MISSOURI S&T

CENTER FOR TRANSPORTATION INFRASTRUCTURE AND SAFETY

NUTC
R356

Feasibility Analysis of System Dynamics for Inland Maritime Logistics

by

Long, Suzanna
Nachtmann, Heather
Oztanriseven, Furkan
Pérez-Lespier, Lizzette

A National University Transportation Center
at Missouri University of Science and Technology

Disclaimer

Technical Report Documentation Page

1. Report No.
NUTC R356

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Feasibility Analysis of System Dynamics for Inland Maritime Logistics

5. Report Date
February 2014

6. Performing Organization Code

7. Author/s
Suzanna Long

8. Performing Organization Report No.
Project # 00043194

9. Performing Organization Name and Address
Center for Transportation Infrastructure and Safety/NUTC program
Missouri University of Science and Technology
220 Engineering Research Lab
Rolla, MO 65409

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DTRT06-G-0014

12. Sponsoring Organization Name and Address
U.S. Department of Transportation
Research and Innovative Technology Administration
1200 New Jersey Avenue, SE
Washington, DC 20590

13. Type of Report and Period Covered
Final

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract
In the last decades, a number of factors have re-shaped the shipping industry, including the growth of international trade, the emergence of new markets, and the development of multimodal supply chains. This has led maritime transportation system, which includes ocean and coastal routes, and inland waterways, along with other modes of transportation such as, railways, roads, and air-freight to become a critical part of the global supply chains and freight transportation systems.   Due to the complexity of such a system: a growing number of systems that are interconnected and working together to achieve a purpose; a system dynamics approach is used in the literature to simulate maritime transportation system and its integration within the supply chain, into the U.S. surface transportation system modes of truck and rail. In the initial phase of this research, an integrative literature review of applications of system dynamics in the maritime transportation system was conducted. The results of this early research provides an overview of system dynamics model applicability in the maritime transportation system and can prosper future research in the field, such as developing a systems dynamic framework model to aid with decision-making strategies that will lead to the improvement of the efficiency of the system.

17. Key Words
Inland Hub; Multimodal Transportation System; System Dynamics; Maritime Logistics

18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classification (of this report)
unclassified

20. Security Classification (of this page)
unclassified

21. No. Of Pages
43

22. Price

Form DOT F 1700.7 (8-72)

Feasibility Analysis of System Dynamics for Inland Maritime Logistics

Long, Suzanna. Nachtmann, Heather. Oztanriseven, Furkan. Pérez-Lespier, Lizzette.

ABSTRACT

In the last decades, a number of factors have re-shaped the shipping industry, including the growth of international trade, the emergence of new markets, and the development of multimodal supply chains. This has led maritime transportation system, which includes ocean and coastal routes, and inland waterways, along with other modes of transportation such as, railways, roads, and air-freight to become a critical part of the global supply chains and freight transportation systems. Due to the complexity of such a system: a growing number of systems that are interconnected and working together to achieve a purpose; a system dynamics approach is used in the literature to simulate maritime transportation system and its integration within the supply chain, into the U.S. surface transportation system modes of truck and rail. In the initial phase of this research, an integrative literature review of applications of system dynamics in the maritime transportation system was conducted. The results of this early research provides an overview of system dynamics model applicability in the maritime transportation system and can prosper future research in the field, such as developing a systems dynamic framework model to aid with decision-making strategies that will lead to the improvement of the efficiency of the system.

TABLE OF CONTENTS

Page

SECTION

LIST OF ILLUSTRATIONS

Figures Page

LIST OF TABLES

ABBREVIATION LIST

MTS – Maritime Transportation System

NUTC – National University Transportation Center

SD – System Dynamics

USACE - U.S. Army Corps of Engineers

U.S. DOT – U.S. Department of Transportation

1. INTRODUCTION

The research in this report focuses on the study and comprehension of a vital part of the global supply chain and freight transportation system: the maritime transportation system (MTS). Because of MTS's logistic network, which is essential to a sustainable growth of local, regional, and national economies, it is vital to understand this transportation mode and its system in order to be able to suggest decision-making strategies that will improve MTS's performance over time being able to enhance customer's and stakeholders' satisfaction.

The ability of North American ports to efficiently manage the emerging cargo volumes that currently take place and those forecasted is really important, since it has a major effect on the trading capabilities and economies of the region as a whole. America's ports are a gateway to the world and a significant component on the nation's economic health. Some issues identified by the U.S. DOT that lead to inefficiency in the MTS, include: overcapacity and congestion due to lack of land available for expansion, congested local markets, and increasing costs due to energy, safety, and environmental issues (U.S. DOT, 2006). The significant number of issues and the economic importance of finding solutions to these problems illustrate the need for this research, which is aimed at transportation infrastructure and modal connectivity. With the foundation of well-positioned, super logistics terminals, America can provide an excellent mechanism for addressing issues affecting the optimality of maritime transportation infrastructures needed to support the country's future and help maintain competitive advantage in a global economy.

North America's transportation infrastructure is heavily dependent on multimodal connectivity. As such, the efficient transition of goods between modes is very important to the flow of freight. Inefficiencies at the connectivity points can severely impact the overall freight management process hence need to be addressed. This research explored the feasibility of using systems dynamics methodology to forge vital multimodal alliances as part of the US Inland Maritime logistics operations. The major research tasks performed include:

1. An Integrated Literature Review: Multiple levels of literature review were conducted and common themed studies and model attributes were identified and categorized. Also, this review examined the feasibility of studying the inland maritime logistics system within a system dynamics environment and identified necessary data sources and categorizations that would aid in the representation of the maritime logistics system with a system dynamics modeling methodology.

2. A Logistics System Model Development: Designed a preliminary model, which examined the efficacy of utilizing system dynamics to study the inland maritime logistics and multimodality impacts.

1.1. MOTIVATION OF RESEARCH

The Nation's "marine highways" are an important component of the nation's transportation system, which carry one-twelfth of the total national freight volume (Stern, 2013). The ability of North American ports to efficiently handle growing cargo volumes has a major impact on the trading capabilities and economies of the region as a whole. U.S. ports handle $5.5 billion worth of goods every day and 2.5 billion tons of cargo every year. This volume is expected to double in the next fifteen years (American Association of Port Authorities, 2007). Therefore, an efficient and effective maritime transportation system can have widespread economic and societal impacts. Thus, the aim of this research is to explore the feasibility of using SD to study and support an efficient MTS.

Developed by Jay Forrester in the late 1950s, SD is "a methodology for studying and managing complex feedback systems." Forrester (1961) describes an information feedback system existing whenever "…the environment leads to a decision that results in action which affects the environment and thereby influences future decisions" (p. 14). Moving away from the conventional approach of viewing system performance and behavior as merely the result of events and their causes, SD emphasizes the interactions between components of a system (Kirkwood, 1998). As an application of systems thinking, SD seeks to identify the underlying structure of a system to gain insight into patterns of behavior, focusing on how components of a system interact and understanding the roles each component plays rather than concentrating on specific events. This allows stakeholders to design policies that seek to eliminate unwanted patterns of behavior through modifying the underlying system structure, rather attempting to mitigate the events themselves, which can lead to a host of other unintended consequences (Kirkwood, 1998). We anticipate that this system structure exists in the maritime logistics system.

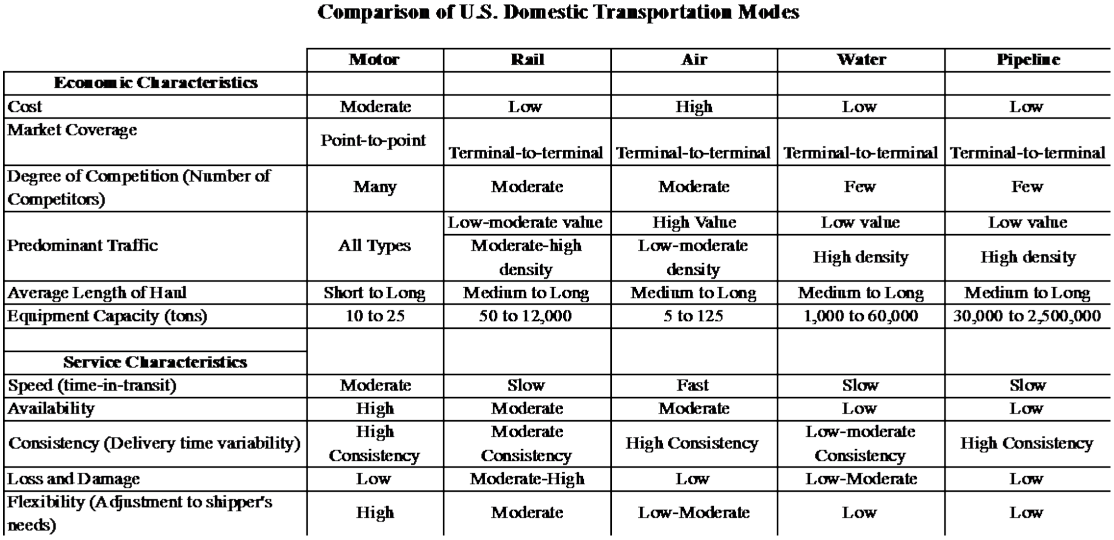
This literature review is the result of a pilot study designed to evaluate methodologies and mechanisms for creating a long-term, sustainable MTS. This work seeks to advance the SD body of knowledge in logistics infrastructure design and implementation. Existing models have been criticized for maintaining the status quo; new approaches to infrastructure development are considered essential in order for the U.S. to remain competitive in the global economy (Urban Land Institute, 2008).

1.2. MARITIME TRANSPORTATION SYSTEM OVERVIEW

With international trade becoming a big part of the world's economic activity, efficient freight transportation systems are becoming even more significant in any supply chain's success. A transportation system moves goods from one location to another as they move from the very beginning of the supply chain to the downstream customer (Chopra, 2007). On average 90 per cent of global goods are transported via international shipping to people and communities all over the world (IMO, 2013). Maritime transportation is the most efficient and cost-effective method of international transportation of freight, hence providing a reliable, low-cost mean of transportation. This is because of maritime's transportation unparalleled physical capacity and ability to carry freight over long distances and at low costs. Therefore, an efficient maritime transportation system plays an essential role when trying to compete in global markets in the 21st century.

Five modes of transportation, each with advantages and disadvantages, carry freight in the U.S.: water, air, rail, road and pipeline (Table 1.1). But it is maritime transport the one that remains the dominant mode for international trade because of its bulk transport of commodities and containerized-bulk cargo, and also because it has transformed its technologies, national registries, and labor resources over the past decades to serve the demands of globalization (Corbett & Winebrake, 2008). Millions of people all around the globe rely on maritime transportation to deliver goods and services. Quoting Nijkamp, Vleugel, Maggi, and Masser (1994), maritime transportation has served as the 'blood circulation' of the global economy through linking marine corridors into complex shipping networks (especially freight) and made different regions around the world more proximate to each other (Hall & Jacobs, 2010). For that reason, maritime transportation is recognized as an enabler of globalization and being a vital part of the global supply chain.

Table 1.1: Comparison of U.S. Domestic Transportation Modes (Stock, James and Lambert, Douglas, 2001)



Comparison of U.S. Domestic Transportation Modes

	Motor	Rail	Air	Water	Pipeline
Economic Characteristics					
Cost	Moderate	Low	High	Low	Low
Market Coverage	Point-to-point	Terminal-to-terminal	Terminal-to-terminal	Terminal-to-terminal	Terminal-to-terminal
Degree of Competition (Number of Competitors)	Many	Moderate	Moderate	Few	Few
Predominant Traffic	All Types	Low-moderate value Moderate-high density	High Value Low-moderate density	Low value High density	Low value High density
Average Length of Haul	Short to Long	Medium to Long	Medium to Long	Medium to Long	Medium to Long
Equipment Capacity (tons)	10 to 25	50 to 12,000	5 to 125	1,000 to 60,000	30,000 to 2,500,000
Service Characteristics					
Speed (time-in-transit)	Moderate	Slow	Fast	Slow	Slow
Availability	High	Moderate	Moderate	Low	Low
Consistency (Delivery time variability)	High Consistency	Moderate Consistency	High Consistency	Low-moderate Consistency	High Consistency
Loss and Damage	Low	Moderate-High	Low	Low-Moderate	Low
Flexibility (Adjustment to shipper's needs)	High	Moderate	Low-Moderate	Low	Low

Historical patterns show how a nation's economic strength and competitiveness depend on an efficient, sustainable and secure freight transportation system. More than 13 billion tons of freight, valued at $11.8 trillion, were transported nearly 3.5 trillion ton-miles in the United States during 2007, according to preliminary estimates from the 2007 Commodity Flow Survey (CFS) (Margreta et al., 2009). That continuous economic globalization, the growing demand for speed-to-market product delivery, and need to manage global supply chains more effectively, has led to the sustained increase in demand towards efficient transportation systems. For that same reason, the Marine Highway Program works relentlessly to incorporate these waterways into the greater U.S. transportation system, especially where marine transportation services are the most efficient, effective, and sustainable transportation option (Maritime Administration: U.S. DOT, 2013). In today's globalized world, multimodal transportation forms the backbone of world trade. Therefore, as the demand for MTS grows and becomes more significant to logistics and efficient supply chain, there is need of heightening the significance of multimodal transportation systems, understanding its elements and how to manage them effectively. Multimodal transportation system refers to the modal coordination or integrated use of two or more modes of transportation for delivering freight from origin to destination in a seamlessly linked and efficiently coordinated flow. Multimodality has grown considerably in the last decades making it an essential constituent of the whole global distribution process. Currently, the Nation's Marine Highway System entails over 29,000 nautical miles of navigable waterways including rivers, bays, channels, the Great Lakes, the Saint Lawrence Seaway System, coastal, and open-ocean routes (U.S. DOT, 2013). Figure 1.1 shows U.S.'s Marine Highway Routes.

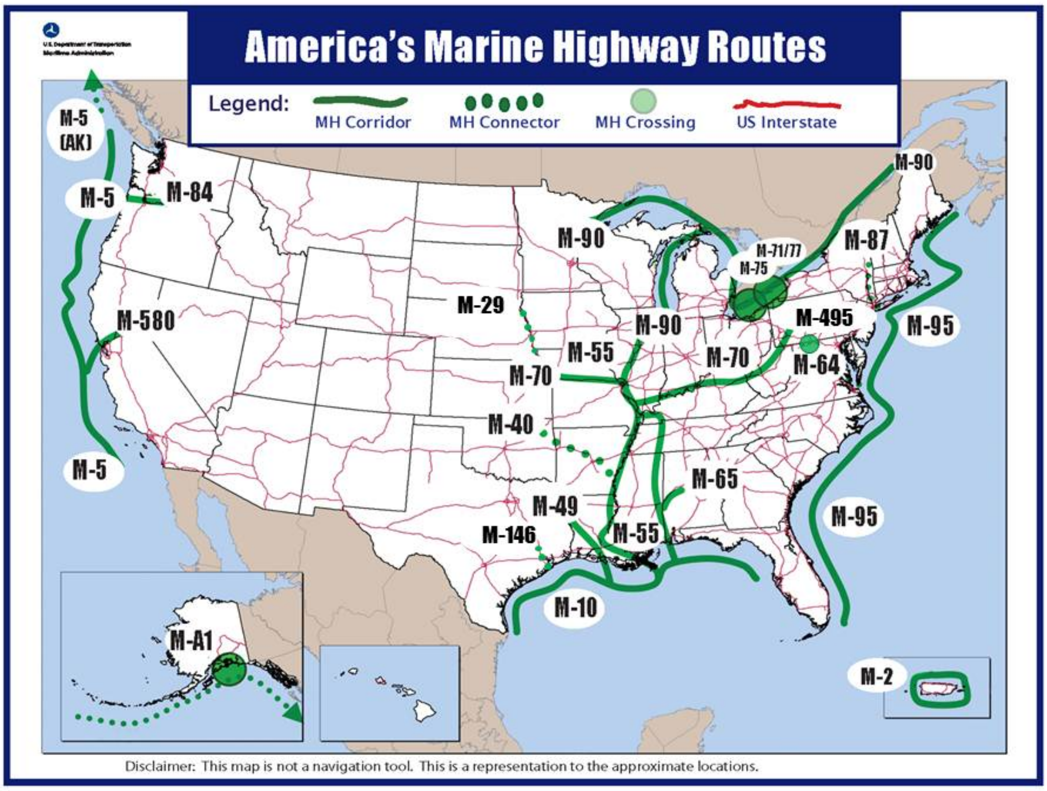


Figure 1.1: U.S.'s Marine Highway Route: Corridors, Connectors and Crossings (Maritime Administration: U.S. DOT, 2013).

Also, the Marine Highway system incorporates the 21 existing all-water Marine Highway Routes that serve as extensions of the surface transportation system. Marine Highway Routes include three categories, called corridors, connectors, and crossings. The 11 Marine Highway corridors are long, multi-state routes that parallel major national highways. The 5 Marine Highway connectors represent those shorter routes that serve as feeders to the larger corridors, and the 3 Marine Highway crossings are those short routes that transit harbors or waterways and offer alternatives to much longer or less convenient land routes between points. The use of these waterways has the potential to provide other benefits such as: the full integration of marine highway vessels and ports into the surface transportation system to ensure increased system resiliency, and a reliable, regularly scheduled, competitive, and sustainable service for shipping.

The U.S. Maritime Administration, on their 2009 report, explains how every year Americans lose 3.7 billion hours and 2.3 billion gallons of fuel just by sitting in traffic jams (U.S. Maritime Administration, 2009). Serious capacity challenges and hence congestion are already existent in today's freight transportation system's flow and are foreseen to be an even greater challenge in the future too. The Department of Transportation's "Freight Analysis Framework" has forecasted a 70% increase in freight traffic by 2020 (U.S. DTOP, 2002). Figure 1.2 looks at the DOT's 2020 projections. The projections not only show that there will be more congestion in the major metropolitan areas, but in the smaller markets as well. Such drastic growth will result in the taxing of the capabilities of all domestic modes of transport, since time, age, wear and tear will reduce their reliability and their efficiency. Therefore, by increasing the use of marine transportation on the commercially navigable waterways can offer relief to landside corridors that suffer from traffic congestion, excessive air emissions or other environmental concerns and challenges.

The U.S. maritime transportation system has managed to accommodate the rising levels of trade in the last couple of years. However, this has had its repercussions and has strained U.S.'s waterways, ports and key corridors. The MTS was already showing its age, since the average age of the 192 commercially active locks in the U.S. exceed 50 years old (U.S. House of Representatives, 2012), and due to the strenuous use, it's deteriorating quickly. Fifty-seven percent of U.S.A's inland system is more than 50 years old, and 37 percent of that system is more than 70 years old. It is literally falling apart and the MTS is falling behind. MTS is critical to the national economy and therefore, action need to be taken upon since this entire aging in the infrastructure and lack of investments and maintenance, ultimately affects the reliability of the system as a whole. Without some rehabilitation and rebuilding, we can expect, to pay more each year for an increasingly unreliable system. Investments in maintenance and major rehabilitations, with some capacity and modernization improvements are needed in the maritime transportation system in order to maintain its reliability and efficiency when it comes to transporting goods and for U.S.A to keep competing in global markets.

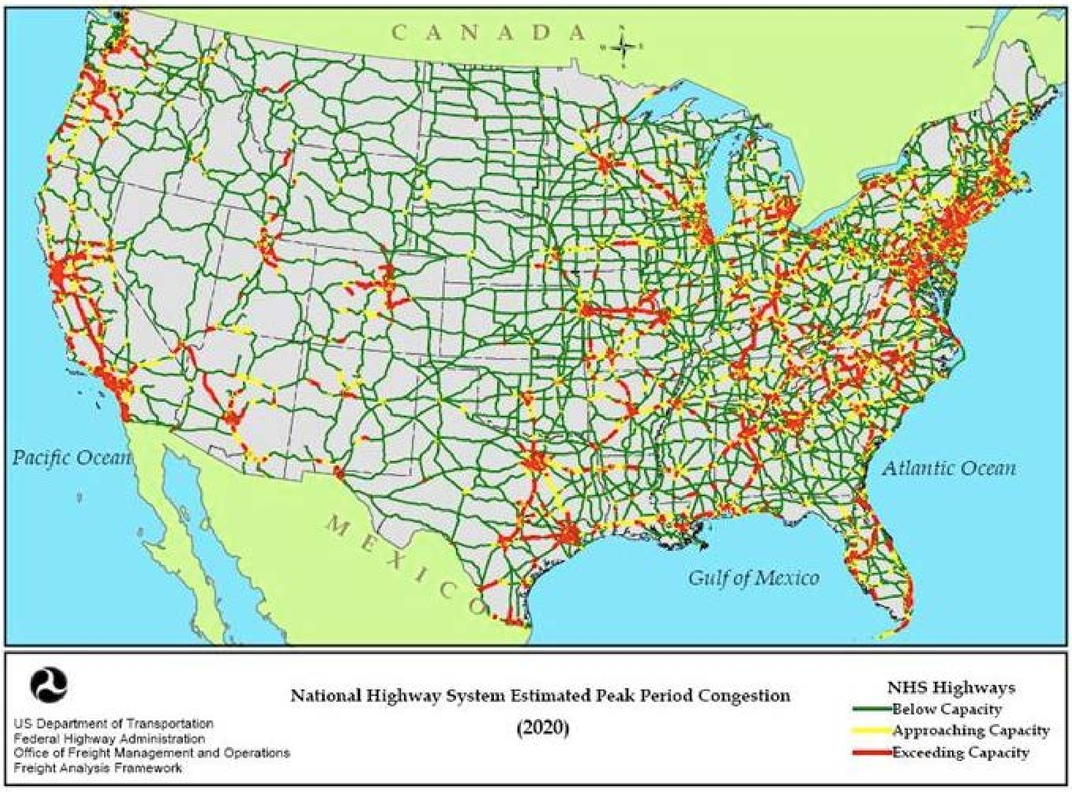


Figure 1.2: National Highway System Estimated Peak Period Congestion in 2020 (U.S. DTOP, 2002).

1.3. SYSTEM DYNAMICS IN MTS

System Dynamics (SD) simulation is a methodology for analyzing complex systems and problems with the help of computer modeling and simulation software. In order for SD to be effective, a deep look at the possible interactions between the subsystems taking part in a broader system needs to take place to create a better understanding of that big picture. Unlike other traditional analysis methods, SD aims to enhance that understanding of a system and the relationships between different system components.

The interest of this report was to find a method that would maximize freight service by addressing obstacles preventing optimal transportation infrastructure required, to compete in today’s global economy. Therefore, a SD model was built to measure the total throughput of the system, so the impact on all modes of transportation system and towards the MTS when addressing the issues of capacity shortage and congestion in the maritime system, could be seen. By understanding the different alternatives and scenarios one would be able to determine what is the best alternative in order to maximize freight service (throughput).

Islam and Olsen (2013) explore the importance of water mode transport system's performance from a supply chain perspective. They discuss how capacity shortages and its consequences are one of the limiting problems that many seaports of the world currently face. Figure 1.3 breaks down the consequences of capacity shortages that have led the maritime transport industry to compel and consider the building of new facilities and infrastructure expansions, along with the improvement of multimodal connectivity and transshipments. The figure 1.3 figuratively explains how capacity shortages create congestion problems, and congestion problems has its consequences as well such as, time delays, which result in cost increases. The capacity shortage problem, along with the ones it creates, need to be addressed in order for maritime transport system terminal to work efficiently and minimize its impact towards inefficiencies of the whole supply chain (other modes) and port service cost increase.

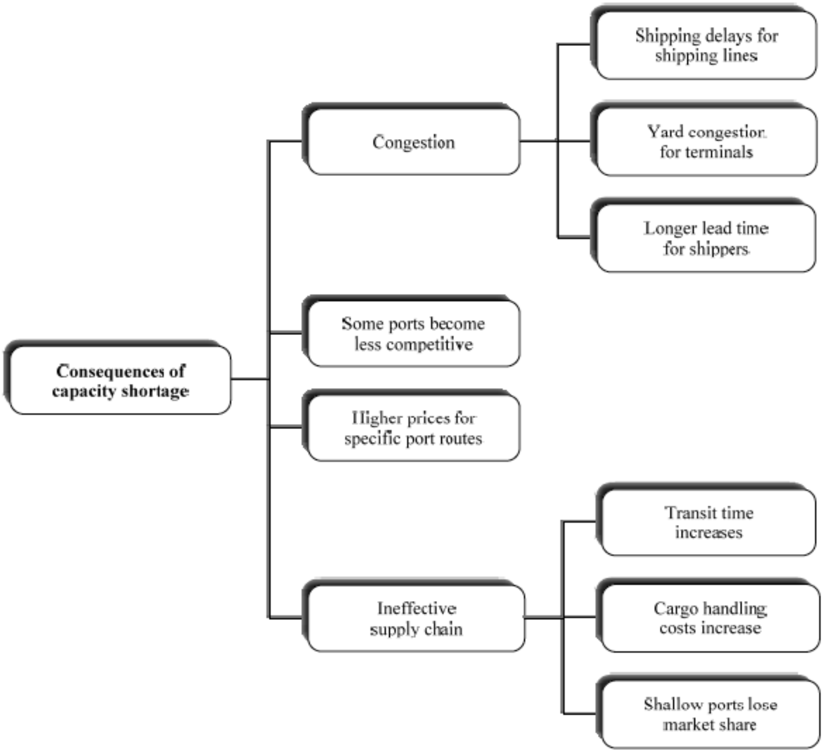


Figure1.3. Consequences of Capacity Shortages at Seaports (Islam and Olsen, 2013)

2. LITERATURE REVIEW

Evidence that SD can be used to study and improve the MTS is found in the literature. Our literature review focuses on the applicability of SD in the field of maritime transportation and indicates that SD is applied to many components of the MTS including maritime disruption studies, port-related studies, and vessel-related studies among others.

2.1. MTS STUDIES USING SD

2.1.1. Maritime Disruption SD Studies

Disruptive events such as the 9/11 terrorist attacks, 2002 Los Angeles/Long Beach lockout, and Hurricane Katrina increased the awareness of policy makers and researchers about the importance of maritime security. Lattila and Saranen (2011) showed that SD could be used to study the impact of general disruptive events in the MTS. More specifically, the authors used SD to investigate potential risk scenarios on the Gulf of Finland and illustrated that a disruption results in export loss (in tons) (Lattila & Saranen, Multimodal Transportation Risk in Gulf of Finland Region, 2011).

When a disruption occurs in the MTS, the system needs to recover to the pre-disruption throughput level. This process is described as the resiliency of a system. In general, resiliency has two dimensions, vulnerability and adaptive capacity (Dalziell & McManus, 2004). Omer et al. (2012) and Croope and McNeil (2011) used SD to study the resiliency of the MTS. Constructing a resilient MTS can minimize potential losses. Research shows that maritime ports are vulnerable against disruptions due to their strategic geographic locations, and a disruption will result in negative local and global impacts (Omer et al., 2012). In a similar vein, Croope and McNeil (2011) used SD to study the resiliency of critical infrastructures and disruption-related costs. Transportation systems in general and specifically the MTS are comprised of critical infrastructure (Clinton, 1996). Critical infrastructures are the core elements of the Nations’ economic and societal assets (Croope & McNeil, 2011).

To decrease vulnerability and increase resiliency; security policies are established by governments and private entities. Yeo, Pak, and Yang (2013) investigated the impacts of security policy changes. Their research illustrated that new security measures can have both positive and negative impacts on cost and port efficiency (Yeo et al., 2013). To summarize, disruptions have negative impacts the MTS. The literature shows that SD has been used to model disruption complexities and uncertainties in the MTS.

2.1.2. Port-Related SD Studies

A portion of the maritime transportation system system dynamics (MTSSD) literature focuses on the implementation of SD to conduct port-related studies. Dundovic et al. (2009), Dvornik et al. (2006), and Munitic et al. (2003) applied a SD model to study port-handling processes. These studies considered loading and unloading operations from ship to shore, transfer operations from shore to wagons and trucks, and warehouses. Similarly, Cheng et al. (2010) focused on the berth and yard operations, which are complex, and handled separately in terms of planning and decision-making. Their research used SD to analyze these two interdependent subsystems and their respective impacts on the overall port performance. Overall, SD simulation is a powerful tool to handle the complex port transshipment processes, but only a limited number of SD studies have been conducted for ports (Cheng, et al., 2010).

Another extension of port-related SD studies is the investigation of the port economics. For instance, Ho et al. (2008) studied port expansion decision and its economic outcomes. Their study showed that if the expected revenue and throughput cannot be generated, the expansion decision will lead to a financial dilemma. In addition, their study showed that simply increasing the number of ports in a specific region may not result in a positive economic impact because ports need to be supported by other infrastructures such as warehouses and shipping connectivity (Ho, et al. 2008). Mingming (2011) illustrated the relationships between port investments, port capacity, economic contribution of ports, and aggregate economy relationship through SD modeling. Li and Wang (2013) analyzed the economic contribution of ports to the regional economy. The authors also integrated an input-output analysis and an econometrics model with their SD simulation. Their integrated methodology is shown to be a powerful tool to analyze port economics (Li & Wang, 2013).

2.1.3. Vessel-Related SD Studies

System dynamics has been used to study the global shipping market in the MTS to understand the behavior of shipping freight rates (Randers & Göluke, 2007). Their model successfully explained the behavior of the tanker market since 1950 by only considering fleet size and fleet utilization data (Randers & Göluke, 2007). Engelen et al. (2009) researched the arbitrage between different vessel types, such as handy, Panamax, and capsize, and explained the correlation of freight rates for different ship segments. Dikos et al. (2006) developed a SD model to use as a decision support tool for freight rates and risk management for the tanker industry. Wijnolst (1975) focused on the relations between national fleet development and national objectives in developing countries. Wijnolst (1975) considered productivity of ships and investment in new ships.

2.1.4. Other MTS SD Studies

Other studies have utilized SD to study the MTS. Schade and Schade (2005) and Fiorello et al. (2010) developed a holistic SD approach. Schade and Schade (2005) integrated five models (transportation, macroeconomic, regional economic, policy, and environmental) into one aggregated model titled ESCOT. The authors developed a sub-model for transportation including water, rail, road, and air that aims to reach a sustainable transportation system and estimates the economic impacts of the German transportation system. Fiorello et al. (2010) built their SD model upon the ESCOT model (Schade & Schade, 2005). Fiorello et al. (2010) considered road, rail, and maritime transportation in their ASTRA (Assessment of Transport Strategies) model and measured investments, capacities, and their respective economic outcomes. Videira et al. (2012) also used a qualitative SD approach for maritime policy development which indicates that cooperation between policy-makers and stakeholders is crucial to selecting the best policy.

2.1.5. Summary

Our review of the MTSSD literature shows that SD is applicable to studying MTS. Engelen et al. (2009) claimed that SD has a potential of applications in a variety areas of maritime transportation research. In addition, SD has the ability of overcoming the drawbacks of time-series and statistical models (Dikos, et al., 2006). SD modeling also takes causality into account, allows what-if scenario analysis, and can be adapted to study fundamental changes in the system. Furthermore, sensitivity analysis can be conducted within the model, which can help policy makers to better analyze the outcomes of MTS policy changes (Dikos, et al., 2006).

2.2. CLASSIFICATION OF THE MTS SD LITERATURE

In this section, we classify the literature review findings to clarify the current body of knowledge and identify future research questions. We classify the literature into study region, types of ports studied, intermodal transportation considered, types of causal relations considered, variable classifications, stock and flow diagram elements, and sensitivity and scenario analysis considerations.

2.2.1.MTS SD Application Classification

2.2.1.1. Study Region

Table 1 describes the study regions covered in the MTSSD literature. The majority of studies focused on the major ports in Asia. With the exception of two hypothetical studies, the papers investigate real-world components of the MTS.

Table 2.1: Study Region Classification

Study Region/Geography	Explanation	Source
Asia	Most Important Asian Ports: Busan (Korea), Hong Kong (China), Kaohsiung (Taiwan), Shanghai (China), Yokohoma (Japan)	Omer et al. (2012)
	Korean Ports	Yeo et al. (2013)
	Port of Hong Kong China’s Pearl River Delta Region	Ho et al. (2008)
	One of the Container Terminals in Malaysia	Cheng et al. (2010)
	Port located in Southeastern China	Mingming (2011)
	Zhuhai Port (China)	Li et al. (2013)
	Port of Busan (South Korea)	Park, Moon, & Lim (2012)
North America	Most Important American Ports: Seattle/Tacoma (US), Oakland (US), and Port of Los Angeles/Long Beach (US)	Omer et al. (2012)
Europe	Port of Sibenik (Croatia)	Dundovic et al. (2009)
	Gulf of Finland Region	Lattila & Saranen (2011)
	Maritime Sustainability Issues in Portugal	Videira et al. (2012)
	Finnish Ports	Lattila (2008)
International	World's Shipping Market	Randers et al. (2007)
	Atlantic and Pacific Basin	Engelen et al. (2009)
	Tanker Market for Niver Lines	Dikos et al. (2006)
Hypothetical	Hypothetical Developing Country	Wijnolst (1975)
	Three Harbors named as A, B and C	Koseler (2008)

2.2.1.2. Port Type

To further classify the type of MTS studied, we considered the type of port studied in the MTSSD literature. The vast majority of port-related studies focus on seaports (Omer, et al., 2012; Yeo, et al., 2013; Lattila & Saranen, 2011; Ho, et al., 2008; Li & Wang, 2013; Wijnolst, 1975; Park, et al., 2012; Lattila, 2008). None of the studies focused on inland waterway ports.

2.2.1.3. Intermodal Transportation Consideration

The third literature classification considers whether or not intermodal transportation is studied. Intermodal transportation studies generally investigate the advantages and disadvantages of the various transportation modes. For instance, bulk freight can be first transported by vessel or barge and then transferred directly to rail car and delivered to the customer. Based on our review, there is limited work that utilizes SD in maritime transportation within an intermodal context (Lattila & Saranen, 2011; Dvornik, et al., 2006; Koseler, 2008).

2.2.1.4. Causal Relation Variables

To describe the SD methodological approaches taken, we identify the types of causal relations that are considered in the literature. The variables classified in Table 2 are grouped into seven categories. The most frequently considered causal relation variables are Resource Capacity, Investment, Throughput Generated, and Resource Availability.

Table 2.2: Causal Relation Variables

Causal Relation	Explanation	Source
Port/Terminal	Security Level	Yeo et al. (2013)
	Attractiveness	Yeo et al. (2013), Cheng et al. (2010)
	Competition	Li et al. (2013)
	Reliability	Yeo et al. (2013)
	Expansion	Ho et al. (2008)
	Efficiency	Cheng et al. (2010)
	Burden	Mingming (2011)
Time	Ship Service Time	Koseler (2008)
	Loading/Unloading Time (Container)	Cheng et al. (2010)
	Vessel Turnaround Time	Cheng et al. (2010)
	Vessel Waiting Time	Cheng et al. (2010)
	Transportation Time	Koseler (2008)
	Conjunction Time for Berthing	Koseler (2008)
Freight Flow	Throughput Generated (Container, Freight)	Yeo et al. (2013), Ho et al. (2008), Cheng et al. (2010), Li et al. (2013)
	Exported Volume	Silva, Coelho, Novaes, & Lima Jr (2011), Lattila (2008)
Transshipment Process	Resource Movements (Crane)	Cheng et al. (2010)
	Vessel/Ship Arrival	Cheng et al. (2010), Dvornik et al. (2006), Munitic et al. (2003)
	Occupancy (Berth)	Cheng et al. (2010), Dvornik et al. (2006), Munitic et al. (2003)
	Speed (Loading/Unloading, Transportation, Forwarding Truck/Wagons)	Dvornik et al. (2006), Munitic et al. (2003)
Capacity and Capacity Utilization	Resource Capacity (Port/Terminal, Crane, Berth, Seaman, Ship)	Cheng et al. (2010), Mingming (2011), Li et al. (2013), Wijnolst (1975), Koseler (2008)
	Resource Availability (Berth, Warehouse Space, Seaman, Terminal, Technology, Crane, Truck)	Dvornik et al. (2006), Wijnolst (1975), Koseler (2008), Munitic et al. (2003)
	Utilization (Fleet)	Randers et al. (2007)
	Desired Utilization (Fleet)	Randers et al. (2007)
	Desired Capacity (Ship Building)	Wijnolst (1975)
Monetary/Economic	Cargo Processing Cost	Yeo et al. (2013)
	Operating Cost	Cheng et al. (2010)
	Export Industries' Logistics Costs	Silva et al. (2011)

	Time Charter Rate	Randers et al. (2007)
	Investment (Port/Terminal, Ship Building Capacity)	Cheng et al. (2010), Mingming (2011), Li et al. (2013), Wijnolst (1975)
	Foreign Trade (Export, Import)	Mingming (2011), Wijnolst (1975), Lattila (2008)
	Maritime Carrier Profit	Silva et al. (2011)
	Port Economic Contribution (GDP, Employment)	Mingming (2011), Li et al. (2013)
	Exchange Rates	Lattila (2008)
	Inflation	Lattila (2008)
Disruption	Possibility of Security Incident	Yeo et al. (2013)
	Congestion (Port, Yard, Berth)	Ho et al. (2008), Cheng et al. (2010)

2.2.1.5. Variable Type

We classify the variable types employed grouped into endogenous, exogenous, and excluded variables as shown in Table 3. In SD modeling, the researcher develops a hypothesis which can explain the phenomena endogenously (Sterman, 2000). The exogenous variables are the ones that are out of the boundaries of the model. Exogenous variables in a SD model are not part of the feedback structure but do impact the system behavior. There are also excluded variables that are not considered in the model. In Table 3, we also illustrate the types of stock, flow rate, and delay variables that are utilized in the MTSSD literature.

Table 2.3: Variable Classification

Variable Type	Explanation	Source
Endogenous Variables Considered	Domestically Generated Throughput	Ho et al. (2008)
	Travel Cost and Time	Fiorello et al. (2010)
	Supply Function	Engelen et al. (2006), Dikos et al. (2006)
	Container Inventories	Koseler (2008)
	Capacity (Crane, Ocean Carrier)	Koseler (2008)
	Empty Container Flows	Koseler (2008)
	Loading/Unloading Crane Capacity	Koseler (2008)
	Harbor Productivity	Koseler (2008)
Exogenous Variables Considered	Container Capacity	Lattila (2011)
	Throughput that originate from Mainland China and from Taiwan	Ho et al. (2008)
	Ship Arrival	Dvornik et al. (2006)
	Demand	Dikos et al. (2006), Koseler (2008)
	Export of the Bulk Commodity	Wijnolst (1975)
	Price of the Commodity	Wijnolst (1975)
	Freight Rate	Wijnolst (1975)
Excluded Variables Considered	Urban Public Expenditure Policies on Roads and Rail	Ho et al. (2008)
	Berthing Conjunction Time	Koseler (2008)
	Total Number of Ocean Carriers	Koseler (2008)
	Profit	Koseler (2008)
	Labor	Koseler (2008)
	Transportation Costs	Koseler (2008)
	Investment in Technology	Koseler (2008)
	Ship Service Time	Koseler (2008)
Stock/Level/State Variables	Empty Container Inventories	Koseler (2008)
	Container Volume	Yeo et al. (2013)
	GDP Aggregate	Mingming (2011), Li et al. (2013)
	Hinterland Backlog	Lattila & Saranen (2011)
	Port Throughput/Transshipment	Ho et al. (2008), Park et al. (2012)
	Cargo on Board and Cargo Delivered	Engelen et al. (2006)
	Capacity moved from Another Port	Lattila & Saranen (2011)
	Port Capacity	Mingming (2011), Li et al. (2013)
	Ships, Lay-up, Scrap	Dikos et al. (2006)
	Ships at Ports	Omer et al. (2012)
Flow/Rate/Derivative Variables	Ships/Vessels	Omer et al. (2012), Cheng et al. (2010),

		Engelen et al. (2006)
	Containers	Yeo et al. (2013)
	Empty Containers	Koseler (2008)
	Capacity (Cranes, Port)	Lattila & Saranen (2011), Mingming (2011)
	Freight	Lattila & Saranen (2011), Ho et al. (2008), Li et al. (2013), Park et al. (2012)
	Money	Mingming (2011), Li et al. (2013)
	New Ship Rate	Dikos et al. (2006)
	Lay-up Rate	Dikos et al. (2006)
	Scraping Rate	Dikos et al. (2006)
Delay/Lag Variables	Demand Lag to Capacity Expansion	Ho et al. (2008)
	Between the Ordering and the Delivery of the Vessel	Engelen et al. (2006), Dikos et al. (2006)
	Between Port Investment and Port Capacity Increase	Mingming (2011)

2.2.1.6. Sensitivity and Scenario Analysis

The MTSSD literature is classified in terms of the employment of sensitivity and scenario analysis grouped into disruption-related, capacity-related, and other analyses in Table 4.

Table 2.4: Sensitivity and Scenario Analysis

Sensitivity and Scenario Analysis	Explanation	Source
Disruption-related	Security Level	Yeo et al. (2013)
	Disaster Response Time	Croope et al. (2011)
	Probability of Disruption Occurrence	Croope et al. (2011)
	Different Port Closures due to Oil Spillage	Lattila & Saranen (2011)
Capacity-related	Warehouse Capacity	Dundovic et al. (2009)
	Ship Capacity	Dundovic et al. (2009), Koseler (2008)
	Hinterland Capacity	Lattila & Saranen (2011)
	Different Level of Port Expansions	Ho et al. (2008)
Other	Demand Change	Randers et al. (2007), Dikos et al. (2006), Lattila (2008)
	Quay Crane Moves per Hour	Cheng et al. (2010)

2.2.2. MTS SD Methodology Classification

Since we are investigating SD as a methodological approach to studying the MTS, we also classify the MTSSD literature in the context of methodology descriptors. We grouped the relevant literature into six methodology descriptors including sub-model consideration, model integration, simulation period, software selection, modeling challenges and difficulties, and validation and verification techniques.

2.2.2.1. Model Integration

First, we identify the literature that considered subsystems. Several papers (Yeo et al., 2013; Croope et al., (2011), Fiorello et al., (2010); Cheng et al., 2010; Dvornik et al., 2006;

Videira et al., 2012; Dikos et al., 2006; Koseler, 2008; Park et al. 2012; and Munitic et al., 2003) considered MTS subsystems that are interconnected with each other.

Some scholars considered another type of model integrated with their SD model to analyze their problem of interest. The list of integrated models and corresponding studies are listed in Table 5.

Table 2.5: Integration of SD with Other Models

Integration with Other Model	Source
Network Optimization	Omer et al. (2012)
Input-Output	Li et al. (2013)
Econometrics	Li et al. (2013)
Regression	Park et al. (2012), Lattila (2008)

2.2.2.2. Simulation Period Employed

The MTSSD literature in Table 6 is classified according to the simulation period employed.

Table 2.6: Simulation Period Employed

Simulation Period	Explanation	Source
Hours	720 and 1500 Hours	Lattila & Saranen (2011)
Days	2 and 4 Days	Croope et al. (2011)
	360,750, and 1500 Days, Time Step=1day	Koseler (2008)
	250 and 730 Days	Lattila & Saranen (2011)
Months	170 Months, Time Step=1 Month	Engelen et al. (2006)
	72 Time Periods (i.e. Months), Time Step=0.25 (i.e. weeks)	Engelen et al. (2009)
Years	1970 - 2020, Time Step=1 Year	Yeo et al. (2013)
	10 Years	Ho et al. (2008)
	1990-2050	Fiorello et al. (2010)
	2007-2009, Time Step=1 Year	Mingming (2011)
	2007-2025	Li et al. (2013)
	1950-2010, Time Step=1 Year	Randers et al. (2007)
	1980-2002, Time Step=1 Quarter	Dikos et al. (2006)
	1970-2010, Time Step=1 Year	Wijnolst (1975)
	1998-2007	Park et al. (2012)
	2010-2030	Lattila (2008)

2.2.2.3. Software Utilized

The list of software products utilized in the reviewed MTSSD literature is shown in Table 7.

Table 2.7: Software Utilized

Software	Source
Vensim	Omer et al. (2012), Yeo et al. (2013), Fiorelloet al. (2010), Engelen et al. (2006), Santella, Steinberg, & Parks (2009), Li et al. (2013), Lattila O. L. (2008)
Powersim	Dundovic et al. (2009), Dvornik et al. (2006), Dikos et al. (2006), Park et al. (2012), Munitic et al. (2003)
Stella	Croope et al. (2011)
iThink	Cheng et al. (2010)
DYNAMO	Wijnolst (1975)

2.2.2.4. Modeling Challenges

We identified two major classifications of modeling challenges found in the literature as data-related and complexity-related challenges shown in Table 8,

Table 2.8: Modeling Challenges

Challenge	Explanation	Source
Data-related	Availability	Santella et al. (2009), Videira et al. (2012), Engelen et al. (2009), Dikos et al. (2006), Lattila (2008)
	Accuracy/Reliability	Ho et al. (2008), Dikos et al. (2006)
	Transformations	Lattila (2008)
Complexity-related	Keep the Model Size Manageable	Fiorelloet al. (2010), Randers et al. (2007)
	Define Metric(s) to Capture System Performance	Omer et al. (2012), Croope et al. (2011)
	Identify Various Types of Interdependencies/Feedbacks	Croope et al. (2011), Lattila & Saranen (2011), Santella et al. (2009), Li et al. (2013)
	Quantify the Dependencies between the Variables	Ho et al. (2008), Engelen et al. (2006), Santella et al. (2009)
	Many Assumption Requirements	Croope et al. (2011)
	Capture Changes in the System Over Time	Croope et al. (2011)
	Entities Possess Characteristic of Heterogeneity	Silva et al. (2011)
	Involve Broad Stakeholder Groups and Lack of Information Management	Videira et al. (2012)

2.2.2.5. Validation/Verification Techniques

Table 9 classifies the validation/verification techniques that are utilized in the MTSSD literature. The most common validation/verification technique is comparing model outputs with historical data and implementing a case study.

Table 2.9: Validation/Verification Techniques

Validation/Verification Technique	Source
Compare with Historical Data and Implement a Case Study	Yeo et al. (2013), Dundovic et al. (2009), Croope et al. (2011), Cheng et al. (2010), Engelen, Dullaert, & Vernimmen (2009), Santella et al. (2009), Mingming (2011), Li et al. (2013), Randers et al. (2007), Dikos et al. (2006), Lattila (2008)
Sensitivity Analysis	Ho et al. (2008), Santella et al. (2009), Koseler (2008), Park et al. (2012)
Expert Reviews	Santella et al. (2009)

3. CONCEPTUAL REPRESENTATION OF MTS USING SD

Naylor et al. (1996) define simulation as the process of designing a mathematical or logical model of a real system and then accompanying it with computer-based experiments. These experiments are the ones that help to describe, explain, and predict the behavior of the real system over an anticipated period of time. System dynamics (SD) modeling, as intended by its precursor Jay Forrester, is concerned with the dynamic behavior of systems. In other words: SD focuses on the behavior of systems over time. In system dynamics modeling, the modeler attempts to identify the patterns of behavior being exhibited by important system variables; and then builds a model that can mimic these patterns. Once a model has this capability, it can be used as a laboratory for testing policies aimed at altering a system's behavior in desired ways (Sterman, 2000).

Previous studies that have applied the system dynamics approach in the transportation field are: Towill (1996) when analyzed how the supply chain responded to various improvements within the system to enhance business performance, Dimitrios et al. (2007) when built an SD model to evaluate dynamic capacity planning of remanufacturing in closed-loop supply chains, and Disney et al. (1997) when established policies to understand how supply chain would respond to robust changes in lead time and randomness in demand. Other researchers have applied system dynamics modeling to study the effects of transshipments on supply chain behavior (Hong-Minh et al., 2000) and the effects of Vendor-Managed Inventory on transport operation (Disney et al., 2003).

Previous research on transportation using SD and our review of literature in section 2, have demonstrated the capability of this methodology within this rather complex field. Although, SD modeling has been utilized for problem solving within the maritime transportation field, limited research addresses the impact of managing limiting factors in maritime transportation’s system and infrastructures has on multimodal system’s efficiency and consequently, the system’s efficiency as well. In order to be able to determine what will improve the MTS or how it can be improved, a thorough understanding is needed in what is the impact these investments and restoration of the infrastructure of the MTS has towards the system as a whole.

System dynamics focuses on the system’s internal mechanism and structure. It stresses the relationship between units and information feedbacks, and also depicts the non-linear logic functions and delay factors inside the system. This research proposes a system dynamics mechanism for addressing issues of optimal transportation infrastructures needed to maintain competitive advantage in the world.

Since the description and correct interpretation of complex systems are crucial in order to understand the system, a breakdown-representation model of the MTS has been built. This representation model breaks down the complexity of the maritime transportation system for its better understanding (Figure 3.1).

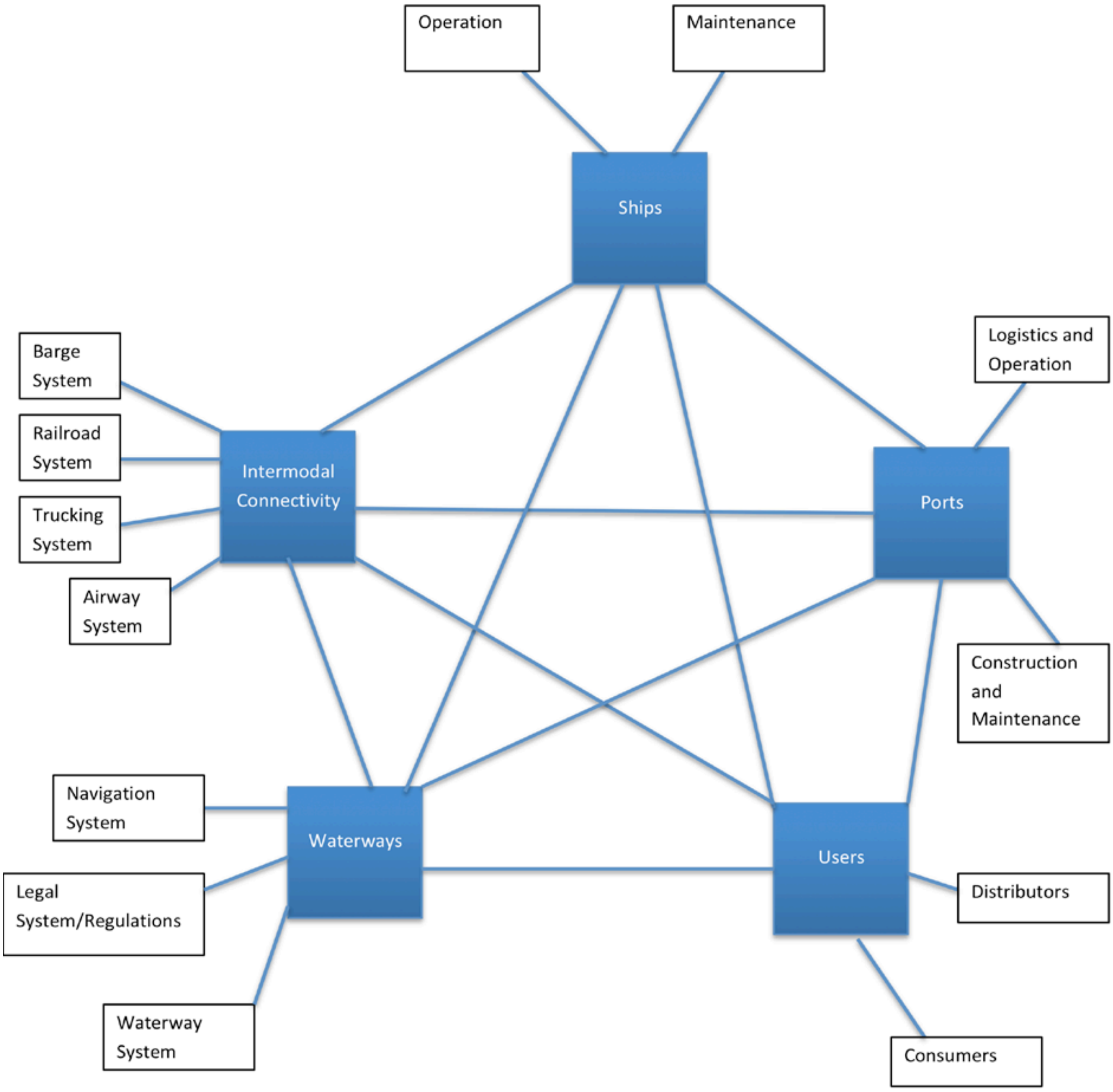


Figure 3.1: Representation Model of Maritime Freight Transportation System

3.1. INTRODUCTION TO THE SYSTEM DYNAMICS MODELING PROCESS

In an engineering environment models are made to better understand the real world and real life. With the help of these models, problems can be simplified and the simplified models provide an opportunity for the examination of these problems as well as for the analysis of emerging ideas of solution to these problems. It is desired to mimic a system’s structure and imitate its behavior as similar as possible to real life scenarios and captivate its whole essence and functioning in order to simulate the system’s behavior. System Dynamic is not the only simulation technique that is targeted at helping to learn about complexity. Different types of models have been in use for decades in order to describe transportation networks. Another example is the utilization of Agent Based Modeling (ABM), which has helped in the representation and analyses of complex, non-linear or discrete behavior and the interactions of its agents. These models, then make it possible to portray real systems using qualitative and quantitative parameters, so further on they can be examined.

In order to use SD methodology, the system under study must be considered a complex system. Maritime transportation systems are often complex with many different types of parameters and their relationships. Most of the time, those parts are connected in such complicated ways that they form a complex system whose property and behavior is not simply defined. Other characteristics that can be found in maritime transportation systems that make it a complex system are (Sterman, 2000):

1) Dynamic
2) Tightly coupled
3) Governed by feedback
4) Nonlinear (effect rarely proportional to cause)
5) Path-dependent
6) Counterintuitive (cause and effect are distant in time and space)
7) Policy Resistant (obvious solutions to problems fail or worsen the situation)
8) Characterized by trade-offs (time delays)

Hence, because MTS possesses those characteristics that make it a complex system, conventional transportation simulation models are in some cases difficult to use since in complex systems it is sometimes restricted or difficult to attain data or relationships, which are necessary to describe the system. In certain cases, system dynamics is that strategic approach used in modeling such systems and determining their behavior.

The description and correct interpretation of complex systems are crucial in order to understand the system. A simulation framework model is built with the objective of understanding the economic impact investing in infrastructure has on the efficiency of the MTS. Before discussing the steps of modeling in systems dynamics in depth as described by John Sterman in his book *Business Dynamics*, it is important to mention that modeling is an iterative process. Models will go though constant iteration, continual questioning, testing and refinement. Figure 3.2 demonstrates the modeling process as an iterative cycle.

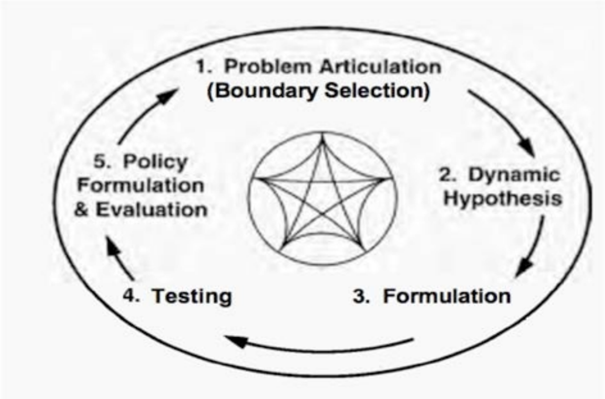


Figure 3.2: SD Steps on the Modeling Process (Sterman, 2000)

The classic system dynamic modeling steps as described by Sterman are the 5 main iterative steps as seen on Figure 3.2:

1) Problem Articulation (Boundary Selection)
2) Develop a Dynamic Hypothesis to explain the cause of the problem
3) Formulation of a Simulation Model
4) Testing
5) And, Policy Design and Evaluation.

But all those five (5) main steps are broken down into more steps in order to ensure that the modeling process is as smooth and successful as possible. A detailed description of all the SD modeling steps broken down into its simpler stages takes place ahead.

1) Problem Articulation

The most important step in modeling is problem articulation. That is supposed to answer the questions: What problem are you trying to address? What is the real problem, not just the symptom of difficulty? A clear purpose is essential for a successful modeling study to take place. For example: In this research our objective is to identify the impact addressing Maritime's system limitations has on the other modes of transport taking part n the supply chain along the effects of these impacts on the efficiency of MTS over time.

A model is said to be your mental representation of real-life. Although, one tries to copy as close to real-life as possible, no model is perfect since it cannot include all the causes of that problem in your model. That is why, within problem articulation, a model boundary is selected by the definition of key variables and establishing a time horizon. Example: for the purposes of this research, the time horizon selected was from year 2000 to year 2020 since the U.S. Department of Transportation data suggests significant increase (70%) in freight traffic in that year; and the key variables, as those that studies have proven to have a negative impact in maritime transportation industry.

Key variables can be divided in three categories that aid in the construction of the model. The *endogenous variables* are those factors in a causal model or causal system whose values are determined by the states of other variables in the system. Those variables are said to be "arising from within" and one can control them within the problem and use them to explain how the behavior changes if you alter the structure. In contrast, exist the *exogenous variables.* These are described as " arising from without" and are those factors that cannot be controlled but are part of the problem and will explain the dynamics of variables that are relevant and whose behavior over time is under study, in terms of other variables that were assumed. And similar to any other model being built, a limit boundary needs to be established. Therefore, the third category of key variable, the *excluded variables* which are those who although might affect the problem, will not be looked upon.

2) Formulation of Dynamic Hypothesis

Once the problem has been defined over an appropriate time horizon, and boundaries and key variables have also been established, the development of a theory, better known as the dynamic hypothesis, should take place in order to model. The hypothesis is dynamic because it must provide an explanation of the dynamics characterizing the problem in terms of the underlying feedback and stock and flow structure of the system. And it is a hypothesis, because it is always provisional, subject to revision as you learn more from the modeling process and from the real world. Fundamental modes and structures of dynamic behavior exist in order to explain the behavior of the system that arises from its structure.

In order to define the dynamic hypothesis of your model, there is need in understanding its behavior. Example: in this research, the dynamic hypothesis is defined to follow a S-Shaped Growth with Overshoot and Oscillations Structure. It is desired that the system counteract any disturbances that intent to move the state of the system away from the desired goal. And since no state can grow or decline forever, in the beginning the system is expected to grow exponentially because of the managing and improving of those causing capacity shortages and congestion, will result beneficial to the efficiency of the system, but then gradually will slow down until the state of the system reaches an equilibrium level that might face some overshoot and oscillate around the desired goal due to time delays amongst many other disruptive factors. The purpose of the model is to find a way of ameliorating and addressing those negative impacts affecting the maritime transportation's efficiency in order to achieve an effective supply chain. This will result in that in the case a discrepancy between the desired and actual state of the MTS exists, a corrective action will be initiated to bring the state of the system back in line or close to the desired goal.

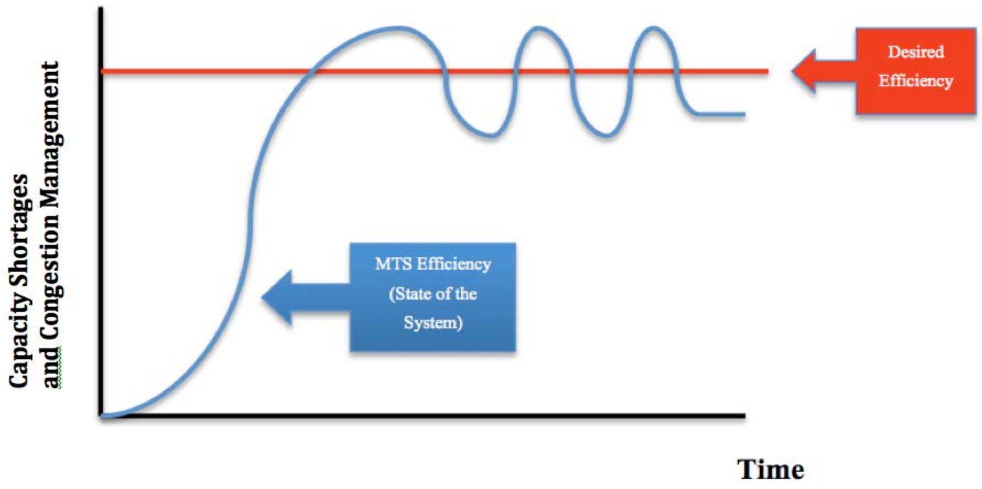


Figure3.3. MTS's Dynamic Hypothesis

3) Formulation of a Simulation Model

a) Causal-Loop Diagram

After the defining the Problem Articulation and Dynamic Hypothesis of the study, the next step is the formulation. First, a causal loop diagram is developed in order to understand the relationships among the various main variables in the MTS. Causal loop diagrams are simply a map from the mental model one attains after doing research and studying the MTS system, in order to simplify the building of the stock and flow simulation. In the causal loop, variables are linked with arrows from cause to effect.

Later, with the use of a computer software, in this research Vensim PLE VEntana Systems Software will be used, those relationships in the causal loop diagram are converted into the stock and flow diagram, which is the simulation of the model. *Stock variables* are those that accumulate over time and provide desired information under study. These stock variables are the ones that characterize the state of the system and are those we want to see how their variation behaves over time. These stocks variables are represented in the model inside boxes. The *flows* are those variables that represent the amount of change their corresponding stocks undergo during a particular unit of time. And the rest of the variables that are not either flow or a stock, are known to be *auxiliary variables* because aid in the model for variables to behave as desired or expected over the same period of time.

4) Testing

After having built your model and input all the corresponding equations that explain the relationship between the elements (variables) composing the system, the correct data needs to be found and input into the model. Data finding can be one of the challenges of this methodology, since it is crucial in order for the model to behave as close to the real-life scenario as possible. This step is really important since is the one that will help you validate your model. During this step is when you reassure that your model is a representation of a real-life situation. Also, it is during testing that a serious of things should take place to corroborate that the model is a real representation of the system that wanted to be replicated.

a) Robustness under extreme conditions

During the testing test it is really important that the model is compared to real life situations of that replicated system in order to corroborate that the model built behaves adequately to the desired purpose. Therefore, different modifications are made to confirm that the model behaves realistically when stressed by extreme conditions or scenarios.

b) Sensitivity

Also, during the testing it is essential to view and understand how the model behaves given some uncertainty in some parameters, initial conditions, and delays, amongst other variations. These will help with the coming up of decision-making solutions to the problem at hand.

5) Policy Design and Evaluation

And, the last but not least important part of the modeling steps is the policy design and evaluation of those policies. Is during this final step that new decision rules, strategies and structures might be defined to try in the model because eventually want to be applied into the real world. Before applying them into the real world, a series of what-if analysis will be implemented into the model, to forecast and understand what the consequences of those implementations will have on the whole system. This will aid in coming up with the best of strategies to obtain the best of the desired outcomes.

One of the benefits of systems dynamics approach is that it can be modified in order to attain a better insight and understanding of the behavior of a system's structure over a time period. As mentioned previously, this methodology of SD modeling goes through constant iteration, continual questioning, testing and refinement, until the best is achieved to solve the problem in question.

3.2. PRELIMINARY MODEL REPRESENTATION

In his paper, *Containerization, inter-port competition, and port selection*, Slack claimed that a good maritime port, addressed: congestion, the networks for linking other mode, the convenience of customs clearance, the capability of facility, port cost, scale and safety. Therefore, in this report, the model built represents the maritime transportation system and subsystems along with the modes of truck and rail. More specifically, the model is structured to represent a container terminal along with its subsystems of container yard and dock, connected to the modes of truck and rail. The operations of each subsystem are determinant factors to the efficiency of the overall maritime-logistics, supply chain operation. Because of the complexity of the container terminal operations, the subsystems of yard and dock are executed separately.

A container terminal is that place where vessels arrive and anchor at a dock, and containers are loaded and unloaded by cranes and stored in a yard to wait for later transshipments: truck, rail, or vessel to retrieve them. As seen, the capacity and time factors are vital for this operation to be as smooth as possible. By building a SD simulation model that captures this whole system and its subsystems, it is possible to look at the impact and the interactions amongst all of them and create a better understanding of the big picture and make decisions on what can be done to improve as desired.

A causal loop diagram describing the operations between the maritime transportation system (operations of: container terminal, and dock and yard) with those operations of truck and rail transport systems was developed. Because a causal loop is capable of capturing the dynamic processes of a system by demonstrating the chain effect through a set of related variables and back to the original cause or effect, this model helped understand the whole system and how our objective of maximizing service (throughput) will be obtained. Figure 1.4 shows the model built in order to study the impacts of addressing capacity shortages and congestion have on the overall performance of the system.

The systems of the truck and rail modes are in more general operational terms than the maritime transportation system, since our interest is to understand in depth the impact maritime and addressing its limiting factors have on the other two modes and the throughput of the system as a whole. The maritime transport system is broken down so that the dynamics of dock operations, the dynamics of yard operations, and consequently the dynamics of the container terminal operations can be exhibited profoundly, and understand the impact each has on congestion and capacity.

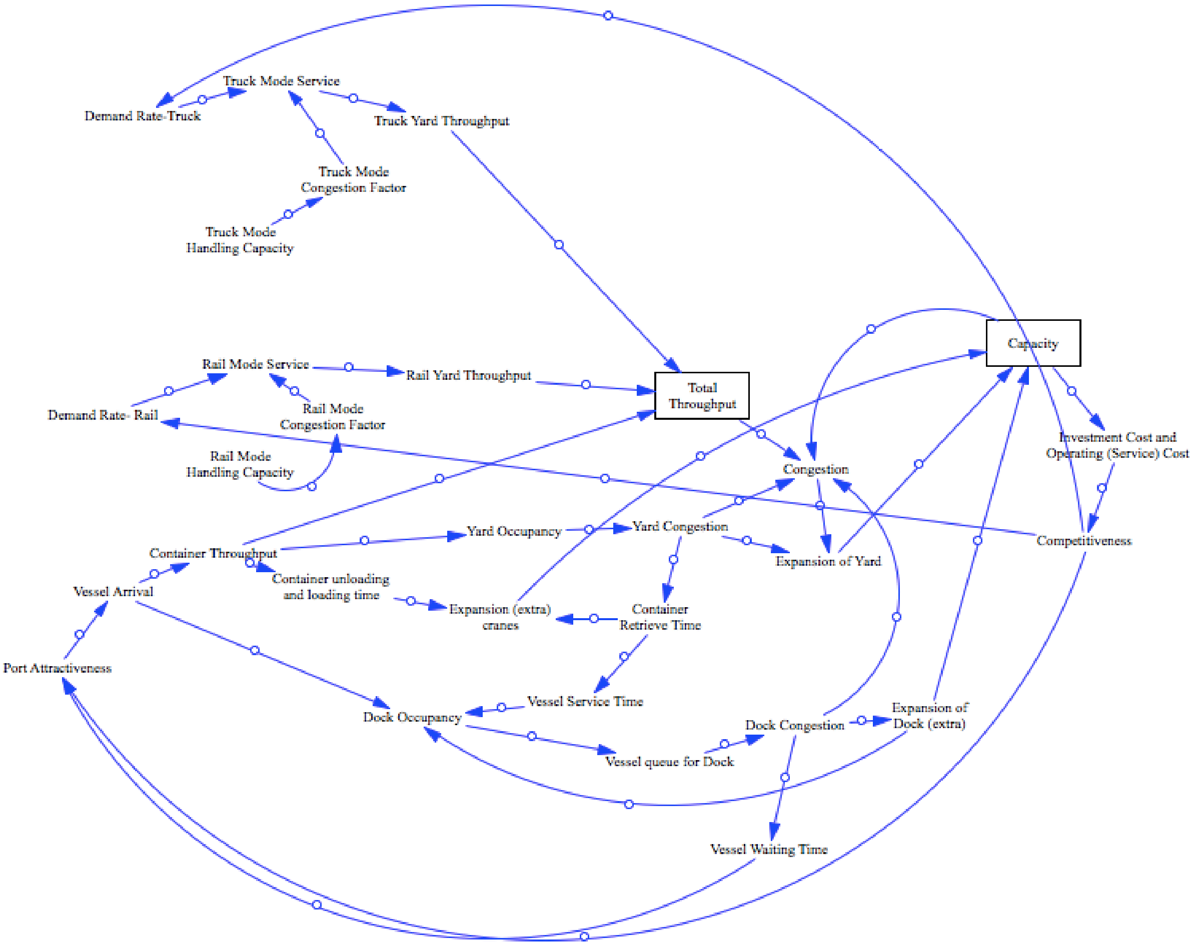


Figure1.4. MTS's Causal Loop Diagram

An explanation of the dock subsystem would be: an increase in vessel arrival will increase the dock occupancy rate and therefore, will increase the number of vessel queuing for dock. This will provoke the dock congestion problem, increases vessel waiting time and therefore increase the vessel turnaround time. These increases in time, due to capacity limitations and congestion, will have a decrease in throughput (efficiency) and therefore, decrease the port attractiveness and result in operational and service costs increases due to insufficient demand from vessels.

Since this is a feedback process and everything has an effect either directly or indirectly towards everything else, due to the shortage in dock availability, congestion resulted, and will have a long effect on the demand of truck and rail modes along with their throughput shortage, hence, making their systems inefficient and incompetent.

Ultimately, the model built measures the total throughput of the system so that one can see the impact of addressing the maritime issues of capacity shortages and congestion, which are limiting factors in the maximizing of the freight service potential. By different scenarios one can be able to determine, which is the best alternative in order to maximize freight service (throughput)?

4. CONCLUSIONS AND FUTURE WORK

This final report presents a review of the MTS SD literature and illustrated the wide variety of SD applications in MTS SD. The literature shows that SD models are successfully utilized to describe the complexity of MTS. Our classification of the MTS SD literature indicates that the existing body of knowledge primarily consists of port studies but there are a few papers that study vessels. Several researchers integrated their SD model with other models and conducted sensitivity analysis and scenario analysis to confirm the validity of their SD modeling, Moreover, the literature review shows that the MTS SD literature primarily face data-related and complexity-related modeling challenges.

This literature review is an initial step in understanding and demonstrating the causal relations between the different components of the MTS. In the future, a SD model will be built in order to further study the behavior of the MTS and understand the impacts on the major elements of MTS performance. This will help with decision-making strategies that will be beneficial for MTS stakeholders and can result in a competitive advantage for policy makers.

ACKNOWLEDGEMENTS

The research presented in this final report was partially supported by the Center for Transportation Infrastructure and Safety, a National University Transportation Center (NUTC) at Missouri University of Science and Technology. We also acknowledge the match funds provided by Missouri University of Science and Technology and University of Arkansas. Their financial support is gratefully appreciated. In-kind support was provided by the University of Arkansas in affliction with the Mack-Blackwell Rural Transportation Center and Maritime Transportation Research and Education Center.

BIBLIOGRAPHY

American Association of Port Authorities. (2007). *America's Ports Today.* Retrieved December 15, 2013, from http://aapa.files.cms-plus.com/PDFs/Campaign%20doc%20-%202-pg%20%20(Sept.%202007).pdf

Cheng, J. K., Tahar, R. M., & Ang, C.-L. (2010). Understanding the Complexity of Container Terminal Operation Through the Development of System Dynamics Model. *International Journal of Shipping and Transport Logistics,* 429-443.

Chopra, S. and Meindl, P. *Supply chain management: strategy, planning, and operation,* Pearson Prentice Hall, New Jersey, 2007.

Clinton, W. J. (1996). *Executive order 13010, establishing the president's.* Washington, D.C.: U.S. Government Printing Office.

Corbett, James J. and Winebrake, James. (2008). The Impacts of Globalization on International Maritime Transport Activity. *Energy and Environmental Research Associates, the United States.* Global Forum on Transport and Environment in a Globalizing World 10-12, Guadalajara, Mexico.

Croope, S. V., & McNeil, S. (2011). Improving Resilience of Critical Infrastructure Systems Postdisaster. *Transportation Research Record: Journal of the Transportation Research Board, No. 2234,* pp. 3–13.

Dalziell, E. P., & McManus, S. T. (2004). Resilience, Vulnerability, and Adaptive Capacity: Implications for System Performance. *International Forum for Engineering Decision Making (IFED).* Stoos Switzerland.

Darabi, Hamid., Gorod, Alex., Mansouri, Mo., Wakeman, Thomas., Efatmaneshnik, Mahmoud. (2012). Using Hybrid Modeling to Simulate Maritime Transportation System of Systems (MTSoS). *Annual IEEE Systems Conference.*

Dikos, G., Marcus, H. S., Papadatos, M. P., & Papakonstantinou, V. (2006). Niver Lines: A System-Dynamics Approach to Tanker Freight Modeling. *Interfaces 36 (4),* 326-341.

Dimitrios Vlachos., Patroklos Georgiadis., Eleftherios Iakovou. (2007). A system dynamics model for dynamic capacity planning of remanufacturing in closed-loop supply chains. *Computers & Operations Research.* Vol. 34, Issue 2. Pp. 367-394.

Disney, S.M., Naim, M.M., Towill, D.R., 1997. Dynamic simulation modelling for lean logistics. *International Journal of Physical Distribution and Logistics Management* 3–4 (27), 174–196.

Disney, S.M., Potter, A.T., Gardner, B.M., 2003. The impact of vendor managed inventory on transport operations. *Transportation Research Part E* (39), 363–380. Dundovic, C., Bilic, M., & Dvornik, J. (2009). Contribution to the Development of a Simulation Model for a Seaport in Specfic Operating Conditions. *Promet-Traffic & Transportation, Vol. 21,* 331-340.

Dundovic, C., Bilic, M., & Dvornik, J. (2009). Contribution to the Development of a Simulation Model for a Seaport in Specfic Operating Conditions. *Promet – Traffic&Transportation, Vol. 21*, 331-340.

Dvornik, J., Munitic, A., & Bilic, M. (2006). Simulation Modelling and Heuristics Optimization of Material Flow of the Port Cargo System. *Promet-Traffic&Transportation, Vol. 18*, 123-135.

Engelen, S., Dullaert, W., & Vernimmen, B. (2009). Market Efficiency within Dry Bulk Markets in the Short Run: a Multi-agent System Dynamics Nash Equilibrium. *Maritime Policy and Management*, 385-396.

Engelen, S., Meersman, H., & Voorde, E. V. (2006). Using System Dynamics in Maritime Economics: an Endogenous Decision Model for Shipowners in the Dry Bulk Sector. *Maritime Policy and Management*, 141-158.

Fiorello, D., Fermi, F., & Bielanska, D. (2010). The ASTRA Model for Strategic Assessment of transport Policies. *System Dynamics Review vol 26, No 3*, 283-290.

Forrester, J. W. (1961). *Industrial Dynamics*. Cambridge, MA: M.I.T. Press.

Fu, M. (2011). Port and Economy Relationship Analysis by System Dynamics. *International Conference on Transportation Engineering (ICTE)* (pp. 162-167). Chengdu, China: American Society of Civil Engineers.

Ho, K. H., Ho, M. W., & Hui, C. M. (2008). Structural Dynamics in the Policy Planning of Large Infrastructure Investment under the Competitive Environment: Context of Port Throughput and Capacity. *Journal of Urban Planning and Development*, 9-20.

Hong-Minh, S.M., Disney, S.M., Naim, M.M., 2000. The dynamics of emergency transshipment supply chains. *International Journal of Physical Distribution and Logistics Management* 9 (30), 788–815.

House of Representatives. House Hearing, 112 Congress. (April 18, 2012). Subcommittee on Water Resources and Environment of the Committee on Transportation and Infrastructure. *How Reliability of the Inland Waterway System Impacts Economic Competitiveness.*

International Maritime Transportation (IMO). (2013). Sustainable Development: IMO's Contribution Beyond Rio +20.

Islam, S., Olsen, T.L. (2013). Factors affecting seaport capacity: Managerial implications for a simulation framework. *22nd National Conference of the Australian Society for Operations Research.*

Koseler, S. (2008). Intermodal Logistics System Simulation Model & the Empty Container Flows.

Lattila, L., & Saranen, J. (2011). Multimodal Tansportation Rsk in Gulf of Finland Region. *World Review of lntermodal Transportation Research, Vol. 3, No. 4,* 376-394.

Lattila, O. L. (2008). Combining Advanced Forecasting Methods with System Dynamics – the Case of Finnish Seaports.

Li, D., & Wang, X. (2013). System Dynamics Simulation Model for Port Economy Analysis. *Proceedings of the Sixth International Conference on Management Science and Engineering Management, Lecture Notes in Electrical Engineering 185* (pp. 475-482). Springer London.

Margreta, M., Ford, C. and Adhi Dipo, M. (2009). U.S. Freight on the Move: Highlights from the 2007 Commodity Flow Survey Preliminary Data. RITA Bureau of Transportation Statistics. *U.S. Department of Transportation.*

Marine Highway Program. (2013). Marine Administration. U.S. Department of Transportation.http://www.marad.dot.gov/ships_shipping_landing_page/mhi_home/mhi_home.htm

Mingming, F. (2011). Port and Economy Relationship Analysis by System Dynamics. *American Society of Civil Engineers*, (pp. 162-167).

Munitic, A., Simundic, S., & Dvornik, J. (2003). System Dynamics Modelling of Material Flow of the Port Cargo System. *System Dynamics Conference.* New York City, New York.

Nijkamp, P., Vleugel, J. M., Maggi, R., & Masser, I. (1994). Missing transport networks in Europe. Aldershot: Avebury.

Omer, M., Mostashari, A., Nilchiani, R., & Mansouri, M. (2012). A Framework for Assessing Resiliency of Maritime Transportation Systems. *Maritime Policy & Management: The Flagship Journal of International Shipping and Port Research,* 685-703.

Park, N.-K., Moon, D. S., & Lim, C.-K. (2012). Port Choice Model of Transhipment Cargo Using System Dynamics. In D.-W. Song, & P. Panayides, *Maritime Logistics Contemporary Issues* (pp. 69-90). Emerald Group Publishing Limited.

Randers, J., & Göluke, U. (2007). Forecasting Turning Points in Shipping Freight Rates: Lessons from 30 Years of Practical Effort. *System Dynamics Review,* 253-284.

Santella, N., Steinberg, L. J., & Parks, K. (2009). Decision Making for Extreme Events: Modeling Critical Infrastructure Interdependencies to Aid Mitigation and Response Planning. *Review of Policy Research, Volume 26, Number 4,* 409-422.

Schade, B., & Schade, W. (2005). Evaluating Economic Feasibility and Technical Progress of Environmentally Sustainable Transport Scenarios by a Backcasting Approach with ESCOT. *Transport Reviews, Vol. 25, No. 6*, 647-668.

Silva, V. M., Coelho, A. S., Novaes, A. G., & Lima Jr, O. F. (2011). Remarks on Collaborative Maritime Transportation's Problem Using System Dynamics and Agent Based Modeling and Simulation Approaches. *IFIP Advances in Information and Communication Technology*, 245-252.

Slack, B. (1985) Containerization, inter-port competition, and port selection. *Maritime Pohcy and Management*, Vol. 12, No. 4, pp 293-303

Sterman, John D., 2000. BusinessDynamics: Systems Thinking and Modeling of a Complex World. *McGraw-Hill Companies*, Inc.

Stock, James., Lambert, Douglas. (2001). Strategic Logistics Management. *The McGraw-Hill Companies, Inc.* New York, NY. 4th Edition. Pp. 329.

Towill, D.R., 1996. Industrial dynamics modeling of supply chains. *International Journal of Physical Distribution and Logistics Management.* Vol. 2. Issue 23. Pp. 23–42.

U.S. Department of Transportation. (2002). Office of Freight Management and Operations. *Freight News*. “Freight Analysis Framework”.

U.S. Maritime Administration. (2009). America’s Ports and Intermodal Transportation System.

Videira, N., Lopes, R., Antunes, P., Santos, R., & Casanova, J. L. (2012). Mapping Maritime Sustainability Issues with Stakeholder Groups. *Systems Research and Behavioral Science Syst. Res. 29*, 596–619.

Wijnolst, N. (1975). The Dynamics of National Fleet Development. *Dynamica*, 3-10.

Yeo, G.-T., Pak, J.-Y., & Yang, Z. (2013). Analysis of Dynamic Effects on Seaports Adopting Port Security. *Transportation Research Part A 49*, 285- 301.