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Systems Engineering Approach to Analyze and Model the Performance of Containerized Shipping and Its Interdependencies with the United States Critical Infrastructure

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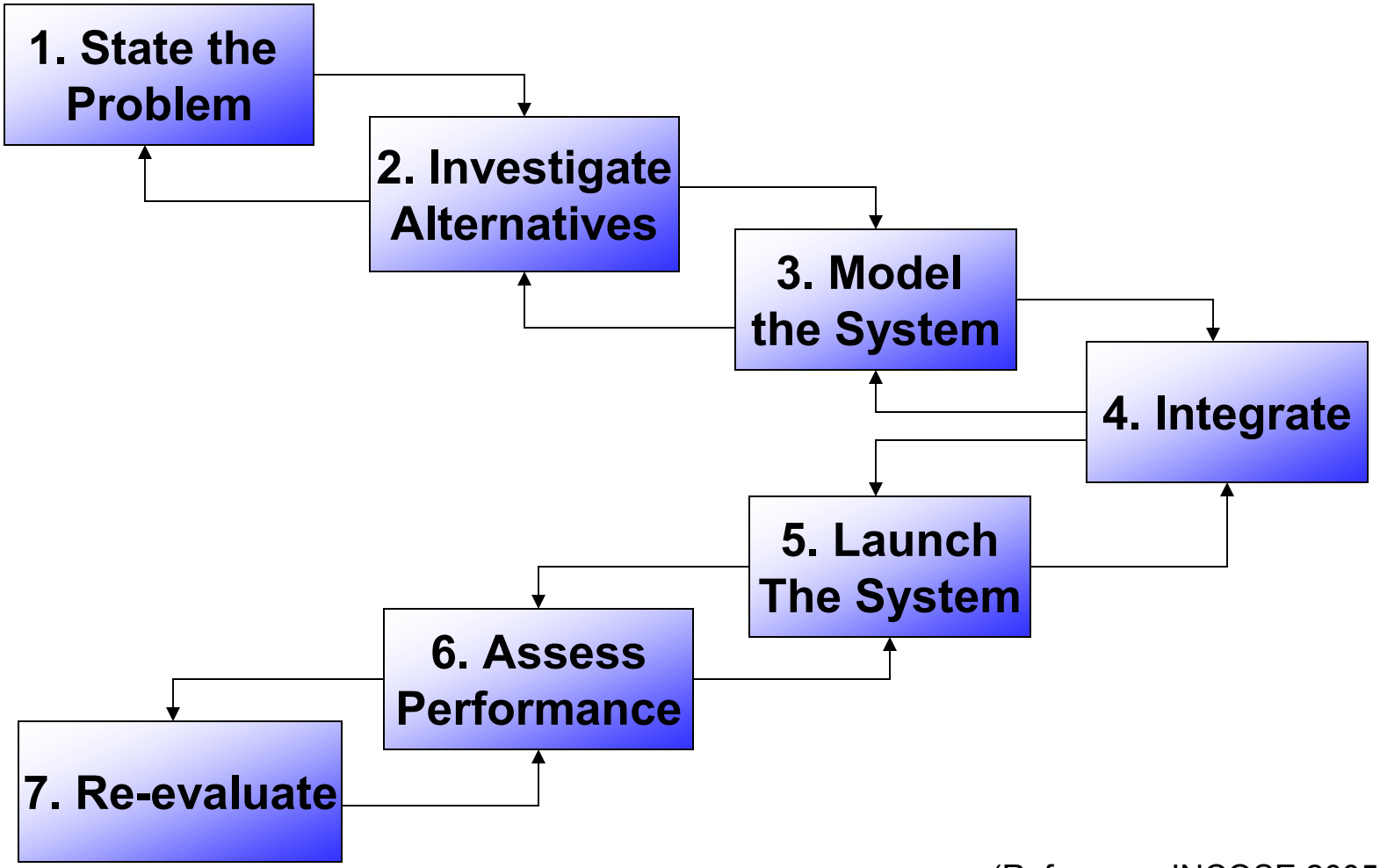
Objective

- This paper presents a systems engineering approach to the research, analysis, modeling, and simulation of containerized shipping performance and the interdependencies of containerized shipping with the complex United States infrastructure.
- Identifying, understanding, and analyzing the interdependencies among infrastructure systems has taken on increasing importance in the last few years.
- This research is for the benefit of the stakeholders and society.

Systems Engineering Process



(Reference: INCOSE 2005)

1. State the Problem

a. The problem is to understand and model the performance of containerized shipping and its interdependencies with the U.S. critical infrastructure.

b. Interdependencies are bidirectional.

c. This research encompasses physical interdependencies; defined to be when a commodity produces or is modified by one infrastructure (an output) is required by another infrastructure for it to operate (an input).

Public Law 107-56 Oct. 26, 2001

USA Patriot Act

Section 1016 - Critical Infrastructures Protection Act of 2001

Definition of Critical Infrastructure

Systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters.

Critical Infrastructures Protection Act of 2001 (cont.)

- Private business, government, and the national security apparatus increasingly depend on an interdependent network of critical physical and information infrastructures, including telecommunications, energy, financial services, water, and transportation sectors.
- This national effort requires extensive modeling and analytic capabilities for purposes of evaluating appropriate mechanisms to ensure the stability of these complex and interdependent systems.
- It is the policy of the US that any physical or virtual disruption of the operation of the critical infrastructures of the US be rare, brief, geographically limited in effect, manageable, and minimally detrimental to the economy, human and government service, and national security of the US.

Identifying the U.S. Critical Infrastructure

PDD-63 (May 1998)	Patriot Act (October 2001)	National Strategy for Homeland Security (July 2002)	National Plan for Research and Development in Support of Critical Infrastructure Protection (2004)
Telecommunications Banking and Finance Transportation Energy Water Systems Emergency Services	Telecommunications Financial Services Transportation Sectors Energy Water	Information and Telecommunications Banking and Finance Transportation Energy Water Public Health Chemical Food Agriculture Postal and Shipping Government Defense Industry	Telecommunications Banking and Finance Transportation Systems Energy Water Public Health and Healthcare Chemical Agriculture and Food Postal and Shipping Defense Industrial Base Emergency Services Information Technology
		Key Assets	Key Resources
		Historic Attractions National Monuments Icons Events	National Monuments and Icons Dams Government Facilities Nuclear Reactors Materials and Waste

GAO Homeland Security Testimony before Congress

Preliminary Observations of Cargo Containers

"A terrorist incident at a seaport, in addition to killing people and causing physical damage, could have serious economic consequences. In a 2002 simulation of a terrorist attack involving cargo containers, every seaport in the United States was shut down, resulting in a loss of $58 billion in revenue to the U.S. economy, including spoilage, loss of sales, and manufacturing slowdowns and halts in production."

Port Security Strategies and Requirements

The National Strategy for Homeland Security – 2002

- Pre-screen containers before they arrive in America,
- Develop technologies to track in-transit containers.

Maritime and Transportation Security Act (MTSA) of 2002

- US Facility and Vulnerability Assessment
- Vessel and Facility Security Plans
- Automated ID Systems (AIS)

The Container Security Initiative (CSI)

- CBP uses intelligence to screen information on 100% of cargo entering our seaports, and all cargo that presents a risk to our country is inspected using large x-ray and radiation detection equipment

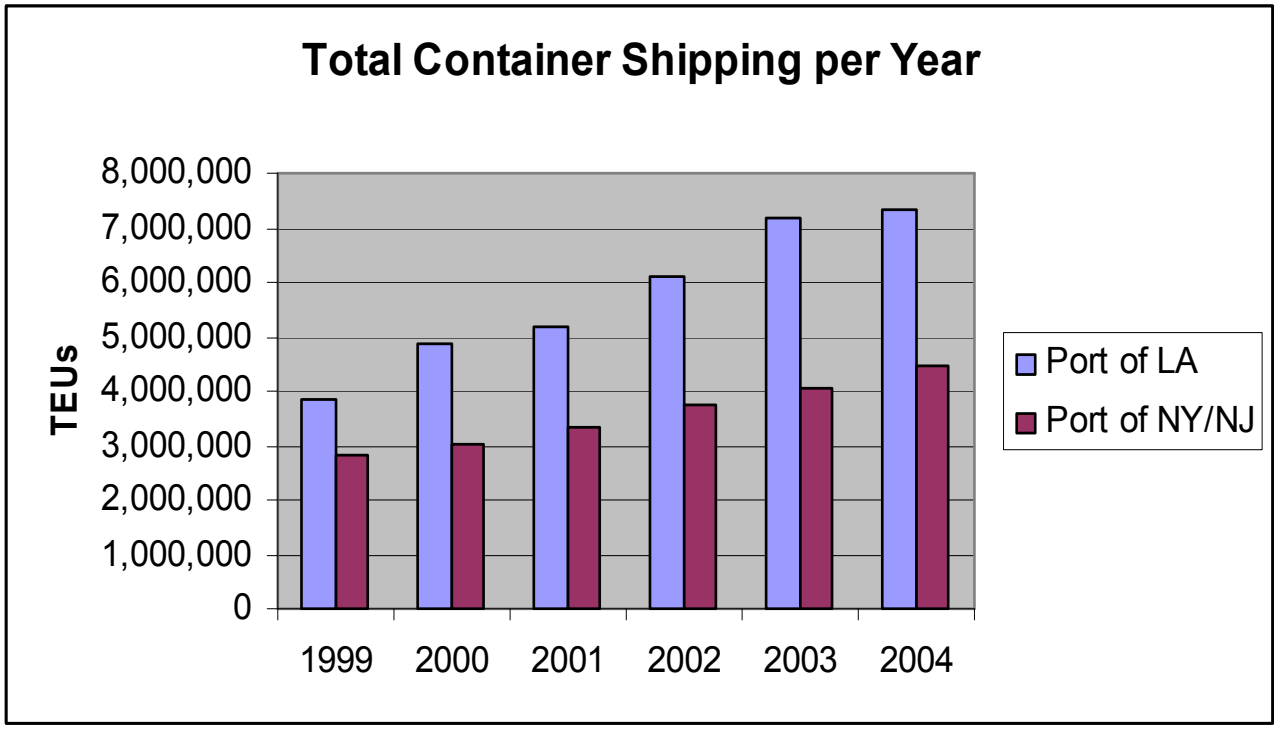
Customs-Trade Partnership Against Terrorism (C-TPAT)

- Cooperative program

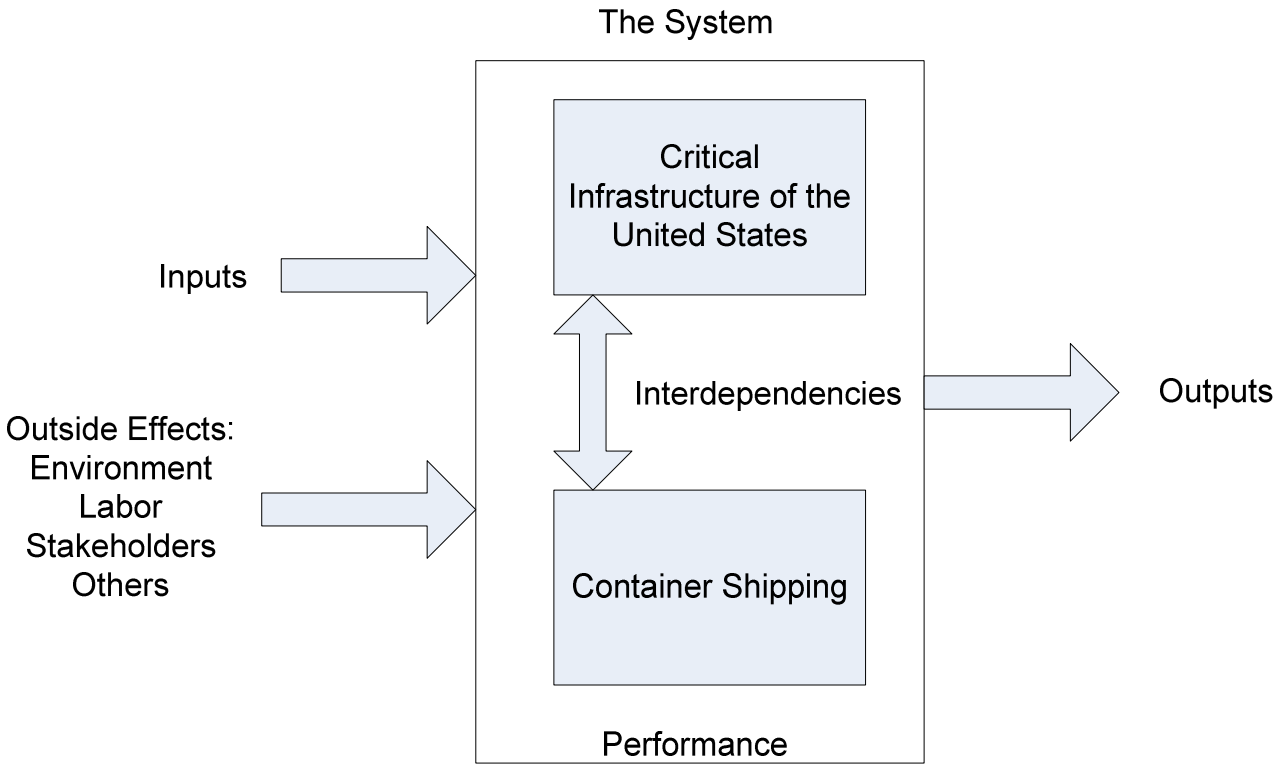
International Ship and Port Security Code

- Risk management concept with requirements for ships and ports

Containerized Shipping has been Continuously Increasing across the Ports of the U.S.

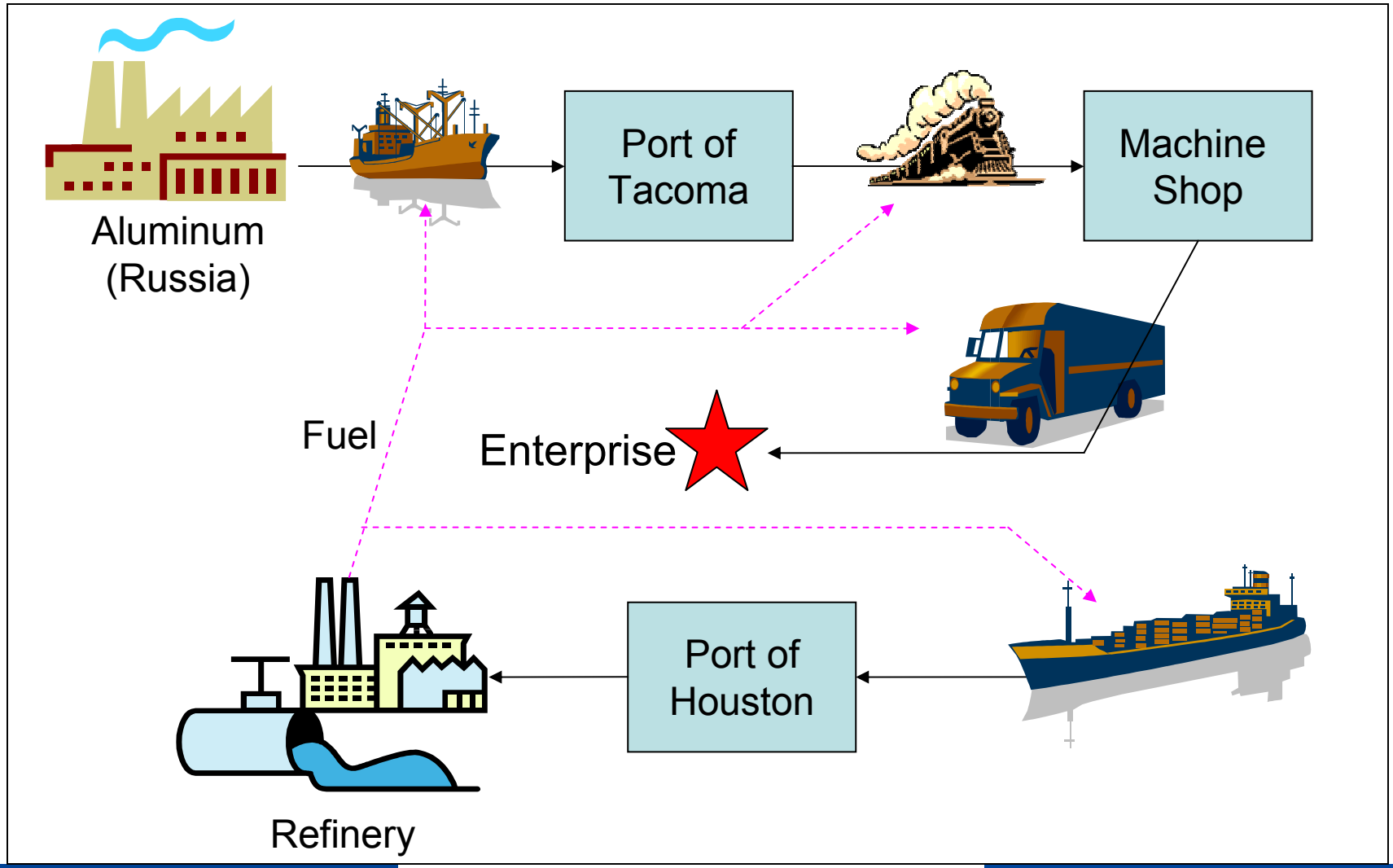


Top Level System Block Diagram



2. Investigate the Alternatives

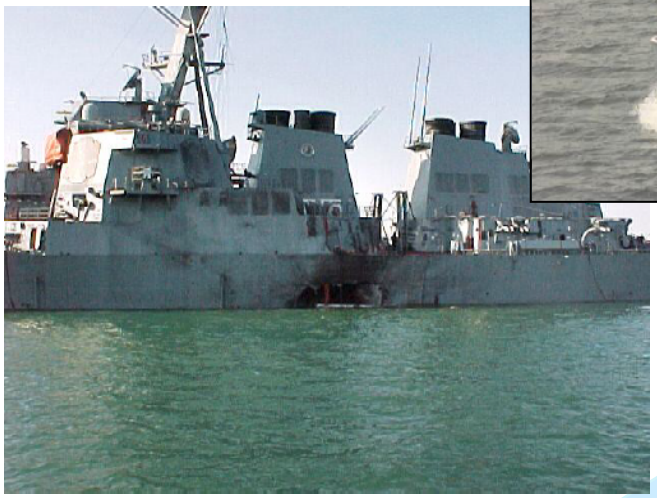
Infrastructure - Example of Interdependencies



Items which Impact Container Shipping Performance

- Threat Level – MARSEC Two, MARSEC Three
- Weather – Hurricane, fog, rain
- Accidents
- Security/Technology
- Available Workers

Maritime Security Conditions



MARSEC Three
"Incident Imminent"

Physical Control

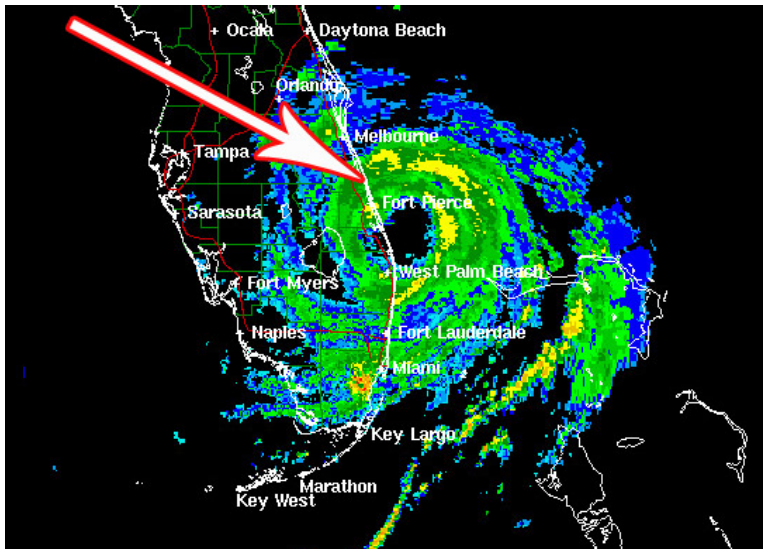
MARSEC Two
"Heightened Risk"

Targeted Control

MARSEC One
"New Normalcy"

Intel & Partnering
Harbor Patrol
Air Surveillance

Weather Effects



Effects due to Accidents

Environmental Accidents

On Friday, November 26, 2004 approximately 265,000 gallons of oil spilled into the Delaware River from the *T/S Athos.* After a three-day shutdown of the Port of Philadelphia immediately after the spill, commercial vessels were allowed back into the port, but must undergo a decontamination process prior to leaving the affected area.

Technology

Baltimore's Seagirt Marine Terminal's seven 20-story high-speed computerized cranes are among the most productive in the industry, averaging 33 to 35 containers an hour. Three of the cranes feature the latest dual-hoist systems, which lift two containers simultaneously.

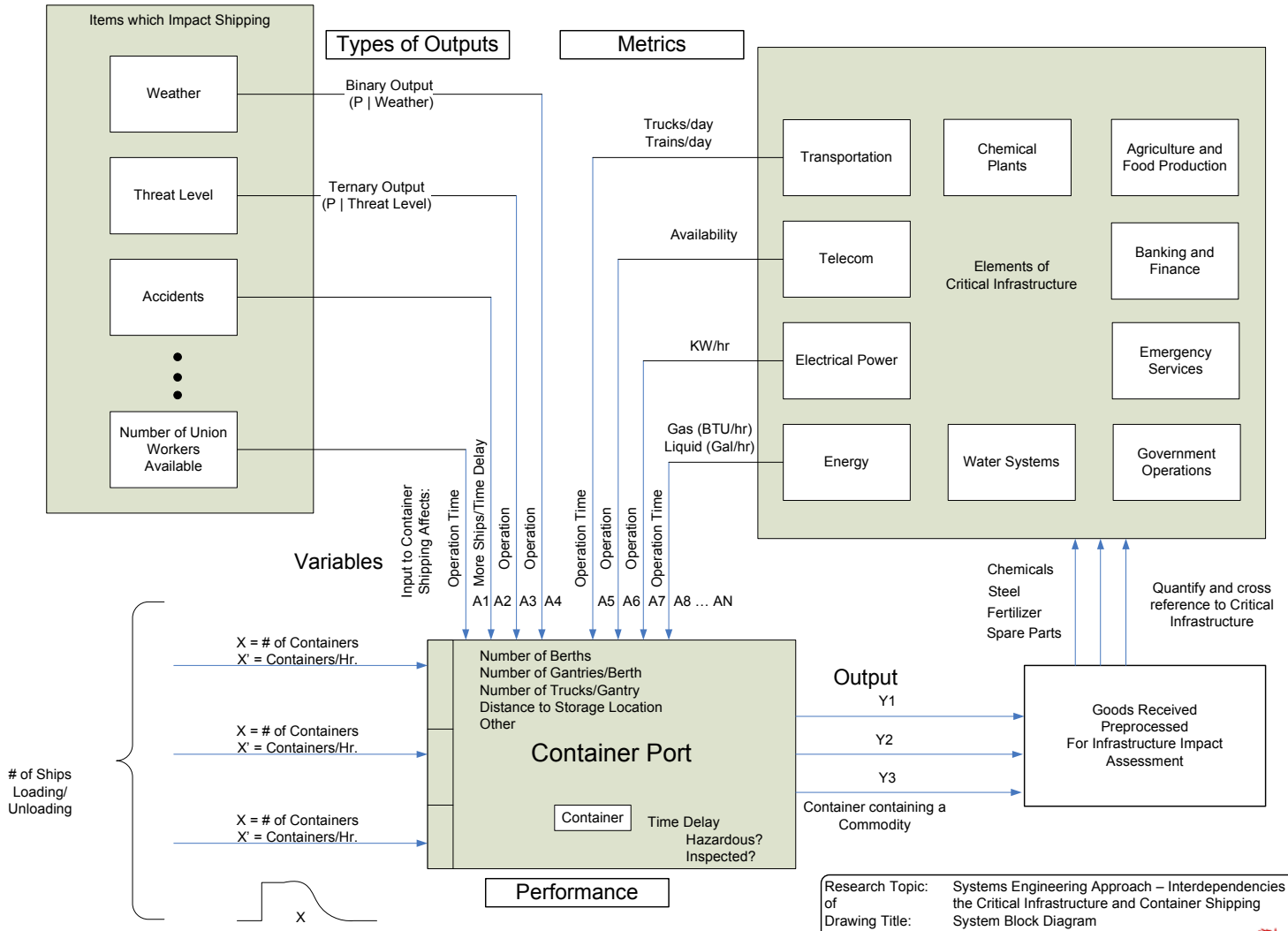
The Portal VACIS® system provides gamma ray images of intermodal cargo containers, semi trailers, and delivery vehicles.

Labor Availability

- We are experiencing very **significant disruptions to both import and export** ocean freight. The shutdown has effectively stopped virtually all activity. Even if back-to-work legislation is introduced quickly, it will be some time before the backlog of vessels and containers can be cleared. Port and Steamship Line officials noted this morning that **each day the shutdown continues, at least four to five days** will be added to the delivery times of Import containers.West Coast Shutdown Still Unresolved Issue 368, October 2, 2002 - 11:30 EDT
  The labor dispute disrupting U.S. West Coast port activity continues, with the negotiations between the two sides still at an impasse as of this morning. A scheduled meeting today between the Pacific Maritime Association and the ILWU was cancelled this morning.

  As of yesterday, President Bush was urging both sides to use mediation in an effort to reach a negotiated settlement. However, with the unwillingness of the two sides to meet today, major USA importers are now demanding President Bush to take immediate action. The Westcoast Waterfront Coalition, in a letter today, is imploring the President to "take whatever steps are necessary to re-open the nation's west coast ports".
- WASHINGTON, Oct. 8 - President Bush intervened in the **11-day shutdown of 29 West Coast ports today**, successfully seeking a court order today to halt the employers' lockout of 10,500 longshoremen, because the operation of the ports is "**vital to our economy and to our military**."

System Block Diagram



Research Topic:	Systems Engineering Approach – Interdependencies
of	the Critical Infrastructure and Container Shipping
Drawing Title:	System Block Diagram
Author:	Susan Vandiver
Date:	2/20/05©

3. Model the System

The system model will integrate the following two models:

1. Model 1 – The time for a container to transfer from arrival at the port domain to departure from the container port a) under normal operating conditions and b) under not-normal conditions due to outside influences such as changes in MARSEC level, weather, technology, stakeholder decisions and dependence on the commodities provided by the US critical infrastructure.
2. Model 2 – The dependence of the critical infrastructure on the commodity provided by container shipping.

Developing Model 1

The performance of container shipping is defined as the amount of time, T, such that

$$T = t_1 + t_2 + t_3$$

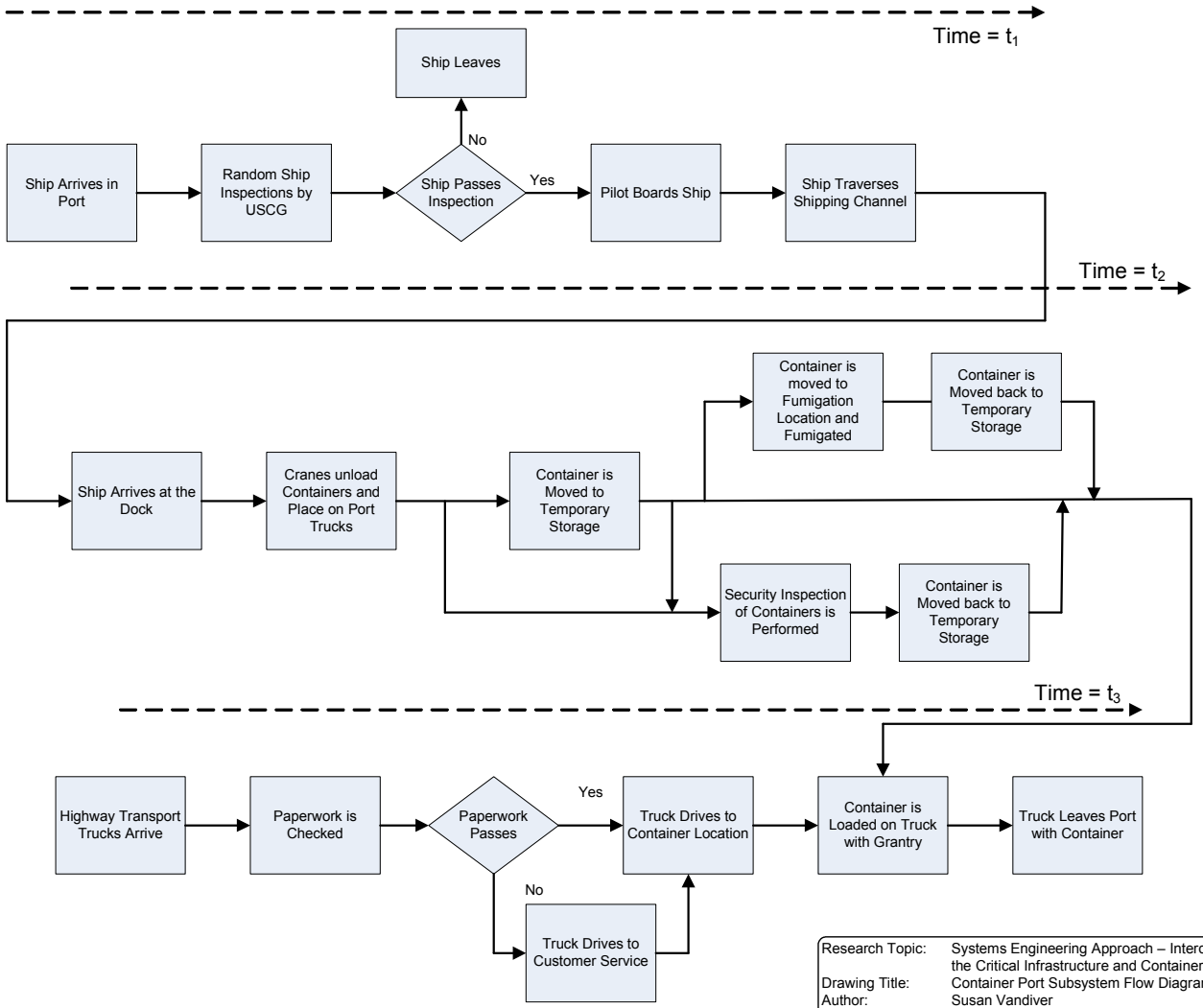
where:

t_1 = the time the ship waits in the port open sea area until authorized, moved, and docked at the port

t_2 = the time for the unloading process in which the container is unloaded and moved to a temporary storage location

t_3 = the time for the container to move from storage out of the port by truck or rail.

Flow Diagram of Port Operation



Research Topic:	Systems Engineering Approach – Interdependencies of the Critical Infrastructure and Container Shipping
Drawing Title:	Container Port Subsystem Flow Diagram
Author:	Susan Vandiver
Date:	5/12/05©

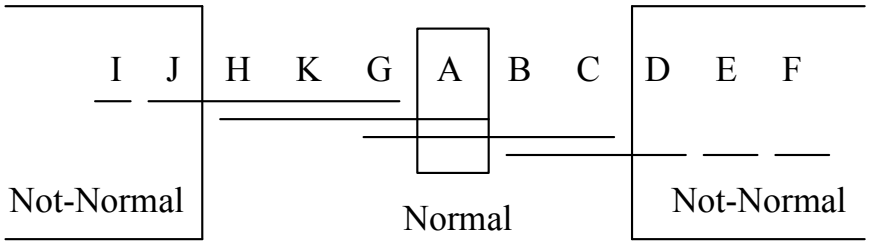
t_1: Time from Arrival at Sea to the Container Dock

Data Analysis for t_1

Table 1 . Number of Daily Ship Arrival Categories

Hours Closed	Category	When the Day before Is
0 – 4	A	
5 – 8	B	
9 – 12	C	
13 – 16	D	
17 – 20	E	
21 – 24	F	
	G	C
	H	D
	I	E
	J	F
	K	The 2nd day after

Using this categorization, a Duncan's Range Test (with an alpha of 5%) provides the following results.



During normal operating conditions the channel is open

Plots for Poisson Distribution of Ship Arrivals – t_1

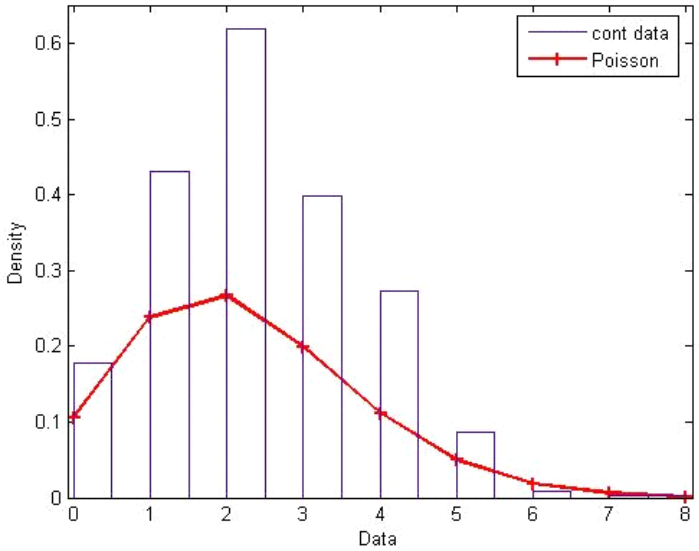


Figure 7. Histogram for the Daily Number of Container Ship Arrivals

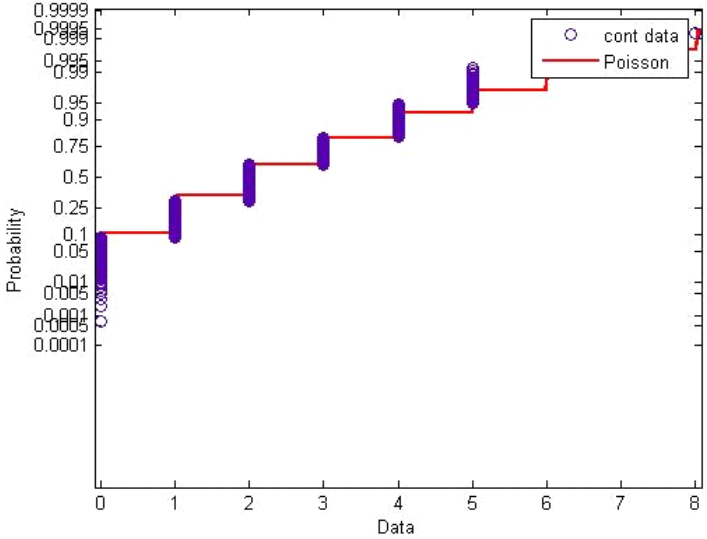


Figure 8. Poisson Probability Plot of the Daily Number of Container Ship Arrivals

Normal Distribution for Time to Move to the Dock Results for t_1

The time for the ship to move from the sea to the dock is determined to be a normal distribution with parameters of mean = μ and variance = σ^2. It is compared to some other distributions on a probability graph in Figure 9.

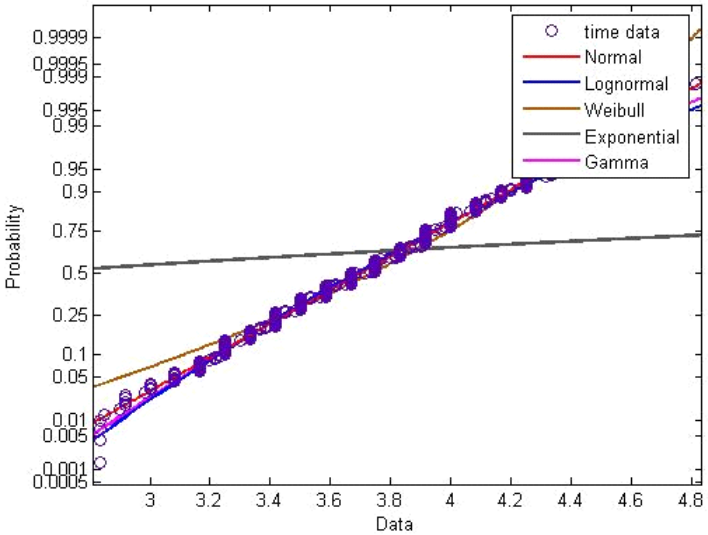
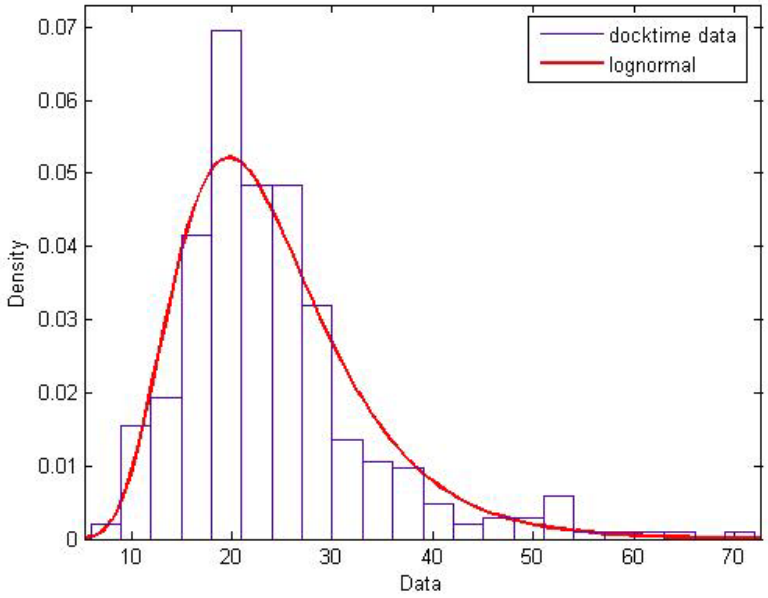


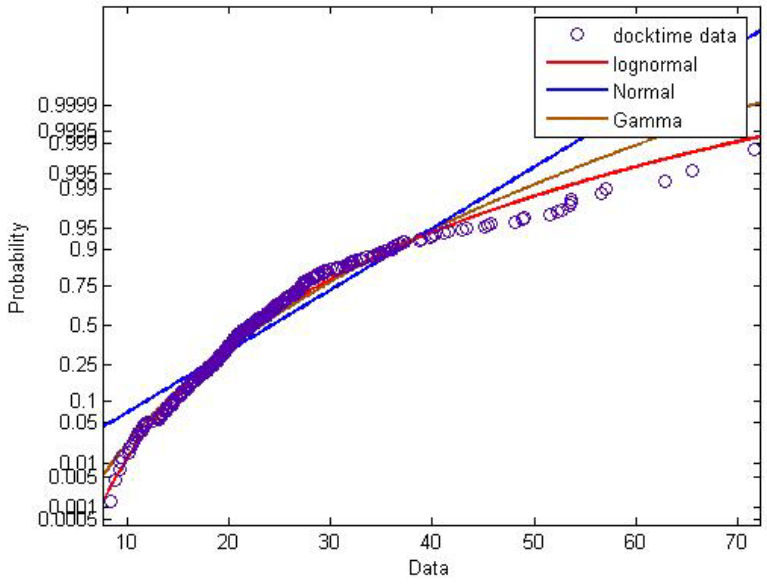
Figure 9. Probability Plot of the Time for a Ship to Move from the Sea to the Dock

t_2: Time to Unload the Container, Move to Storage and Wait for Intermodal Truck Transport

Ship Time in Dock (Time to Unload and Load)

The Time in Dock (TID) is determined to be a lognormal distribution as shown in the following figures.





Step-Wise Regression of Time in Dock (TID)

$$y = -7.22517 + .02705x_1 - .00000554x_1^{\,2} + .00998x_3^{\,2}$$
$$-15.79114x_4 + 1.83433x_4^{\,2} + 33.02215x_5$$

y	Time in Dock
x_1	Number of Containers (Cont)
x_2	Dock Number (DockRO)
x_3	Hours Channel Closed (TotHcl)
x_4	Cranes (RRatio)
x_5	Shipping Company (Desig)

Regression yielded an R^2 of 67%.

t_3: The Time for the Container to Move from Storage out of the Port

Developing Model 2

Identify the commodities which are important to the infrastructure that are imported in containers.

Imports of Goods by End-Use Category and Commodity

Commodity	$M Ytd	% Increase
• Foods, feeds, and beverages		
– (1) Fish and shell fish	6,787	4.48
– (2) Meat products	4,175	6.13
– (9) Green coffee	1,482	29.22
• Industrial Supplies and materials		
– (5) Industrial supplies, other	11,617	11.98
– (7) Chemicals-organic	9,706	11.89
– (14) Chemicals-fertilizers	4,508	27.24
• Capital goods, except automotive		
– (2) Telecommunication equipment	20,801	17.25
– (3) Computers	17,160	19.48
• Consumer goods		
– (1) Pharmaceutical preparations	32,600	3.2

(US Census Foreign Trade Bureau – Exhibit 8)

4 & 5. Systems Integration and Launch

- The two models are to be integrated into a system performance model.
- The model is then launched in a graphical visual simulation.

6. Assess System Performance

- The system model will be evaluated for accuracy, tolerance intervals, residuals, and coefficients of determination (R and Cp values).
- The system model will be validated with the acquired data through demonstration.
  - The demonstration will show the changes in system performance due to interdependencies and external events.

7. System Re-evaluation

- The systems engineering process and model development will be documented such that it may be updated when additional data is available.

Conclusions

- The research is currently in the data analysis phase.
- The final model determination will be based upon the data analysis.
- The outcome of the research will be a graphical simulation which illustrates the performance of containerized shipping with the interdependencies of the U.S. critical infrastructure.
- This research is for the benefit of society and protection of the United States critical infrastructure.

Future Research

- This research is paving the way for significant future research.
  - Container shipping viewed as a service provider for exporting.
  - Application of the system block diagram to the other subsystems of the infrastructure to analyze its interdependencies with the critical infrastructure.
  - Other categories of interdependencies, i.e., logical, geographical, and cyber.