Abstract - Maritime Transportation System (MTS) is a critical infrastructure system that enables economic activity through transferring goods between national and international destinations and hence, is extremely important for the U.S. National Security. This research applies a systems approach to define MTS as a System of Systems (SoS). The presented definition of Maritime Transportation System of Systems (MTSoS) enables us to study its critical attributes such as resilience and security, and increases understanding of how to govern it more effectively. A variety of systems engineering models have been applied to MTS. However, it is necessary to form a structure for understanding MTSoS and to develop a new System of Systems Engineering (SoSE) toolset that help us in viewing interdependencies and adopting effective governance. Based on Boardman-Sauser characteristic-based definition of SoS, We defined MTSoS as integration of interdependent constituent systems. While each constituent system seeks its own goals, their collective body pursues a unified objective, which is transferring goods in a safe, secure, and efficient manner. This approach enables us to create a SoSE framework that can be used as a tool for more effective governance in MTSoS.

Keywords: Maritime Transportation System of Systems; SoSE Management; Governance.

1 Introduction

Systems Engineering (SE) is a discipline that enables us to include some of the new complexities in problem-solving processes. A constant challenge however, is to conquer new disciplines that help us take into account higher levels of complexity. While SE methodologies let us study a system beyond characteristics of its components, it does not provide us with the opportunity to see a system in a larger environment to which it belongs and consequently is not adequate in dealing with complexities that are caused by interrelated network of several complex systems. The objective of System of Systems Engineering (SoSE) is to face a new level of complexity regarding systems studies and includes successful engineering of multiple integrated complex systems [1]. This paper focuses on applying a SoSE approach to view Maritime Transportation Systems (MTS) as a System of Systems (SoS).

To view MTS in a SoS context, we adopted the Boardman-Sauser characteristic-based definition of SoS [2]. The idea has been introduced in the literature before [3], however in this paper, we intend to apply a SoSE approach to define Maritime Transportation System of Systems (MTSoS) for better understanding its complexities and processes. The outputs of this paper is based on a previous research that have been conducted by Mansouri et al. on development of a management/governance framework for MTSoS [4]. In the next sections we define MTSoS and by adopting the SoSE management framework proposed by Gorod et al. [5], we propose a framework for governance in MTSoS. The proposed framework can be used as a tool for simulation of the system’s behavior in future researches.

2 Maritime Transportation System of Systems

Maritime Transportation Systems are critical infrastructure systems that enable economic activity through transferring goods between national and international destinations [6]. In Homeland Security Presidential Directive-13, “Maritime Domain” is defined as “all areas and things of, on, under, relating to, adjacent to, or bordering on a sea, ocean, or other navigable waterway, including all maritime-related activities, infrastructure, people, cargo, and vessels and other conveyances” [7]. This description alone reveals the level of complexity involved in the dynamics of maritime systems.

Maritime systems are always exposed to variety of organizational and environmental risks that may disrupt their services and potentially result in large amounts of direct and indirect financial losses [8]. These threats range from natural to man-made disasters [9]. Mansouri et al. categorize the roots of uncertainty in four major groups as: natural, organizational, technological, and human factors [10]. Since disruption as a result of uncertainty is
inevitable, such systems need to be designed and operated in such a manner that they can adopt appropriate strategies such as flexibility, resilience, and agility in the face of disturbances.

Many enterprises participate within the boundaries of maritime systems. There are a lot of direct and indirect roles in MTS that are interrelated through a network of complicated rules, regulations, and business processes. For instance, each year about 7,500 foreign ships enter U.S. ports staffed by more than 200,000 foreign sailors [11] that interact with millions of other people who are parts of the MTS enterprise in the U.S. ports alone. Even if we consider the effects of this single factor on security management in American ports, it will be almost impossible to take all of the stemmed complexities into account. It has been a lot of efforts and investments dedicated to security related issues, however in reality, we are far away from calling our ports secured. According to Hultin et al., public American ports are exposed to all kinds of risks and even though a much greater security is provided by entities such as Custom’s Container Security Initiative (CSI) and Customs-Trade Partnership Against Terrorism (CTPAT), only 2-3 % of the cargo entering to the U.S. is physically checked [12].

Many autonomous organizations from civil society, governmental, and private sectors are involved in conducting MTS business. These entities are stakeholders of MTS and each has a different perspective. Yet as they perform in a hierarchy within their organization, they also interact with other entities in a network-centric level. Such characteristic extends MTS to a “network of maritime operations” [3] that can be described by the term “holarchy,” [13-15]. We have adopted the “holarchical view” to define Maritime Transportation System of Systems as a whole that embraces its autonomous constituent systems.

The organizational components that form such a complex network can be categorized in a variety of groups. However, from a systems perspective, we can identify them through their roles in overall performance of MTSoS. In this paper, we have chosen the classic categorization of such systems’ major agents available in the literature [3, 4, 16, 17], which defines them as: 1) ships; 2) ports; 3) intermodal connects; 4) waterways; and 5) users. As it is depicted in Figure 1, although these agents are a whole within their own boundaries and thus performs as an autonomous as well as independent system, they are also parts of a superior structure, which is in fact, MTSoS. We briefly describe these agents in this section by explaining those characteristics of them that have a systematic impact on the performance of MTSoS as a whole.

Each one of MTSoS constituents is an independent operational system and includes several interdependent subsystems that work in hierarchy. If we go deeper in presenting MTSoS, it can be shown how entities of each layer are also connected horizontally. These interdependencies construct complexity in terms of communication as well as interoperability. Security entities exemplify interdependencies of MTSoS in lower layers. These agents include all the governmental as well as private agencies involved in the process of making ports safe and providing security for the maritime domain.

![Figure 1 Maritime Transportation System of Systems (adapted from [4])](image)

The federal government takes the lead in protecting American ports; however, private companies, mostly the trading entities, hire some of the security personnel. The Department of Homeland Security (DHS) secures American ports primarily through the activities of Customs and Border Protection (CBP) and the U.S. Coast Guard. CBP is responsible for cargo security, and screens cargo entering the country through American port. The U.S. Coast Guard is however, responsible for maritime security and reviewing and approving security plans for vessels, port facilities and port areas that are required by the Maritime Transportation Security Act (MTSA), International Maritime Organization (IMO), and International Ship and Port Facility Security (ISPS) Code.

There are also other cargo security programs including: the Container Security Initiative (inspection of U.S. import cargo by CBP prior to leaving the outbound foreign port); use of radiation detection equipment to screen for weapons of mass destruction; use of other non-intrusive inspection devices; and the Customs Trade Partnership Against Terrorism (CTPAT), which encourages maritime stakeholders to verify their security measures. In general, while the governmental agencies take the lead on waterside and cargo security, the process is shared with several players of the system, namely port authorities, facility and vessel operators, also the state and local police [18].

Therefore, activities related to the security of MTSoS are shared among all five constituents. Consideration of a
factor such as security in connection with all of these entities and the process, which is created as the result, could be a topic of a future paper. Here, we only consider the system in a high level and will not continue into defining lower layers of this large network.

3 Constituents of the System

These are the five constituents of Maritime Transportation System of System:

3.1 Ships

Ships are instruments for transferring goods and freights from the ports at the originating countries (cities) to those of destinations. Maritime shipment is performed using: bulk carriers, tankers, and container ships. Bulk carriers transfer bulk cargo items such as ore or food staple namely rice, grain, etc. Tankers are used to transport fluid such as crude oil, petroleum products, liquefied petroleum gas, liquefied natural gas, and chemicals as well as vegetable oils, wine and some other kinds of food. Finally, container ships carry their entire load in truck-size standard units. These kinds of ships form a common means of commercial intermodal freight transportation.

3.2 Ports

Ports are facilities for receiving ships and transferring maritime passengers and cargo from waterways to land. All of functions and operations necessary to run a port are referred to as port services, which cover infrastructure related activities as well as loading/unloading ships and releasing them. Port infrastructures include wharfs, cargo-handling equipment, maneuver ships, as well as custom and administrative facilities. Consequently, any kind of services related to marine construction, the infrastructures' maintenance, dredging, operation of cranes, forklifts, harbor pilots, barges, tugboats, chandler’s operations, ports maintenance, steamship operations, quality inspection, temporarily freight warehousing, terminal operations, also custom related and administrative activities are considered within the territory of port services [19]. Several groups such as longshoremen, stevedores, forklift and tugboats operators, and so forth, provide these services. The ports’ major subsystems are: marine construction; port maintenance; port operation; and logistics.

3.3 Intermodal Connects

Intermodal connectors are responsible for moving the unloaded cargo from the port facilities. Ships usually transport a huge amount of cargo, many times more than the capacity of other transportation means such as train and trucks [20]. Thus, it is necessary to store the shipped cargo at the ports terminals for a short period of time. The activities of intermodal connects engage several groups including transportation operators, warehousing staff, and to some extent distribution employees. Intermodal connectors have an important role in the flow of cargo out of port terminal and through the entire nation. Trucking and train transportation systems are major subsystems of this constituent. In some cases, barges transport smaller portion of cargo through major rivers in the nation, which can be considered as an extension to MTS and therefore, is excluded from this group.

3.4 Waterways

Waterway refers to the body of water that is navigable by ships and other vessels. Oceans, seas, as well as lakes and some of the rivers and canals, which have certain characteristics, are constituent systems of MTSoS. Waterways must be: deep enough to allow draft depth of ships using it; wide enough to let passage of beam width using it; and free of physical or current related barriers. Canals are waterways, constructed to provide a new path of travel for ships. They offer passage for huge ships from two bodies of water, divided with land from one another. Panama, Suez, and Erie canals are examples of this kind of waterways, which have significant roles in the flow of maritime cargo.

Since there are a lot of ships using waterways around the globe as means of transportation, there must be a navigation control system in operation. Such system helps ships to sail within their designated paths and also provides them supports by monitoring their location. In this sense, waterways are very similar to roadways and airways. Waterways that belong to a certain country’s body of waters are governed under that country’s rules and regulations. There are also some maritime areas recognized as international waters. Attributes such as traffic, security, legal availability, as well as international laws and regulations impact the functionality of waterways and as a result can influence MTSoS.

3.5 Users

The collection of all the people at both ends of MTSoS contains its users. This might include manufacturers, intermodal connect people, port services personnel, distributors and even wholesalers, retailers, and consumers. Trading entities, which include the entire group of private, nonprofit, or governmental organizations that are involved in import/export processes, are in fact the main users of MTSoS services. These entities are small and midsize companies or large corporations. They are major players of MTS as well as nation’s economy regardless of size or the volume of their transactions. The impact of these entities on the economy is so essential that some call the U.S. a maritime country [21].

Some of the larger trading entities have their own systems of distribution, which is a part of their supply chain that starts from manufacturing firms in the originating countries to wholesalers and retailers in the USA. On the other hand, the majority of trading entities (import/export companies) in the country are small businesses [22] which rely on independent contractors for distribution services. That is why considering distributors independently make
sense in the system from a commercial or economic perspective. Many midsize and small import and export businesses work closely with distributor entities, which help them with disposition of their goods nationwide from/to the ports. In this sense, distributors are the natural end-users of trading enteritis’ output.

4 The External Factors

There are also many external factors, which have crucial impacts on behavior of Maritime Transportation System of Systems. Since we do not intend to identify or describe these factors here, their effects have been considered through a black box perspective. We categorize these factors into: law and policy; financial; natural environment; and human factors for which we present a brief description in this section.

4.1 Law and Policy Factors

Laws and policies factors shape the dynamics of maritime activities. They affect MTSoS via enforcing regulations for operational processes as well as imposing restrictions to certain activities. DHS policies and regulations, international trading laws, environmental advocates, and security entities are examples of such factors. Law and policy factors are creators of organizational as well as functional forces that direct the high level movements of MTSoS and set the pace of processes and activities of the entire system by providing quality assurance guidelines for the system’s activities. Except for international trading laws and regulation as well as some of the security concerns, which are totally imposed externally, some aspects of the laws and policies factors are charged and fed internally, through the behaviors of other members of MTSoS. As a result, such forces are partially created and applied to MTSoS by its own dynamics.

4.2 Financial Factors

MTSoS is an enabler of financial transactions. From one perspective, shipment as the ultimate objective of MTS is a representation of financial activities among trading entities, distributors, port services, and consequently the entire players of global economy. Financial entities are very important part of MTSoS as they initiate development as well as maintenance projects and direct the flow of activities throughout the system. Not only private-based operations, but also governmental and even nongovernmental activities are greatly dependent on the availability of funds and investment capacities. Therefore, financial resources empower MTSoS to play its essential role. Interestingly, most of these activities, except for those of environmental advocates and other nongovernmental institutions, are self-sustained and fed by MTSoS-created wealth. Thus, financial entities are the main and most basic creators of the maritime industry. It is almost impossible to model the details of financial relationships within MTSoS.

However, we include these entities as an external black box that affects maritime systems.

4.3 Natural Environment Factors

Maritime activities are also under the influence of natural environment factors. Such factors may affect MTSoS through: hydrologic hazards; atmospheric hazards; or geological and seismic hazards, and impose considerable costs in the form of maintenance, reconstruction, and preparedness on the systems every year. Floods and coastal erosions are examples of the hydrologic hazards, while tsunamis and earthquakes are categorized as geological and seismic threats. Also, atmospheric hazards in the form of hurricanes and cyclones happen regularly at the maritime domain. Natural environment factors usually affect the maritime systems as external disruptive events and their impacts are intense to the extent that one could not model MTSoS without considering them into the picture. Since the effects of environment are out of control, such factors have been viewed as outputs of an external black box.

4.4 Human factors

Human is the center of decision-making processes. A collection of all decision-makers and stakeholders in fact, construct the cognitive body of MTSoS. Such a cognitive state, which is a function of many other external restrictions, encompasses the entire human factor inputs to MTSoS. There are myriad of external factors that affect the MTS decision-makers. Here, we name time, budget as well as tools and knowledge constrains as examples of such factors. People have to make decisions in limited periods of time and only by taking their limited available financial, technical, and informational resources into account. The restrictive nature of these factors brings about new complexities to the context of MTSoS that makes it even more dynamic and less controllable. Therefore, it is necessary to model the imperfection of the MTSoS cognitive state as a function of external restrictions as well as subjectivity of human beings that makes them behave in certain patterns.

5 A Framework for Governance

Having a clear understanding about characteristics of Maritime Transportation System of Systems combined with accurate knowledge on capacity and/or limitations of human resources, who are responsible for its leadership enable the development of a holistic framework for governance in MTSoS. The governance framework is developed based on characteristics of the constituent systems. We suggest that the results of such holistic investigation can be applied as a SoSE tool for governing the entire complex network of maritime systems. The proposed framework is presented in Figure 2.

The framework has a holistic approach to MTSoS and the relationship among its constituent systems. The emphasis of the framework is on the importance of the
feedback loops that connect the actual state of MTSoS with its cognitive status at any given time. This connection is possible through installation of certain sensors that gather information from processes of the entire system through variety of predefined metrics. We suggest design and installation of sensors that describe the actual state of MTSoS through measurement of the distinguishing characteristics of its constituent. In particular, we suggest gathering information on the levels of “autonomy, belonging, connectivity, diversity, and emergence” for each constituent system, namely ships, ports, waterways, intermodal connects, and users.

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Figure 2 A Framework for Governance in Maritime Transportation System of Systems (adapted from [4])

The gathered information about each agent’s status within the spectrum of distinguishing characteristics’ opposing forces will be constantly saved in the system’s knowledge base and shape structure of the MTSoS’s cognitive state. The decision-making parties among the system’s stakeholders will use this body of knowledge for analysis and apply their governing criterias to influence the MTSoS’ performance. Such a tool provides the decision-makers with an effective way to influencing MTSoS distinguishing characteristics and leads them toward the desired positions. This loop becomes complete when the actual state of MTSoS is tracked and recorded again through the described information system. Since the results gathered by the information system are constantly saved and analyzed by decision-makers, they become a part of cognitive capacity of MTSoS. Therefore the collection of all tools, techniques, processes, procedures, software, strategies, policies, and management approaches construct cognitive status of the system.

It is also important to consider the effects of MTSoS environmental influences as well as human factors. Such external factors constrain the implementation of the proposed framework through imposing undesired forces or producing judgmental biases. That is why the described external factors should be considered as a risk to the framework’s effectiveness.

6 Conclusion

A study on the literature shows that a variety of systems engineering models have been applied to the domain of Maritime Transportation Systems. However, it is necessary to form a structure for understanding Maritime Transportation System of Systems and to develop a new and applicable System of Systems Engineering toolset that enable the stakeholders to view interdependencies and to adopt effective governing strategies for the system. In this paper, we tried to bring a new meaning to the context of maritime activities by redefining it as a System of Systems and providing a framework for its governance based on the Boardman-Sauser characteristic-based definition and previous researches of Gorod et al. on development of management frameworks.

The proposed framework of this paper views maritime activities in a network-based level. It gathers information from the processes of the system through organizational sensors and save them in a knowledge base, which constitutes the actual state of the system. This knowledge will be utilized by the stakeholders of the system in the process of governance through which certain regulations are enforced to the system. The proposed framework also considers the external factors that influence the cognitive state of decision-makers as well as stakeholders. This approach make possible future studies on each and every part of the system as well as its external factors through Agent-based Modeling and System Dynamics simulation tools.

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