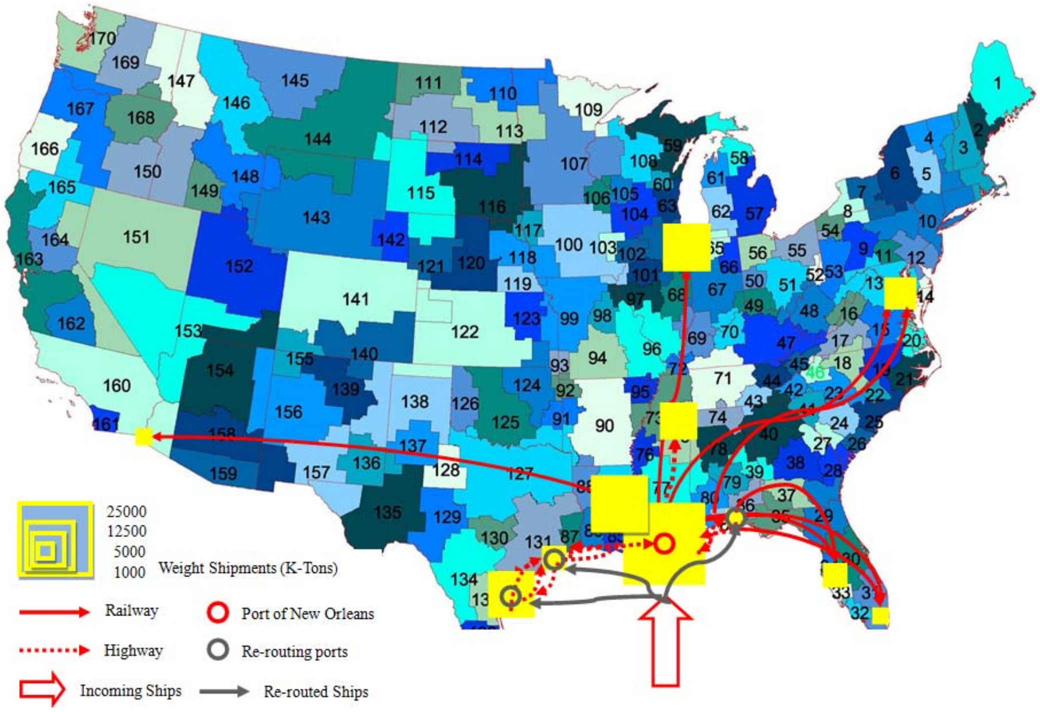


Figure 16 Sketch Map of the Transportation System

Analytical Methodology

The framework of the simulation tool includes four parts: 1) procedures for port operators to input port characteristics, scenario information and security/recovery policies and planning; 2) developed components such as intermodal network, intermodal freight flow data, generic congestion/ volume functions, and generic functions for the economic impact; 3) components to develop simulations for a port and its recovery from terrorist attacks/natural disasters; and 4) visual outputs of economic and operational impacts of the policies under various scenarios. The tool suite is expected to be applicable for all major public ports situated on U.S. coasts and inland waterways over long periods. Figure 17 shows the construction of the simulation tool suite.

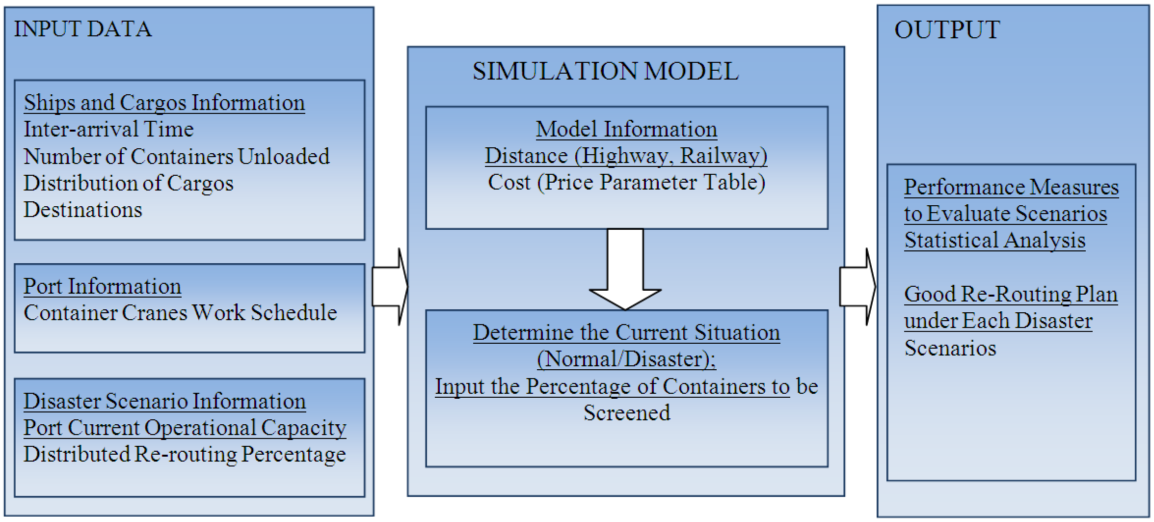


Figure 17 Steps to Construct the Simulation Tool Suite

The following flow chart (Figure 18) represents the sequence of operations involved in the simulation model. The flow chart includes the operations at the original port, re-routing ports, and the inland transportation system.

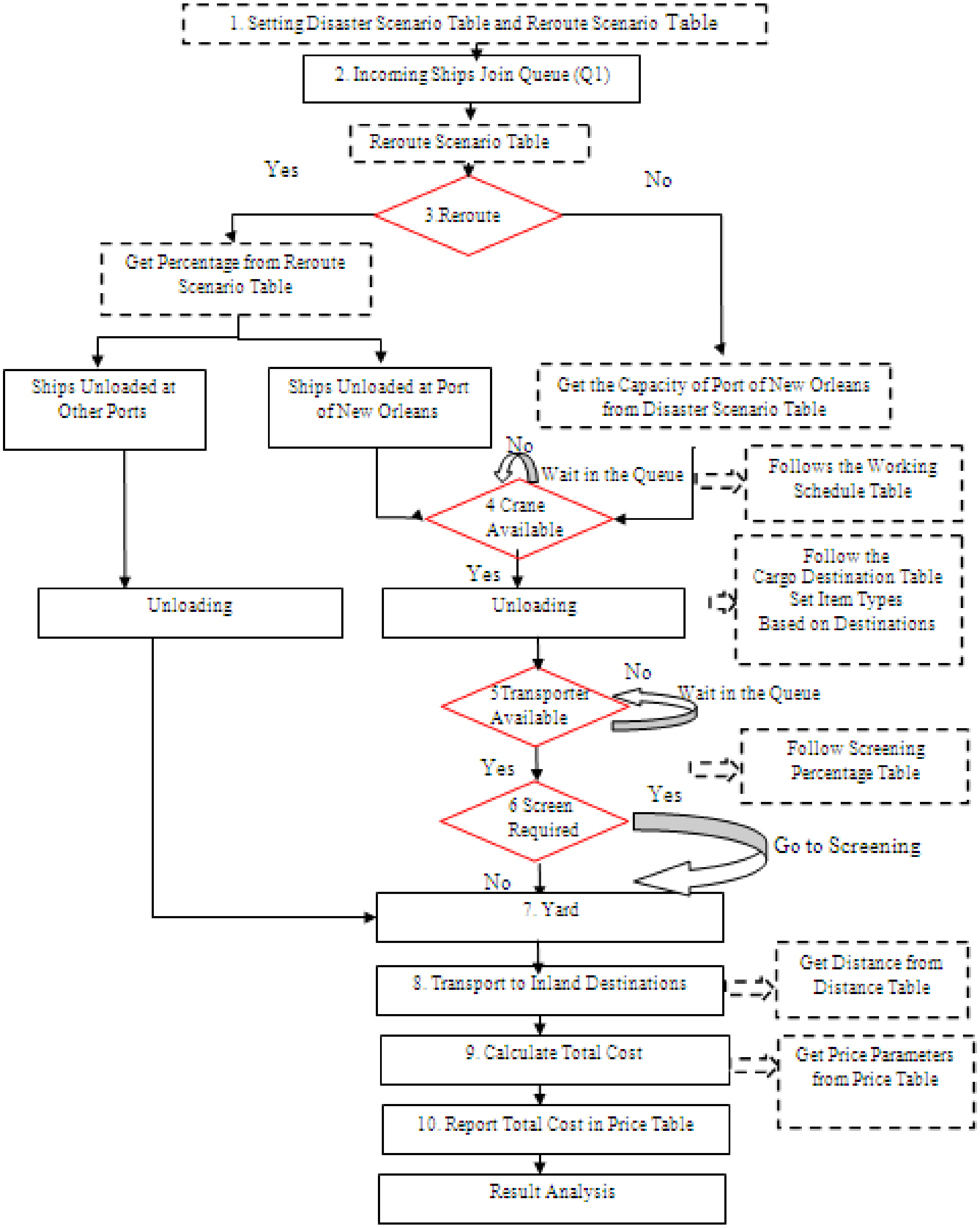


Figure 18 Framework of the Simulation

In the flow chart of the model:

1. The system begins at defining and setting parameters in the Disaster Scenario Table and Re-route Scenario Table.
2. When ships arrive at a port, they first join a queue (Q1) in order to gain access to the port. After ships have entered the port, they wait at the entering queue (Q2) to wait for a availability of the unloading berth.
3. Based on the Reroute Scenario Table, the simulation model sends ships according percentage of ships to our target port and other re-routing ports.
4. Containers are unloaded from ships by container cranes. The container cranes will not work all day, the working schedule can be got and modified through the Working Schedule Table.
5. Following the unloading operations containers that are unloaded join queue (Q3) where they wait for a transporter (trailer, straddle carrier, or automatic guided vehicle (AGV)) that will transport them to the screening machine or stacking yard.
6. The percentage of containers sent to the screening machine can be retrieved and set in the Screening Percentage Table.
7. The containers will stay at the yard until their scheduled carriers (truck or train) come and then they are transported to the inland destinations. The same operations will take place at re-routing ports under crisis conditions.
8. The mode of transportation from a port to a final destination depends on the distance between them. For destinations within a certain miles distance (e.g.500 miles in this model) to the port, the simulation model transports

containers through highways. Otherwise, the simulation model transports containers through railways.

9. All of the above operations incur cost. The cost structure can be set in the Price Parameter Table.
10. After running the model, the Result Table will present result information for each particular scenario, including total cost, average cost for each container, total time of the containers, and average time for each container in the system.

The software package consists of a simulation model developed in FLEXSIM with a user interface. There are seven user interface tables in the flow chart. The tables involve all of the data to describe the port transportation system. The tables are presented in dotted line in the flowchart above are used as graphical user interface (GUI) in this simulation model. The tables allow the user to customize the simulation model easily and interact with the tool suite.

System Assumptions

The system is simulated based on the following modeling assumptions:

1. A seaport terminal operates several types of cargos, such as break bulk cargoes, liquid, automobiles (roll on-roll off), containerized cargoes, and project cargoes, etc. Only containerized cargoes will be analyzed in this study.
2. In general, there are three transferring modes within a seaport terminal, import, export and transshipment. It is assumed that only import will be analyzed and simulated in this study.

3. The waiting time in the container yard and the delay caused by the failure of trains or trucks arriving on time are not considered and studied in this thesis.
4. In this study, we consider only the ship class of small feeders. The number of containers to be unloaded of each ship is uniformly distributed between 96 and 126. Note that other classes of ships can easily be adapted by the user.
5. In this study, all incoming ships are assumed to carry cargos with different destination.
6. In this study, the operation time of each ship depends on the number of containers on it.
7. The arrivals of ships to a port are assumed to follow a Poisson Process. The inter-arrival time of ships is exponentially distributed with the mean value of 16.9 hours. The distribution can be defined by the users.
8. It is recorded that the practical efficiency of the quay crane is 20-30 units per hour, so this study uses the operational time per containers of 3 minutes.
9. This study does not consider the scenario in which the operational capacity is reduced by 100 percent, because there will be a 100% re-routing in this case.
10. The numbers of containers on each ship is assumed to be normally distributed. Based on the import data from Piers, the mean value of number of the containers to be unloaded is 116 and standard deviation value is 11.6.

Freight Flow Management during Crisis Conditions

Different scenarios are defined based on the container-handling capacity of the affected port. This mechanism influences the flow of the containers entering the seaport terminal system. There are three key decision variables:

- Percentage of ships to be re-routed under crisis
- Percentage of how the cranes serve the ships
- Percentage of containers to be inspected

Percentage of Ships to be Re-Routed under Crisis

When the simulated port is disrupted with reduced capacity, a certain percentage of incoming ships need to be re-routed to other ports. Typically when there is a crisis at the port, the port shall send messages in advance to the incoming ships. A table called Reroute Scenario Table is assigned to the anchoring queue (Q1). The table indicates the re-routing measures of the simulating port. Information about the current status of the port will be read from the table. The flowchart of this operation is shown in Figure 19.

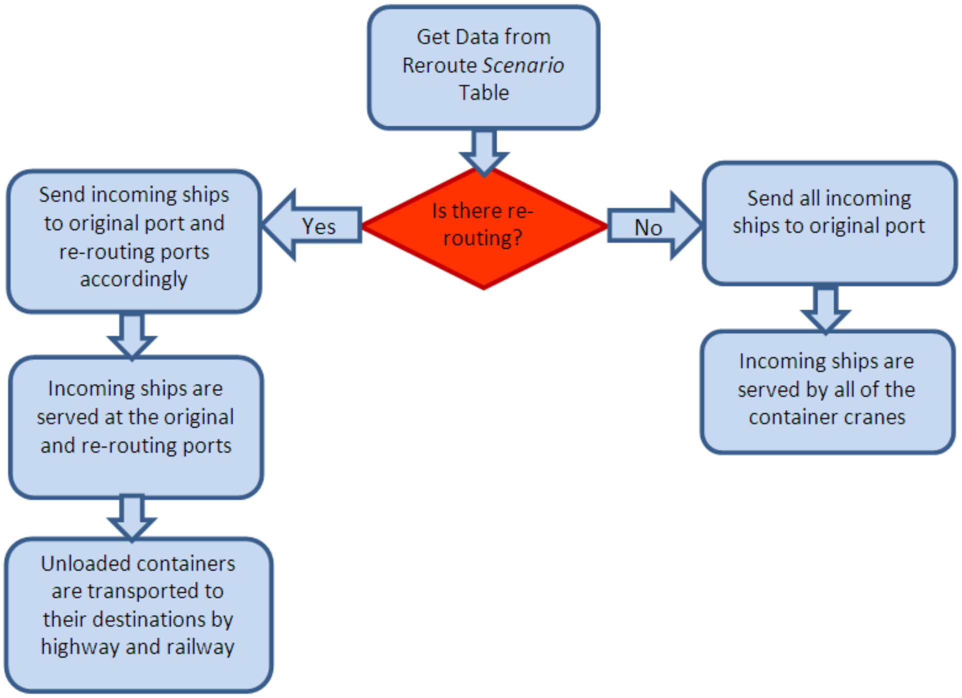


Figure 19 Flow Chart of Re-Routing Process under Crisis Condition

Percentage of Cranes Serve the Ships

When one port is subject to a crisis, a certain percentage of the port's operational capacity is reduced and the capacity will be impacted to different extent. A table called Disaster Scenario Table is assigned to the entering queue (Q2), this table indicates the capacity condition of the simulated port and how to assign ships to the port's cranes. The description of the current capacity will be achieved by the number of container crane in use. Different ways of cranes operations at the seaport terminal system can be achieved by adjusting the sending percentage of entering queue (Q2) and the flow chart of the operation is shown in Figure 20.

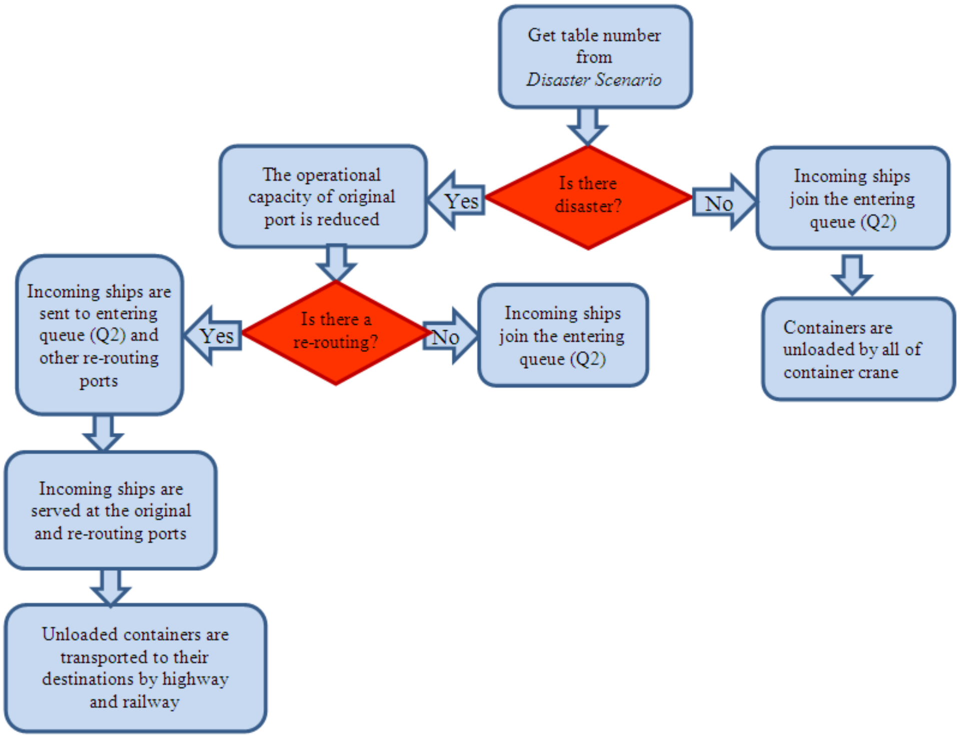


Figure 20 Flow Chart of Operations Process of the Original Port

Percentage of Containers to be Inspected

A certain percentage of containerized cargoes receive inspection. As soon as an arrival of a container ship is generated by the simulation tool, an item type is assigned to each ship. Item type 1 indicates that the arriving ship departures from a Container Security Initiative (CSI) agreed port, which means the unloading containers have been pre-screened before they arrive at the United States port, so these containers will go directly to the stacking yard after unloading. Containers with item type 2 are those containers which need partial inspection before they enter the container yard.

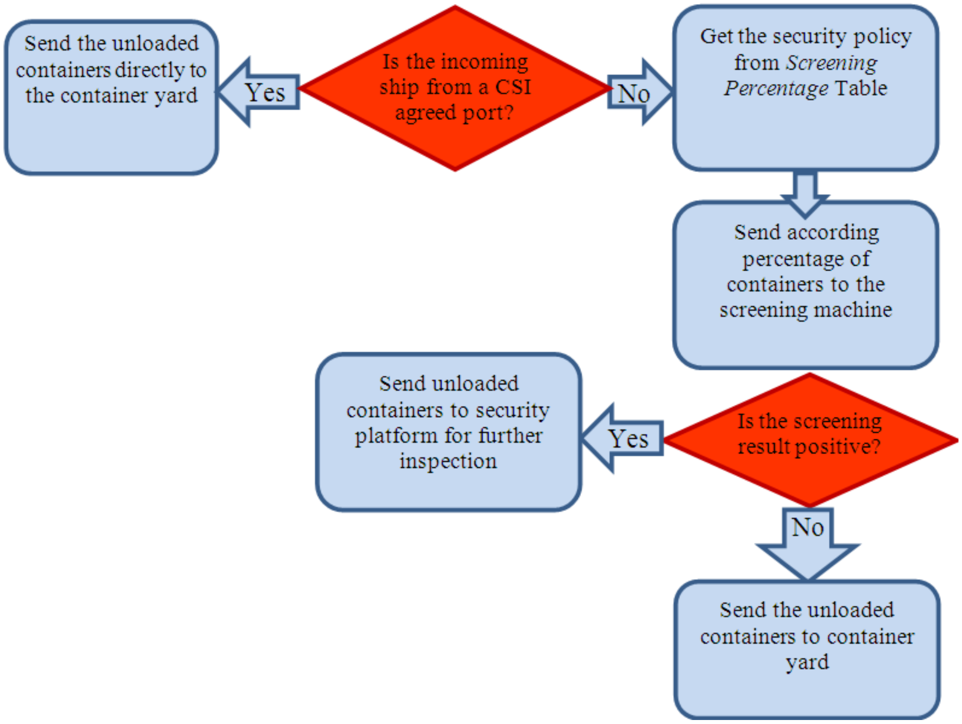


Figure 21 Flow Chart of Assigning Inspection to the Incoming Containers

Performance Measures

The total time that a container spends in the whole system is considered as the main performance measure of the simulation. This represents the time interval between the arrivals of a container to the system from its origin and when it arrives at the final destination. In other words, the performance element is the total lead time of the containers. In this study, the lead time under different scenarios is analyzed and statistically compared. This study considers the following three performance measures.

Average Time of Containers Spend through the System

N — The set of containers which pass through the port and get to their inland destination, $n \in N$.

I — The set of imported ports, including the original port and its neighbor re-routing ports, $i \in I$.

J — The set of destination of containers, including the area of imported ports and other inland destination, $j \in J$.

T_{ij}^{n} — The time that the nth container spends from the imported port *i* to its destination *j*, $n \in N, i \in I$ and $j \in J$.

T_{ijp}^{n}— The time that the nth container spends at the imported port *i* when it goes from this port *i* to its destination *j*, $n \in N$,$i \in I$ and $j \in J$.

T_{ijt}^{n} — The time that the nth container spends on highway or railway transportation when it goes from the imported port *i* to its destination *j*, $n \in N$, $i \in I$ and $j \in J$.

$\overline{T}$ — The average time of all of the containers (*N*) spend in the system.

The time that the nth container spends in the freight flow system (T_{ij}^{n}) includes the time the nth container spends in the port (T_{ijp}^{n}) and the time the nth container spends in being transported to its inland destination (T_{ijt}^{n}). Time spent for docking, positioning, unloading/loading, screening (if necessary), transporting, dwelling, and other port activities are included in T_{ijp}^{n}. During a crisis the waiting time and operational times will typically increase not only at the facility directly affected by the crisis but also at other facilities. For example, limited capacity and operation time of the inspector may block the port operations, and consequently increase the operational time of the cargo in the seaport system. The average time of containers spend in the system can be described as

$$\overline{T} = \sum_{n=1}^{N}\left(\sum_{i \in I}\sum_{j \in J}\left(T_{ijp}^{n} + T_{ijt}^{n}\right)\right)/N \qquad \text{(Eq. 1)}$$

Average Cost of Containers through the System

X_{ijR}^{n}– Binary variable that describes whether the n^{th} container is transported by railway, $n \in N$, $i \in I$ and $j \in J$.

$F_{railcar}$ – Fix cost of using a railcar.

D_{ij}^{r} – Distance from imported port i to destination j by railway transportation, $i \in I$ and $j \in J$.

C_r – Variable cost per mile of railway transportation.

$C_{blocking}$ – Ccost of block handling.

X_{ijT}^{n} – Binary variable that describes whether the n^{th} container is transported by railway, $n \in N$, $i \in I$ and $j \in J$.

F_{truck} – Fix cost of using a truck.

D_{ij}^{t} – Distance from imported port i to destination j by highway transportation, $i \in I$, $j \in J$.

C_h – Variable cost per mile of highway transportation.

X_{ij}^{r} – Binary variable that describes whether there will be a blocking process from the imported port i to destination j if this route includes railway transportation, ,$i \in I$ and $j \in J$.

$C_{depreciation}$ – Depreciation cost of container.

X_{s}^{n} – Binary variable that describes whether the n^{th} container need pre-screening to enter the port, $n \in N$.

$C_{screening}$ – Cost of screening a container.

C^n – Transportation cost of the n^{th} containers.

$\overline{C}$ – Average transportation cost of containers.

Transportation cost is the sum of the fees paid to the transportation facility providers for the use of the facilities (e.g. truck, rail, port, and container). For a particular route, whether the n^{th} container is transported by highway or railcar depends on the distance from the imported port i to the destination j. For some routes, railways may not be used. For some routes, containers are mainly transported by railways, so truck cost may not appear. For the nth container from an origin in a particular world region *i* in the U.S., to a particular place *j* in the U.S., the transportation cost C^n is

$$C^n = X^n_{ijR} *(\mathrm{F}_{\mathrm{railcar}} + \mathrm{D}_{\mathrm{railway}} * \mathrm{C}_{\mathrm{railway}} + X^r_{ij} * \mathrm{C}_{\mathrm{blocking}}) + X^n_{ijT} *(\mathrm{F}_{\mathrm{truck}} + \mathrm{D}_{\mathrm{highway}} * \mathrm{C}_{\mathrm{highway}}) + X^n_s * \mathrm{C}_{\mathrm{screening}} + \mathrm{C}_{\mathrm{depriciation}} * T^n_{ij} \qquad \text{(Eq 2)}$$

For container *n*, the value of X^n_{ijR}, X^n_{ijT}, X^r_{ij}, X^n_s are all binary variables. X^n_{ijR} equals to 1 means the *n*th container is transported by railcar, X^n_{ijR} equals to 0 means the *n*th container is transported by truck. $X^n_{ijR} + X^n_{ijT} = 1$. X^n_s equals to 1 means container n will be screened at the screening machine, X^n_s equals to 0 means container n will not be sent to the screening machine.

Ahuja [58] assumed the average cost of an intermediate handling is $50. Eksioglu [59] generated the cost structure of railway and highway transportation as following

$$C_{railcar} = 498.05 + 0.585 * dist \;,\; C_{truck} = 311.28 + 2.747 * dist \;.$$

The average cost of containers spend in the system can be described as

$$\overline{C} = = \sum_{n=1}^{N} C^n / N \qquad \text{(Eq 3)}$$

Total Number of Containers through the System

Because both crisis and different security policies will affect the operating capacity of the port, therefore crisis and security policies will impact the total number of containers to be unloaded at the port and transported to their inland destination. Except the above two performance measures, the total number of containers through the system is another important measure to evaluate different re-routing strategies and security policies. When the model cannot tell which re-routing strategy or security policy is better based on the above two performance measures, the third performance measure, total number of containers through the system will help to find a good re-routing strategy or security policy

CHAPTER IV

SIMULATION RESULTS AND ANALYSIS

The results and statistical analysis provided in this section demonstrate how the simulation model can be used by various decision makers such as port managers, ocean carriers, transportation service providers, and customers (i.e. shippers).

Data Collection

The data required for the simulation model includes port operational information, a transportation network system, crisis information, and port security policy. There are data to be input for the simulation tool, shown in Figure 22.

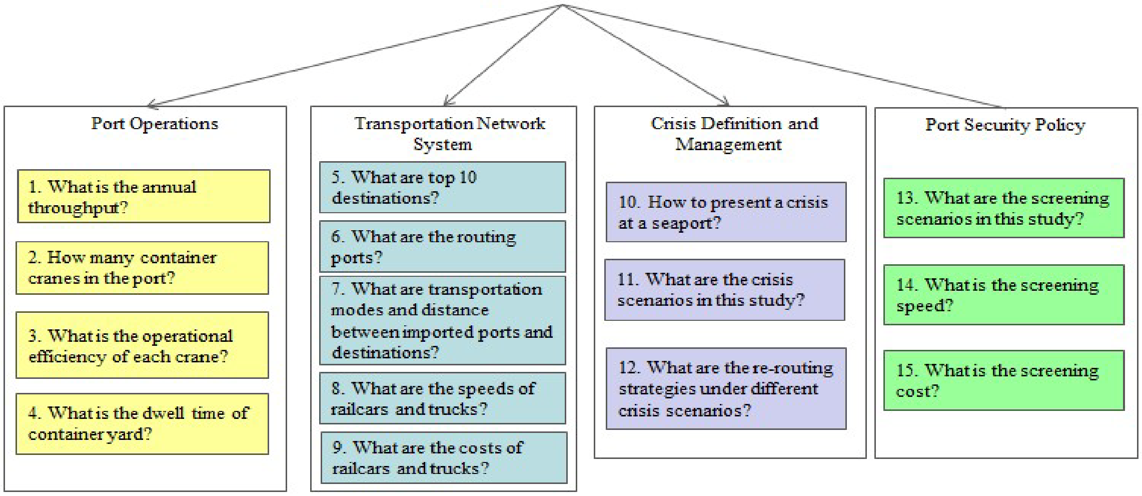
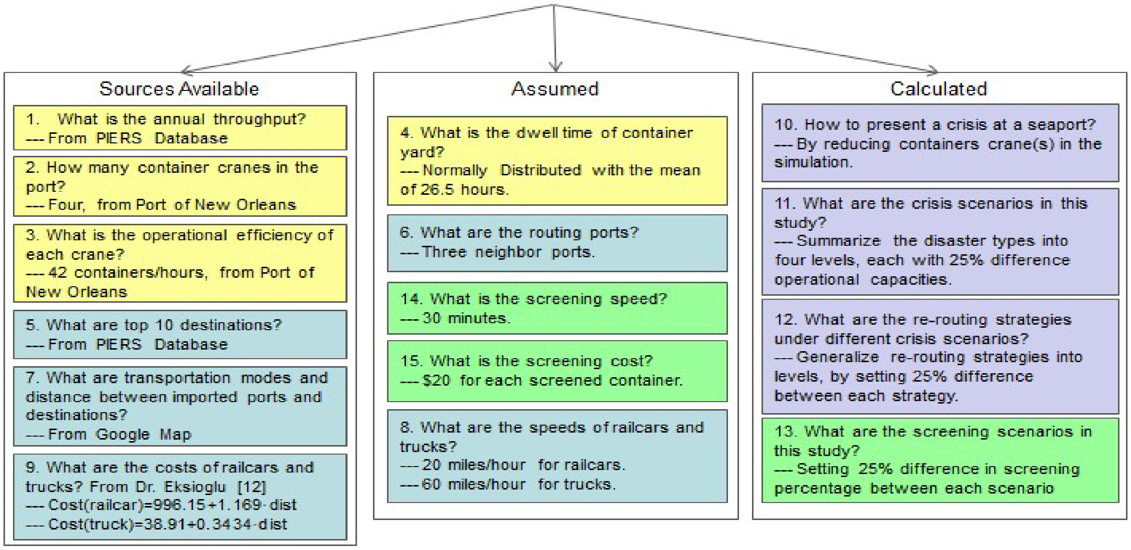


Figure 22 Required Data for the Simulation Model

Some data are collected from PIERS and the Port of New Orleans. For instance in this simulation model, we select the top 10 destinations except the area of New Orleans as the destinations of unloaded containers from the 2007 throughput of Port of New Orleans. The data are shown in Table IV 1. PIERS is a global import and export data information service. The organization records ship information through ports in the U.S. The collected data are summarized in Figure 23.



1. What is the annual throughput?
--- From PIERS Database

2. How many container cranes in the port?
--- Four, from Port of New Orleans

3. What is the operational efficiency of each crane?
--- 42 containers/hours, from Port of New Orleans

5. What are top 10 destinations?
--- From PIERS Database

7. What are transportation modes and distance between imported ports and destinations?
--- From Google Map

9. What are the costs of railcars and trucks? From Dr. Eksioglu [12]
--- Cost(railcar)=996.15+1.169·dist
--- Cost(truck)=38.91+0.3434·dist

4. What is the dwell time of container yard?
--- Normally Distributed with the mean of 26.5 hours.

6. What are the routing ports?
--- Three neighbor ports.

14. What is the screening speed?
--- 30 minutes.

15. What is the screening cost?
--- $20 for each screened container.

8. What are the speeds of railcars and trucks?
--- 20 miles/hour for railcars.
--- 60 miles/hour for trucks.

10. How to present a crisis at a seaport?
--- By reducing containers crane(s) in the simulation.

11. What are the crisis scenarios in this study?
--- Summarize the disaster types into four levels, each with 25% difference operational capacities.

12. What are the re-routing strategies under different crisis scenarios?
--- Generalize re-routing strategies into levels, by setting 25% difference between each strategy.

13. What are the screening scenarios in this study?
--- Setting 25% difference in screening percentage between each scenario

Figure 23 Collected Data for the Simulation Model

Table 4 Comparison of Simulation Software Packages

DMS_ORIG	DMS_DEST	Total KTons	Percentage
New Orleans	New Orleans	25036.30	47.13%
New Orleans	Baton Rouge + Remainder of Louisiana	12669.47	23.85%
New Orleans	Houston + San Antonio	5436.57	10.23%
New Orleans	Chicago	4457.89	8.39%
New Orleans	Mississippi + Tennessee	2198.40	4.14%
New Orleans	New York	1486.60	2.81%
New Orleans	Beaumont + Lake Charles	898.34	1.69%
New Orleans	Tampa	534.25	1.01%
New Orleans	Los Angeles	219.94	0.41%
New Orleans	Miami	123.82	0.23%
New Orleans	Mobile	59.68	0.11%

The containers will go to different inland destinations after they are unloaded from ships, so containers from the same ship may go to different final destinations. In this study, it is assumed that the destinations of containers are independent of incoming ships. In other words, every ship carries a group of containers that have the same statistically distributed destinations.

Normal Port Operation

In this study, the Simulation of Port model (SPORT Model) will run under normal condition. After that by setting the port information, the simulation model will run under different crisis conditions and under various security policies. The results of the simulation study are summarized in the end of this section, which compares the average time that containers spend in the system, the average cost for the containers to go through the system, and the total output of the system under different scenarios.

The following picture (Figure 24) is top-view of the simulation model. The picture includes the layout of Port of New Orleans and the transportation network throughout the U.S.

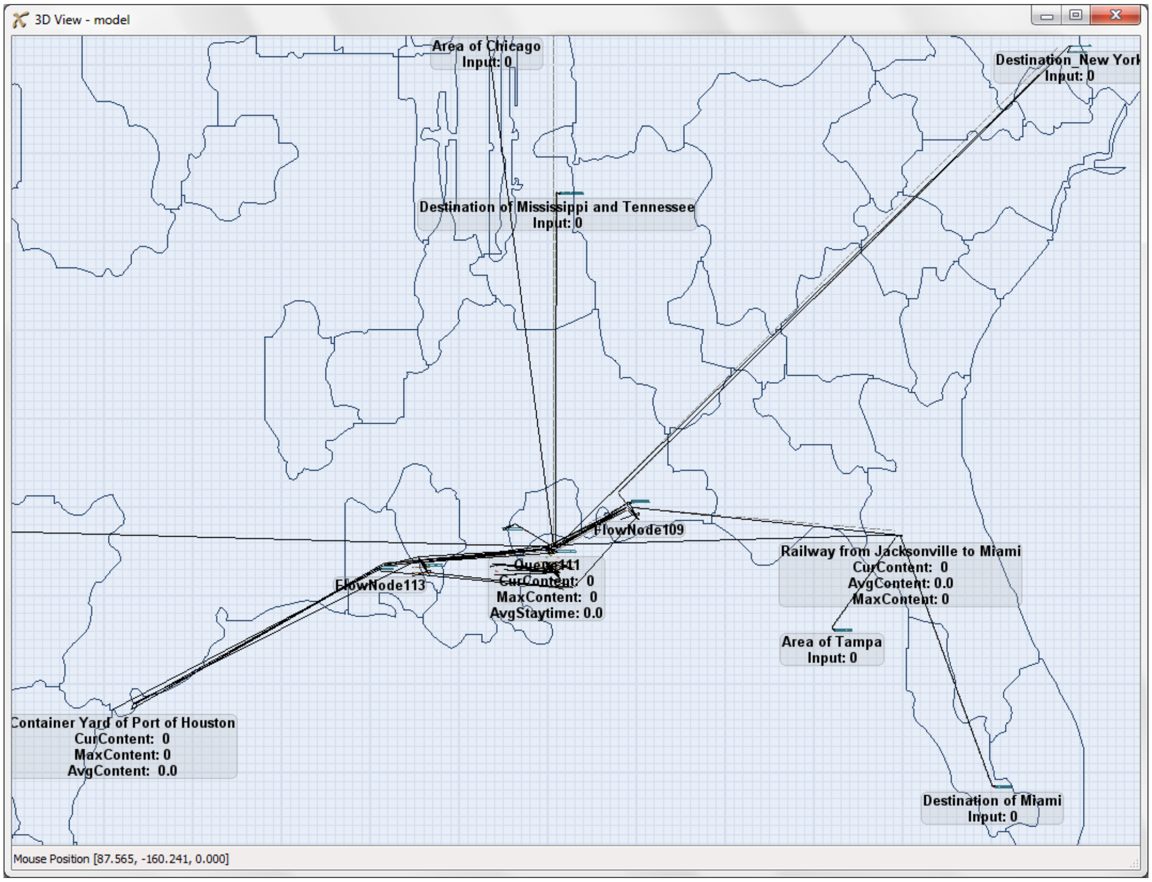


Figure 24 Top View of the SPORT Model

Description of FEXSIM Objects

In FLEXSIM terms, the model contains the following constructs:

Source: The source in this study will generate incoming ships. The inter-arrival time of ships follows a certain distribution and can be easily adapted by the user. In this study, we use the experiential distribution to predict the inter-arrival time of ships.

Queues: When ships arrive at a port, they first join an anchoring queue (Q1) in order to gain access to enter the port. When ships have entered the port, they wait at the entering queue to wait for the availability of the unloading berth. The entering queue (Q2) will send incoming ships to these container cranes.

Following the unloading operations containers that are unloaded join queue (Q3) where they wait for a transporter that will transport them to the screening machine or stacking yard.

Separators: Separators work as container cranes in this model. The number of containers to be unloaded of each ship follows a certain distribution and can be easily adapted by the user. The operation time of each ship depends on the number of containers to be unloaded.

Operators: Operators work as screening machines and grouping station of rail-cars. The operation time of screening machines is 30 minutes; the operation time of grouping station is 3 hours.

Transporters: Transporters transport containers within the port. The speed of transporters is 10 miles/hour. The capacity of each transporter is one container.

Stacks: Stacks work as container yards in the simulation model. The dwell time of containers follows a certain distribution and can be easily adapted by the user. In this study, we consider the dwell time is exponentially distributed with the mean of 96 hours and standard deviation of 9.6.

Conveyors: After waiting at the stacking yard, the containers will be picked up and send out of the port system by trucks or trains. Conveyors work as highways and railways in this study. The speed of highway is 60 miles/hour. The speed of railway is 30 miles/hour.

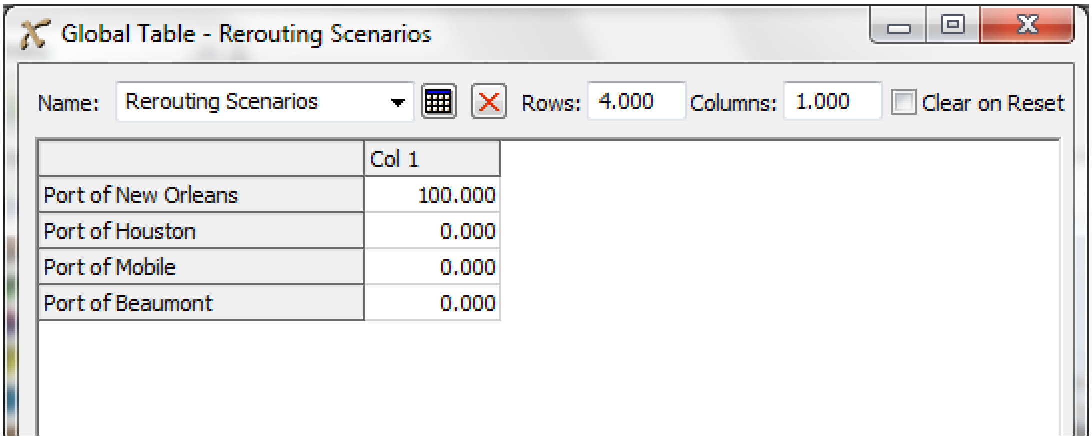
Sink: Sinks act as inland destination in this study. It will record the time a container spends in the system and the cost for transporting a container under different crisis conditions. It will also calculate the average time the containers spend in the system under different crisis conditions.

Description of User Interface

Detailed instructions of the input tables are represented below:

- Rerouting Scenario Table (T1):

  Under basic scenario, this table will assign 100 percent ships to Port of New Orleans. Under disaster scenario, this table will assign different percentage of ships to Port of New Orleans and other ports when reroute is necessary. If 100 percent ships enter the Port of New Orleans, there is no reroute; otherwise there is reroute.



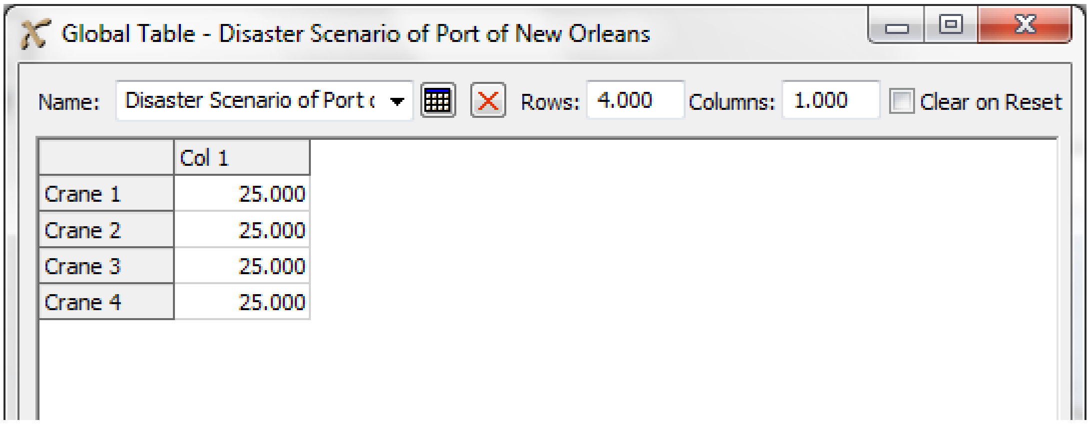
Name: Rerouting Scenarios Rows: 4.000 Columns: 1.000 ☐ Clear on Reset

	Col 1
Port of New Orleans	100.000
Port of Houston	0.000
Port of Mobile	0.000
Port of Beaumont	0.000

Figure 25 Reroute Scenario Table in FLEXSIM

- Disaster Scenario Table (T2):

  This table represents whether there is a disaster at the port. Under basic scenario, this table assigns equal proportion of ships to the cranes at port. Under disaster scenarios, the capacity of port will be reduced, this table assigns unequal number of ships to the cranes.



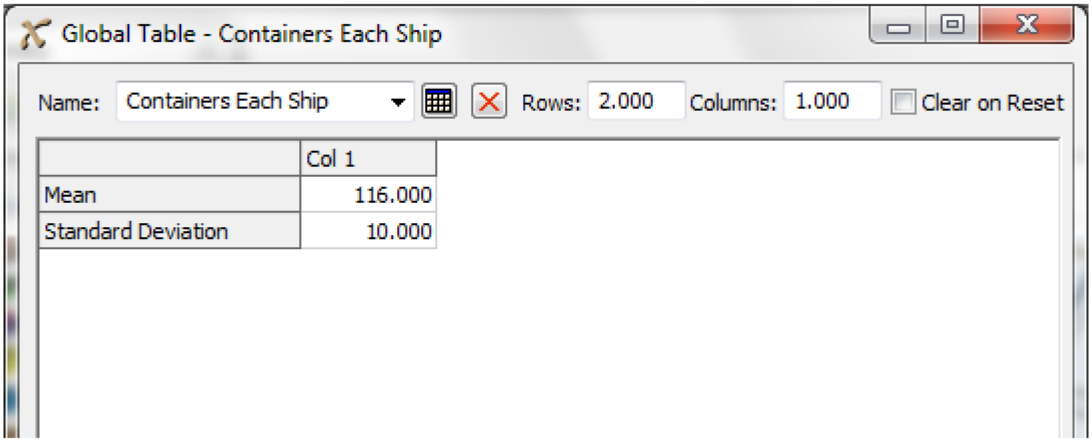
Name: Disaster Scenario of Port (Rows: 4.000 Columns: 1.000 ☐ Clear on Reset

	Col 1
Crane 1	25.000
Crane 2	25.000
Crane 3	25.000
Crane 4	25.000

Figure 26 Disaster Scenario Table in FLEXSIM

- Containers Each Ship Table (T3):

  Based on expert opinion and conversations with port managers, the arrivals of ships to a port are assumed to follow a Poisson Process. The inter-arrival time of ships is exponentially distributed with a rate parameter λ. The numbers of containers on each ship is assumed to be normally distributed. Based on the import data from Piers, the mean value of number of the containers to be unloaded is 116 and standard deviation value is 11.6. These numbers can be defined by the user as well.

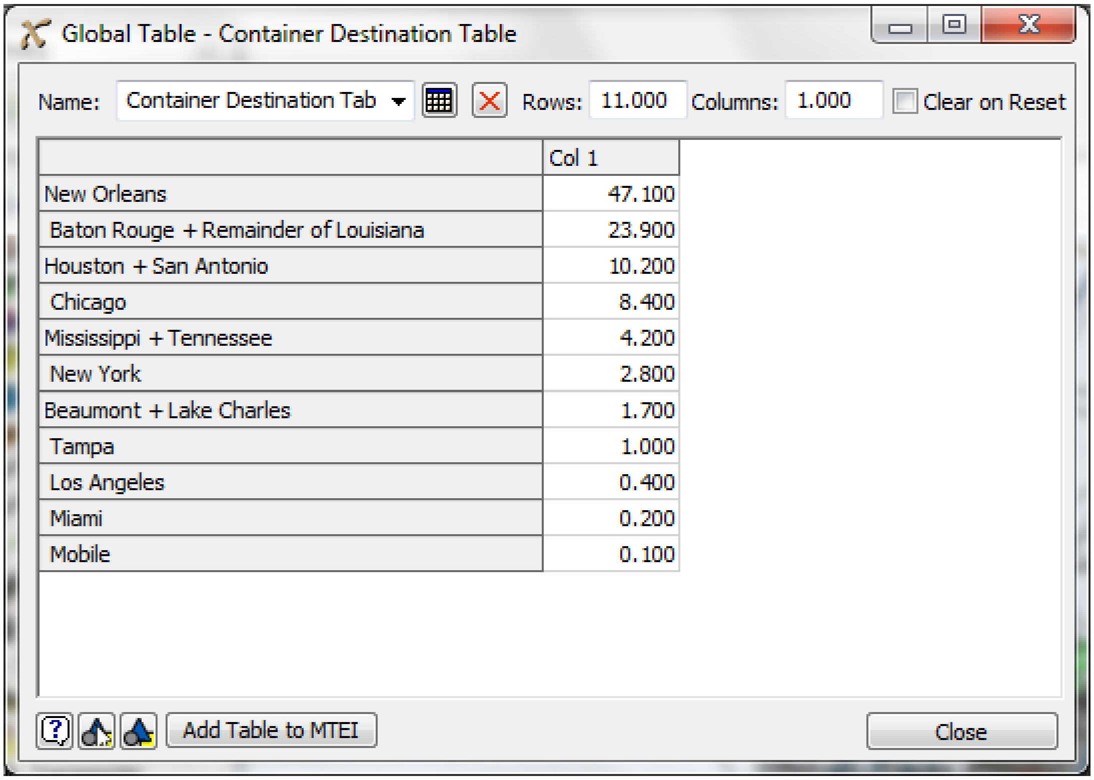


	Col 1
Mean	116.000
Standard Deviation	10.000

Figure 27 Container Each Ship Table in FLEXSIM

- Containers Destination Table (T4):

  This table shows the destinations of unloaded containers, and the percentage of unloaded container to be transported to the destinations. In this study, we select the top 10 destinations of unloaded cargo except the area of New Orleans based on the 2007 throughput of Port of New Orleans. The percentages we use to transport in the model is showed in the following Figure 28.



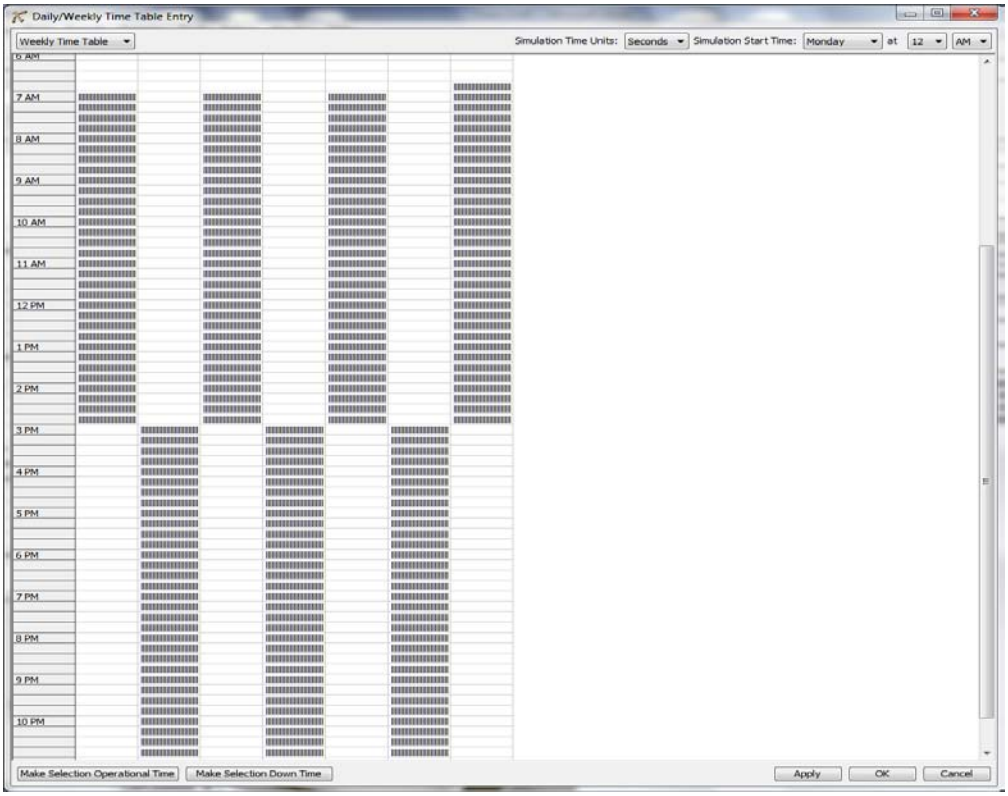
Name: Container Destination Tab Rows: 11.000 Columns: 1.000 ☐ Clear on Reset

	Col 1
New Orleans	47.100
Baton Rouge + Remainder of Louisiana	23.900
Houston + San Antonio	10.200
Chicago	8.400
Mississippi + Tennessee	4.200
New York	2.800
Beaumont + Lake Charles	1.700
Tampa	1.000
Los Angeles	0.400
Miami	0.200
Mobile	0.100

Figure 28 Cargo Destination Table in FLEXSIM

- Working Schedule Table (T5):

  Working Schedule Table containers are unloaded from ships by container cranes. The container cranes will not work all day, the working schedule can be got and modified through the Working Schedule Table. In this study, the container cranes will work from

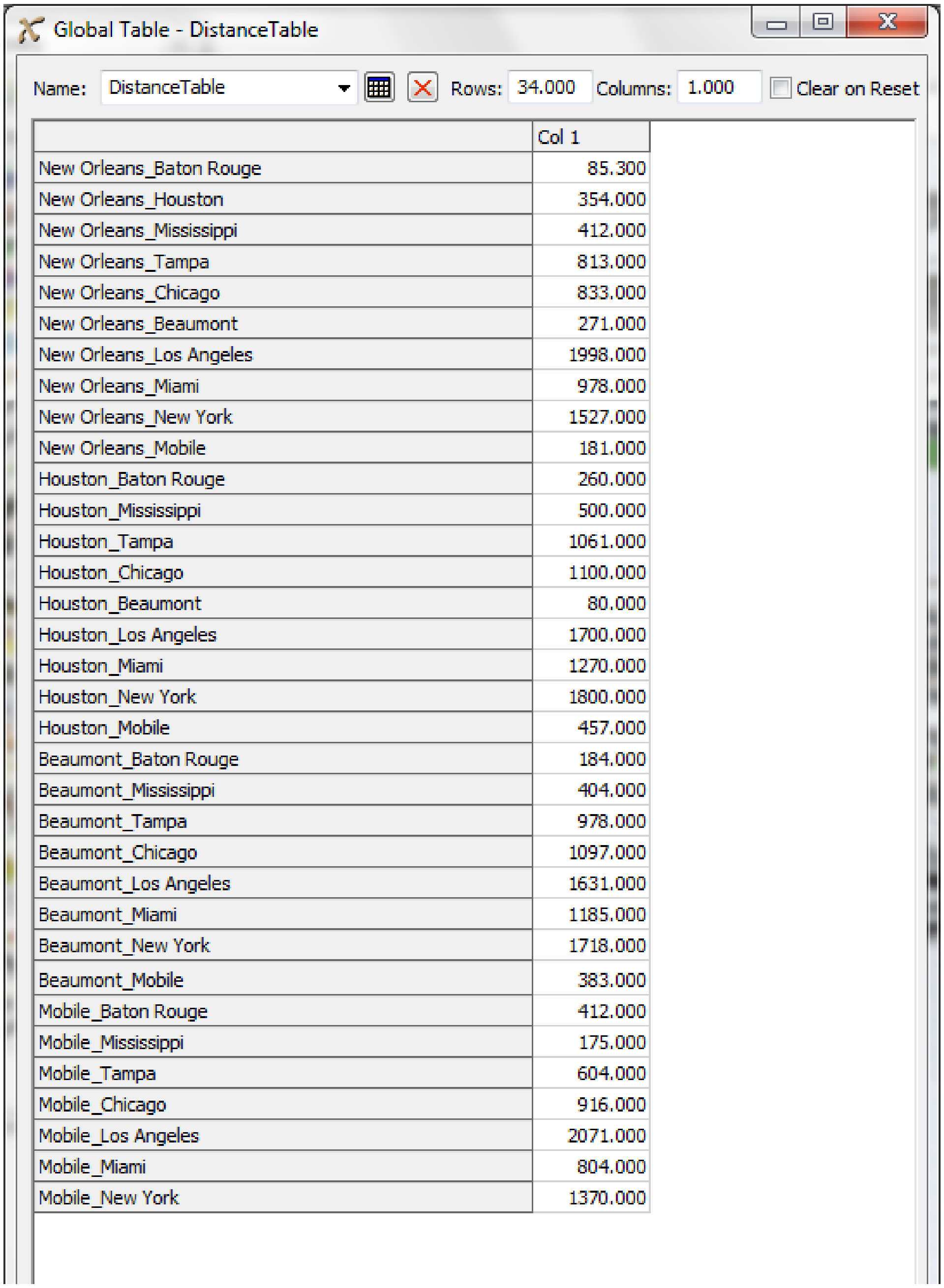


Simulation Time Units: Seconds
Simulation Start Time: Monday at 12 AM

Figure 29 Working Schedule Table in FLEXSIM

- Distance Table (T6):

  Containers are transported to their inland destinations. For destinations within a certain miles distance (500 miles in this model) to the port, the model transports containers through highway. For destinations of the longer distance, the model transports containers through railway. The time of transportation depends on the speed of vehicles and distance. Typically there is more than one route to choose to transport, so the distance between two points varies. To change a route and set a different distance between two places, the user can change the distance in the Distance Table. This table contains distance information will be used to calculate total cost. There are two transportation modes that containers will be transported to destination, one is the highway, and the other one is railway.



Global Table - DistanceTable

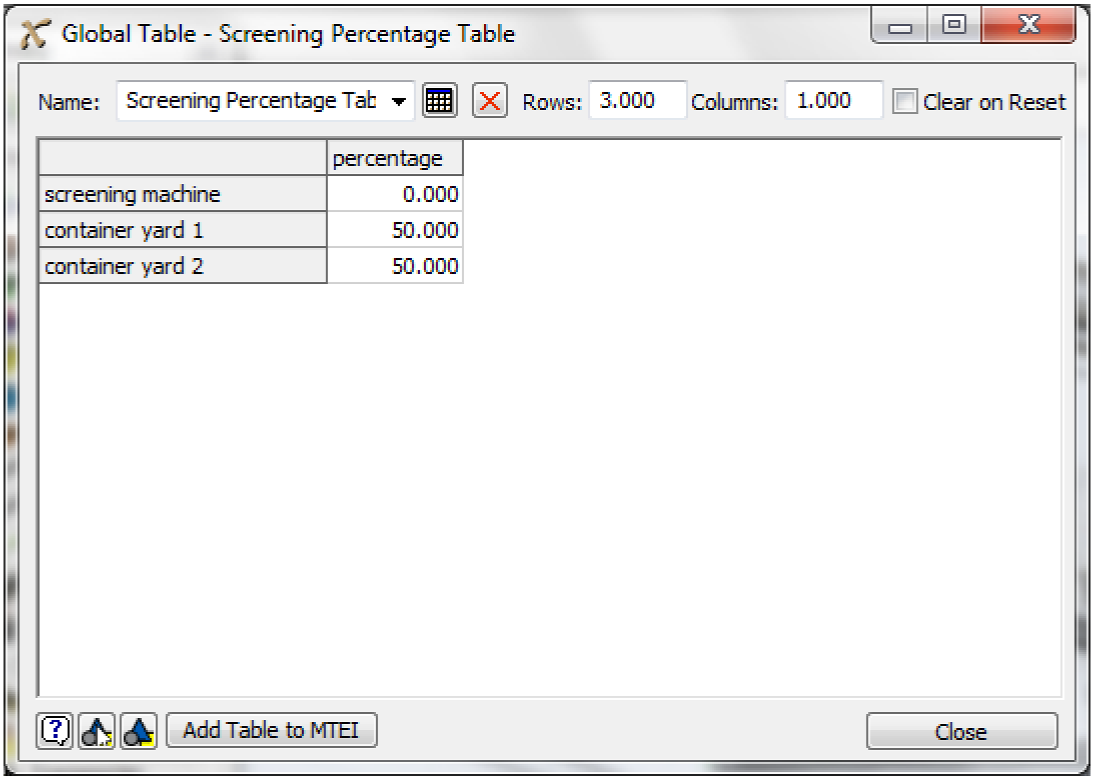
Name: DistanceTable Rows: 34.000 Columns: 1.000 ☐ Clear on Reset

	Col 1
New Orleans_Baton Rouge	85.300
New Orleans_Houston	354.000
New Orleans_Mississippi	412.000
New Orleans_Tampa	813.000
New Orleans_Chicago	833.000
New Orleans_Beaumont	271.000
New Orleans_Los Angeles	1998.000
New Orleans_Miami	978.000
New Orleans_New York	1527.000
New Orleans_Mobile	181.000
Houston_Baton Rouge	260.000
Houston_Mississippi	500.000
Houston_Tampa	1061.000
Houston_Chicago	1100.000
Houston_Beaumont	80.000
Houston_Los Angeles	1700.000
Houston_Miami	1270.000
Houston_New York	1800.000
Houston_Mobile	457.000
Beaumont_Baton Rouge	184.000
Beaumont_Mississippi	404.000
Beaumont_Tampa	978.000
Beaumont_Chicago	1097.000
Beaumont_Los Angeles	1631.000
Beaumont_Miami	1185.000
Beaumont_New York	1718.000
Beaumont_Mobile	383.000
Mobile_Baton Rouge	412.000
Mobile_Mississippi	175.000
Mobile_Tampa	604.000
Mobile_Chicago	916.000
Mobile_Los Angeles	2071.000
Mobile_Miami	804.000
Mobile_New York	1370.000

Figure 30 Distance Table in FLEXSIM

- Screening Percentage Table (T7):

  The percentage of containers to send to the screening machine can be got and set in the Screening Percentage Table.



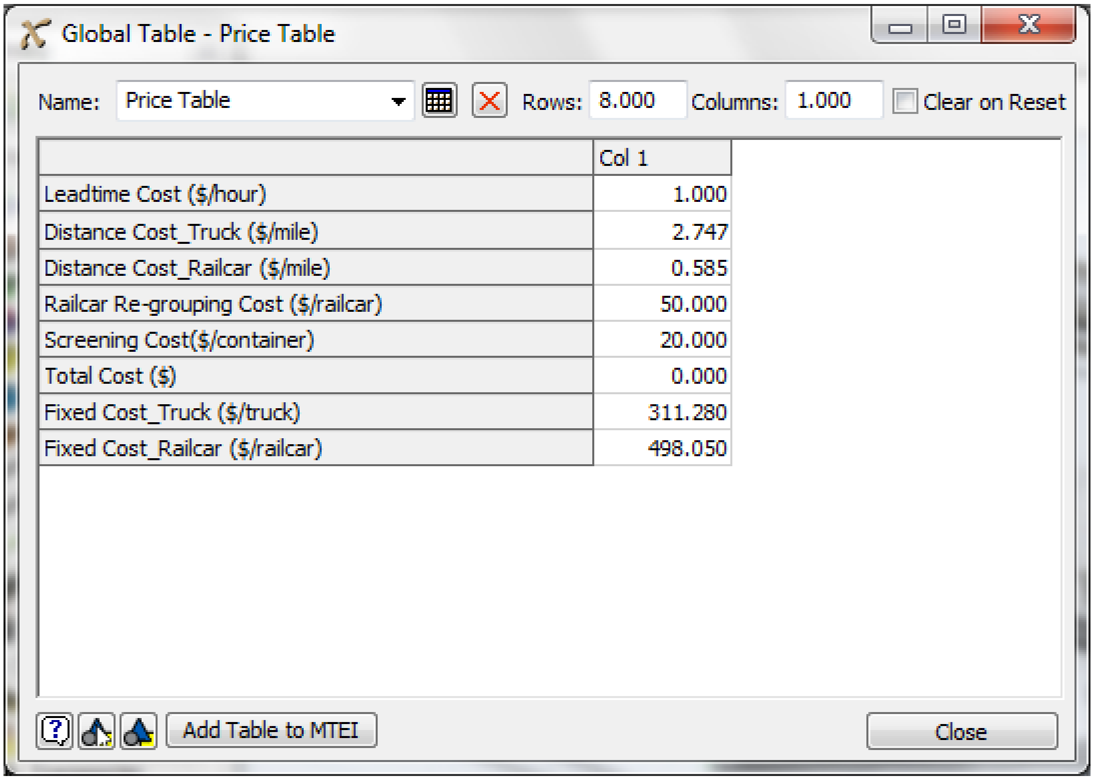
Name: Screening Percentage Tab Rows: 3.000 Columns: 1.000 ☐ Clear on Reset

	percentage
screening machine	0.000
container yard 1	50.000
container yard 2	50.000

Figure 31 Screening Percentage Table in FLEXSIM

- Price Parameter Table (T8):

  All of the operations above will generate cost. Different operations cost differently. Parameters can be set in the Price Parameter Table. After running the model, the Result Table will present result information for each particular scenario, including total cost, average cost for each container in this system, total time of the containers in the system, average time for each container in this system. This table gathers all of the price information. In this example, we assume the lead time cost of containers is $1 per hour. If one container is transported by truck, the transportation cost depends on the distance cost and fixed cost. If one container is transported by railcar, it is possible that regrouping is required, so the transportation cost depends on the distance cost, fixed cost and the railcar regrouping cost. The total cost is showed in this table as well.



Name: Price Table Rows: 8.000 Columns: 1.000 ☐ Clear on Reset

	Col 1
Leadtime Cost ($/hour)	1.000
Distance Cost_Truck ($/mile)	2.747
Distance Cost_Railcar ($/mile)	0.585
Railcar Re-grouping Cost ($/railcar)	50.000
Screening Cost($/container)	20.000
Total Cost ($)	0.000
Fixed Cost_Truck ($/truck)	311.280
Fixed Cost_Railcar ($/railcar)	498.050

Figure 32 Price Table in FLEXSIM

After the user defines these required data components, the simulation model is run to evaluate the performance of the transportation system. The resulting performance measures are reported by the simulation model in accordance with specified re-routing scenario. In this study, the performance measures of interest are the total time that a container spends in the system under different scenarios (i.e. no crisis conditions, crisis conditions with no re-routing, crisis conditions with different re-routing scenarios, no crisis conditions with different pre-screening scenarios). Under a crisis condition, the user continues simulating and comparing the performance of the different re-routing strategies.

In Scenario 0, we assume that the port is operated under normal conditions without any crisis. Imported cargo arrives by maritime vessels and leaves the terminal via truck or train. NO (0%) unloaded containers which are not from a CSI agreed port will be inspected. The results of the simulation study (Scenario 0) are summarized in Table IV-1.

Table 5 Simulation Results under Scenario 0

	Rerouting Percentage	Average Cost per Container ($)	Average Time per Container (Hours)	Number of Transported Container (TEU)
Scenario 0	0%	511.6	81.1	118192

Crisis Management

To demonstrate the use of the model we simulated and evaluated the performance of ports based on the following cases: (i) under normal conditions without any disruptions and (ii) under the conditions where a certain percentage of containerized cargos which are not from a CSI agreed port need inspection clearance before entering a country and (iii) under crisis conditions where the container port are affected by a disaster. The simulation model also enables the decision maker to perform what-if analysis by specifying different scenarios on impacted operation capacities after the disaster. Although one would expect a significant increase in lead time when there is a percentage of containerized cargos need to be inspected before importing, it is not clear if there are significant differences among various inspection scenarios. Statistical analyses are conducted in order to evaluate whether or not there are significant differences in the lead time under normal and inspection scheduled conditions, and also among various re-routing strategies for disaster evacuating.

Re-Routing Strategies

In our study, a port is subject to a crisis condition. To simulate the crisis condition, this paper studied four scenarios representing the approximation of operational capacity of the port and each scenario includes five rerouting strategies. The following is the description of these four scenarios:

- Scenario 1: 0% of the port operational capacity is reduced.
- Scenario 2: 25% of the port operational capacity is reduced.
- Scenario 3: 50% of the port operational capacity is reduced.
- Scenario 4: 75% of the port operational capacity is reduced.

Each re-routing strategy under the scenarios is replicated 10 times and each replication is simulated for 8760 hours to analyze the performance of the system. When simulating the different scenarios, common random numbers for exponentially distributed arrival rate are used. It is taken into consideration that some decision makers may pay more attention to the average cost, but other decision makers (e.g. a Just-In-Time manufacturer) may think the average time per container is more important. So both the average cost of a container and the average time a container spends in the system were studied and calculated. Data used in the above scenarios can be changed to any realistic data of any particular port. Table 6 shows the result of port operation and transportation system.

Table 6 Simulation Results under Scenario 1, 2, 3 and 4

	Rerouting Percentage	Average Cost per Container ($)	Average Time per Container (Hours)	Number of Transported Container (TEU)
Scenario 1	0%	521.8	90.4	118265.2
	25%	728.3	94.5	121675.4
	50%	920.9	103.6	114143.0
	75%	920.9	105.6	112501.5
	100%	1121.6	110.8	103494.0
Scenario 2	0%	541.2	92.9	118284.7
	25%	738.0	95.3	121756.2
	50%	926.9	106.8	114151.9
	75%	944.5	109.9	112874.3
	100%	1130.1	110.4	103472.1
Scenario 3	0%	548.3	119.6	112564.4
	25%	738.0	101.5	114873.3
	50%	944.4	105.1	117204.0
	75%	1155.4	121.7	122440.7
	100%	1121.6	121.7	103492.6
Scenario 4	0%	2465.6	1992.9	66893.0
	25%	1457.9	755.2	95116.0
	50%	983.1	122.4	112768.0
	75%	1033.4	108.5	107159.1
	100%	1121.8	110.4	103201.5

Analysis of Re-Routing Impact

Analysis of Re-Routing Impact on Cost

We can see from the table that under crisis scenario 1, a good re-routing strategy among these five re-routing strategies is 0% re-routing. All other re-routing strategies will increase the average transportation cost per container. When the port's operational capacity is reduced by 25%, a good operation strategy is also to re-route 0% of incoming ships. If there is more re-routing, the waiting time at the entering queue (Q2) will decrease but the traveling time to other ports and the traveling time inland will cause an increase in the total transportation cost. It is necessary to point out that the possible reason for the cost increase is that re-routing will eventually increase the average transportation time of New Orleans-destination containers. Since there is a lead time cost of containers, increasing the average transportation time of New Orleans-destination containers will increase the average transportation cost of the system. When there is a 50% reduction of operational capacity caused by a crisis at the Port of New Orleans, a good re-routing strategy is to route 0% of the incoming ships to the neighbor ports. If there is more re-routing, the waiting time at the entering queue (Q2) will decrease but the traveling time to other ports and the traveling time inland will cause an increase in the total transportation cost. We can see from Table IV 2 that a good re-routing strategy under crisis scenario 4 is 50% rerouting. Other re-routings will increase the average cost per container. In conclusion, the result tells us that that it is not always good to re-route incoming ships when there is a crisis.

Analysis of Re-Routing Impact on Time

We can see from column of average time per container in the Table IV 2 that a good re-routing strategy under crisis scenario 1 is 0% rerouting. All other re-routing strategies will increase the average time the containers spend in the system. When the port's operational capacity is reduced by 25%, all of the re-routing strategies increase the average time of containers. It is necessary to point out that the possible reason for the increase is that re-routing will eventually increase the average time of New Orleans-destination containers, hence increase the average time of the system. The reason for the observation is that a big portion of New Orleans-destination containers will be re-routed to other ports and transported back to area of New Orleans by highway, therefore the average time will be increased. When there is a 50% reduction of operational capacity caused by a crisis at the Port of New Orleans, a good re-routing strategy is to route 25% of the incoming ships to the neighbor ports. If there is no re-routing, the waiting time at the entering queue (Q2) will increase and hence the average operation time will increase. If there is a more than 50% re-routing, the increase in transportation time in highway or railway will result in an increase in average operation time. We can see from Table IV 2 that a good re-routing strategy under crisis scenario 4 is 50% rerouting. Other re-routings will increase the average time the containers spend in the system. It is important to observe that when there is 0% re-routing, the average time per container to New Orleans almost equals to the average time to all other destinations. This result shows that when there is no re-routing the waiting time at entering queue (Q2) is very long. The increased waiting time consequently reduces the difference rate of the average time between New Orleans-destination containers and all other destination containers. In conclusion, the result tells us that that it is not always good to re-route incoming ships when there is a crisis.

Comparison between No Re-Routing and Re-Routing Strategies

Table 7 shows the difference between crisis scenarios and normal scenario (Scenario 0) under no re-routing strategy. Table 8 shows the difference between crisis scenarios and normal scenario (Scenario 0) under optimal re-routing strategies. The comparison between no re-routing and optimal re-routing strategies in the corresponding performance measure analyzes how much the re-routing relieves the congestion at the port under crisis conditions. Particularly, Figure IV 12 compares the improvement of optimal re-routings with no re-routing based on total output under different crisis scenarios. Figure IV 13 compares the improvement of optimal re-routings with no re-routing based on average cost under different crisis scenarios. Figure IV 14 compares the improvement of optimal re-routings with no re-routing based on average time to all destinations under different crisis scenarios.

Table 7 Comparison of Crisis Scenario with Scenario 0 under No Re-Routing Strategy

	4 cranes	3 cranes left	2 cranes left	1 crane left
Rerouting Percentage	0%	0%	0%	0%
Total Output (containers)	0	0.00	-0.05	-0.43
Cost per Container (dollars)	0	+0.02	+0.07	+3.65
Average time per container to all destinations (hours)	0	+0.13	+0.47	+22.71
Average time per container to Destination of Houston	0	+0.10	+0.66	+34.32
Average time per container to Destination of Los Angeles	0	+0.04	+0.22	+11.77
Average time per container to Destination of Beaumont	0	+0.10	+0.65	+34.60
Average time per container to Destination of New York	0	+0.04	+0.24	+13.91
Average time per container to Destination of Mobile	0	+0.10	+0.66	+36.09
Average time per container to Destination of Tampa	0	+0.44	+0.79	+24.88
Average time per container to Destination of Miami	0	+0.36	+0.65	+20.62
Average time per container to Mississippi and Tennessee	0	+0.09	+0.60	+31.65
Average time per container to Destination of Chicago	0	+0.04	+0.24	+13.98
Average time per container to Destination of Baton Rouge	0	+0.11	+0.70	+37.24
Average time per container to Destination of New Orleans	0	+0.11	+0.72	+38.11

Table 8 Comparison of Crisis Scenario with Scenario 0 under Optimal Re-Routing Strategy

	4 cranes	3 cranes left	2 cranes left	1 crane left
Rerouting Percentage	0%	0%	25%	50%
Total Output (containers)	0	0.00	-0.03	-0.05
Cost per Container (dollars)	0	+0.02	+0.44	+0.92
Average time per container to all destinations (hours)	0	+0.13	+0.29	+0.52
Average time per container to Destination of Houston	0	+0.10	+0.32	+0.57
Average time per container to Destination of Los Angeles	0	+0.04	+0.06	+0.26
Average time per container to Destination of Beaumont	0	+0.10	+0.34	+0.74
Average time per container to Destination of New York	0	+0.04	+0.14	+0.43
Average time per container to Destination of Mobile	0	+0.10	+0.37	+0.81
Average time per container to Destination of Tampa	0	+0.44	+0.62	+0.54
Average time per container to Destination of Miami	0	+0.36	+0.52	+0.55
Average time per container to Mississippi and Tennessee	0	+0.09	+0.34	+0.72
Average time per container to Destination of Chicago	0	+0.04	+0.15	+0.33
Average time per container to Destination of Baton Rouge	0	+0.11	+0.39	+0.84
Average time per container to Destination of New Orleans	0	+0.11	+0.40	+0.83

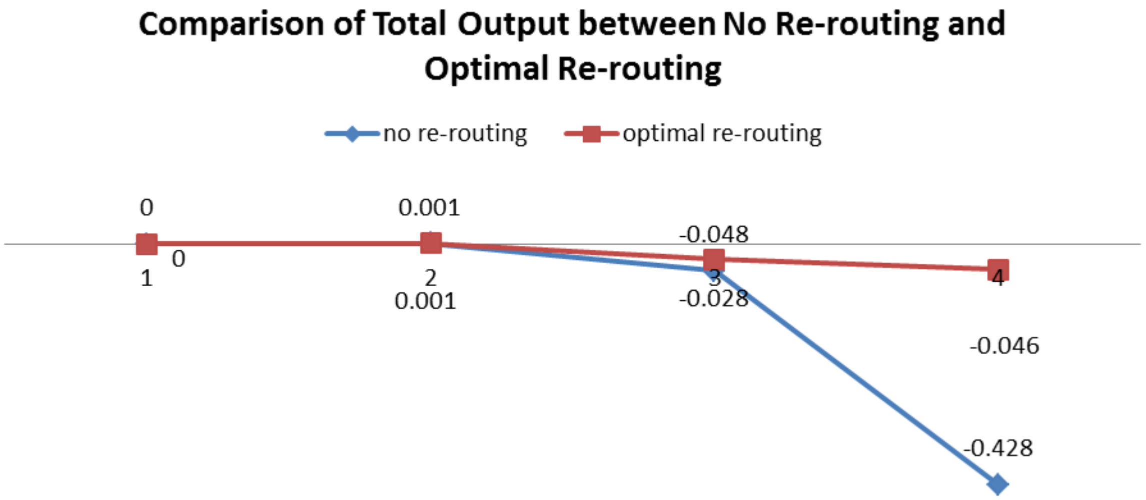


Figure 33 Comparison of Total Output between No Re-Routing and Optimal Re-Routing

Re-routing increases the total output when there is a big reduction of the port operation capacities. Particularly, when the port's operational capacity is decreased by 75%, a 50% re-routing may increase the number of incoming ships. That is because the neighbor ports may have more available operational capacity (e.g. the Port of Houston has more container cranes than Port of New Orleans).

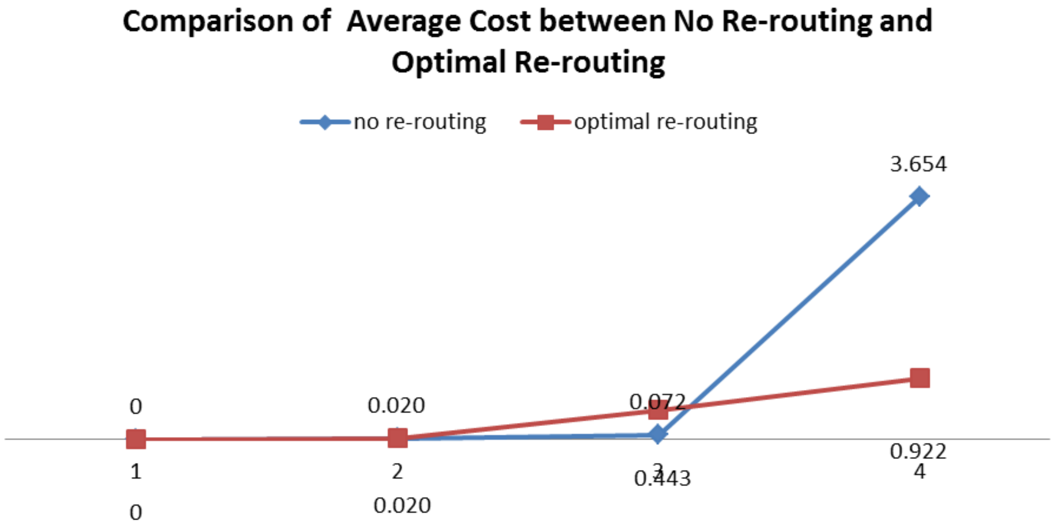


Figure 34 Comparison of Average Cost between No Re-Routing and Optimal Re-Routing

Re-routing decreases the average cost before re-routing when there is a reduction of the port operation capacities greater than or equal to 50%. It is noticed that when the port's operational capacity is decreased by 75%, a 50% re-routing will reduce the average cost to a large extent compared with there is no re-routing. It is also noticed that even though the number of ships enter the system may increase because of re-routing, the average cost still increases because of the increased transportation fee.

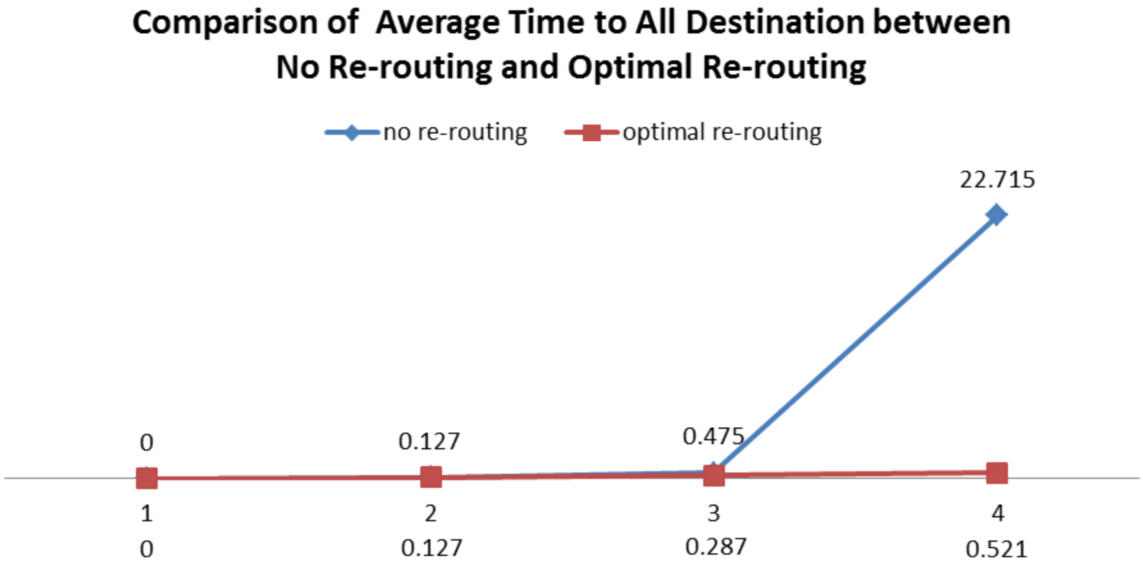


Figure 35 Comparison of Average Time between No Re-Routing and Optimal Re-Routing

Re-routing decreases the average time to all destinations before re-routing when the port's operation capacities is reduced greater than or equal to 50%. It is noticed that when the port's operational capacity is decreased by 75%, a 50% re-routing will reduce the average time to all destinations to a large extent compared with there is no re-routing. It is also noticed that even though the number of ships enter the system may increase because of re-routing, the average time still increases because of the increased highway and railway transportation.

Port Security Screening

Security Inspection Policies

The port security screening modeling is based on the situation that all ports are operated under normal condition without any crisis. The Department of Homeland Security's Automatic Targeting System assigned around 4% - 5% containers for security inspection [60] and it is presented by J. Emmanuel and R. Marquez that roughly between 2% and 5% of all the containers received in USA ports are scrutinized [61]. T. Altiok used 3%-10% as the inspection percentage to study the impact of inspection on containers' total port time by presenting 'what-if' scenarios. In this study, 5 'what-if' scenarios are simulated and analyzed. One scenario is chosen to be below the average inspection percentage. Two scenarios are chosen to be above the average inspection percentage.

- Scenario 5: 0.4% containers received by the US port will be inspected.
- Scenario 6: 5% containers received by the US port will be inspected.
- Scenario 7: 10% containers received by the US port will be inspected.
- Scenario 8: 15% containers received by the US port will be inspected.
- Scenario 9: 20% containers received by the US port will be inspected.

Re-Routing Strategies

Table 9 Simulation Results under Scenario 5, 6, 7, 8 and 9

Screening Percentage	Average Cost per Container ($)	Average Time per Container (Hours)	Number of Transported Container (TEU)
2% (Scenario 5)	511.17	82.18	118986.8
25% (Scenario 6)	513.16	82.21	118630.3
50% (Scenario 7)	513.85	82.36	118556.1
75% (Scenario 8)	515.14	82.44	118542.0
100% (Scenario 9)	515.15	82.87	117863.5

It can be summarized from Table 10 that increasing the percentage of containers to be inspected increases the average time each container stays in the transportation system. This increase in inspection percentage will also enhance the secure level of an import port. Based on the result of this study and quite goal of each port, the port managers can have their own choice in formulating the security policies.

CHAPTER V

CONCLUSIONS AND FUTURE RESEARCH

The result of this simulation study shows a good re-routing strategy under each specific crisis scenario. The simulation tool can be used to estimate the performance of a port at a macro level. The result of this study also shows re-routing is not always a good choice when there is a crisis. A certain percentage of reduction in port's operational capacity does not mean there should be a same re-routing percentage. This simulation model studies and analyzes the performances of a port under different security policies. An increase of the inspection percentage will not result in a big increase in the average cost and average waiting time at the port, but this increase in inspection percentage will enhance the secure level of an import port. Based on the result of this study, the port managers can have their own choice in formulating the security policies.

Ports are critical transfer nodes of a transportation network. At the same time, they are vulnerable to crisis conditions. The simulation tool developed in this study enables decision makers to prepare for possible crises at U.S. ports by providing a capability to analyze ways to adjust the sudden changes. The simulation model captures and presents the general behavior of complex port operation and land transportation interactions, both under normal conditions and under different user-defined crisis scenarios. This study demonstrates how simulation can be used to mitigate the impact of crisis condition. The simulation tool can be used to prepare port managers for disruptions through "what if" analyses. This view can also improve the effectiveness of strategic decisions made by ocean container carriers, logistics companies, federal emergency management agencies, and port operators.

Future enhancements to this simulation tool could include the integration of optimization methodologies. Instead of what-if analyses, stochastic optimization and heuristic optimization could be employed to find the “best” percentage of re-routing and inspection that minimizes the increase in cost and increase in lead time and congestion during crisis conditions. Additionally, the severity of the crisis can be quantified. For example, a function can be developed that estimates change in setup and operational times with respect to the change in the number of containers a port receives. However, further modeling and data collection would be required to expand this study.

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