Factors affecting seaport capacity: Managerial implications for a simulation framework

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Abstract: A seaport is a key part of a supply chain. However the problem of system-wide capacity shortage puts seaport authorities under pressure to keep up to date with ways in which to solve it. The purpose of this study is to propose a System Dynamics (SD) framework for managerial decision making that is developed based on the factors affecting seaport capacity. Hence the proposed capacity management framework inherits the potential for use at ports in capacity-management-related problem solving. The framework would be of importance in assisting managers in identifying possible capacity expansion opportunities. Academics and those with corporate interests in the capacity management of ports have raised many issues in recent years in which there has been steady growth in the number of containers transported worldwide.

Keywords: *Simulation, System Dynamics (SD), container terminal, capacity management, port*

1. INTRODUCTION

From a micro-level perspective, a seaport facilitates in the transfer of containerized goods from one mode of transport to another, such as; from container trucks to ships, or from ships to container trucks (Carbone and De Martino, 2003). In a broader sense and from a different perspective, a port is an important part of a chain of organizations that brings products to the final customers (Panayides, 2006). To indicate the importance of performing that role correctly within a cluster of organizations (e.g., wholesalers, retailers, importers and exporters) within the supply chain, Panayides and Song (2008) used the phrase *"integration of ports and particularly container terminals in supply chains"*. Apart Panayides and Song, many other researchers have also mentioned the crucial role of a port in the context of a supply chain (Martin and Thomas, 2001, Marlow and Paixão Casaca, 2003, Carbone and De Martino, 2003, Bichou and Gray, 2005, Panayides, 2006). Along the same lines of exploring the importance of port performance from the perspective of a supply chain, some studies have used the terms "efficiency" and "effectiveness" in addressing a port's performance (Tongzon and Ganesalingam, 1994, Tongzon, 2001, Barros, 2003, Tongzon and Heng, 2005). Similarly, supporting this crucial idea of measuring port performance and identifying its consequences, the study of Wang and Cullinane (2006) suggested that *"...ports should ensure that existing infrastructure and equipment is utilized to maximum economic and technical efficiency in order to optimize the container production process"*. In contrast, ports often lack the necessary capacity to execute their operations competently. This weakens the goal of supply chain integration with other members of the same network of organizations. Capacity shortage is one of the limiting problems currently facing many ports of the world (Paul and Maloni, 2010).

2. REASONS FOR CAPACITY SHORTAGE

Many seaports of the world are currently facing the problem of capacity shortage (Paul and Maloni, 2010). Several factors are influencing the demand for container port capacity as shown in Figure 1. For example, in the 1980s manufacturers replaced their production facilities and moved them to countries where production costs were comparatively lower; in addition, the Chinese manufacturers started exporting their products worldwide in the 1990s and 2000s and this caused a major trade boom throughout the world (Pallis and de Langen, 2010). Secondly, the prediction for GDP (Gross Domestic Product) growth rates indicates a positive trend that will have an impact on worldwide trade volume in the future (Chin et al., 2009). A positive economic relationship is expected between GDP growth rate and seaport demand development (Ocean Shipping Consultants Limited, 2009). Thirdly, number of Twenty-foot Equivalent Unit (TEU) containers transported annually increased from 39 million to 356 million between the years of 1980 and 2004 with an annual growth rate of 10 percent and this is expected to continue until 2020 (David and Sichman, 2009). The growth rate is positive because of the TEU's unique advantages (cheaper and easier cargo handling facility). Fourthly, the liner shipping companies are increasing their ship size (Stopford, 2009); this is due to the fact that when ship size increases, unit transportation cost decreases. Although some ports are adopting ways to increase container terminal capacity, other port authorities are under pressure due to issues pertaining to capacity shortage (Chao and Lin, 2011).

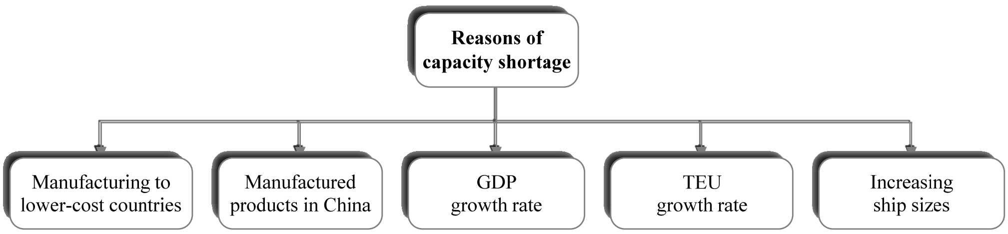

Figure 1. Reasons for capacity shortage at seaports

3. CONSEQUENCES OF CAPACITY SHORTAGE

The capacity shortage problem has compelled seaport authorities to build new facilities and infrastructure for their container terminals. For example, between the years 2007 to 2015, around 700 new container terminals will be required to be built in order to accommodate the growing number of containers in East Asian ports (UN and Korea Maritime Institute, 2007). The maritime transport industry is growing at a more rapid rate than the seaports are able to build sufficient facilities to smooth the flow of freight transportation (Pallis and de Langen, 2010); this is due to the fact that it takes many years (ranging from 2 to over 10) from decision making to the completion of changes to port infrastructure to increase capacity (Henesey, 2006). As many ports are exceeding capacity limits, seaports need to deal with the problems discussed as shown in Figure 2.

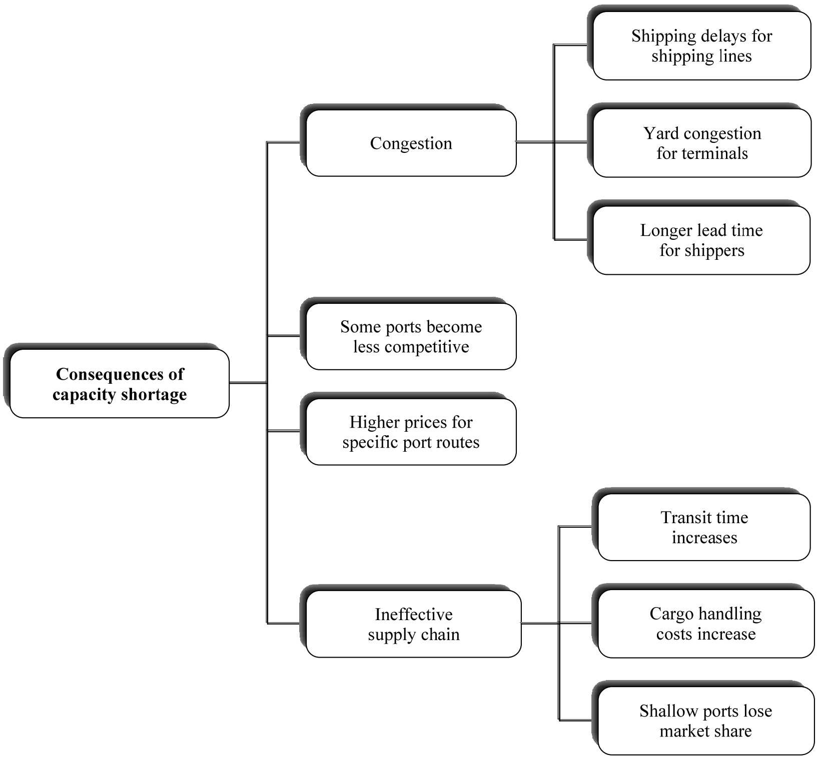

Figure 2. Consequences of capacity shortage at seaports

Firstly, capacity shortage creates congestion problems in the terminals and congestion has consequences for port users. For example, congestion accelerates during delays that occur and cost increases. Some typical examples of such delays are; missed feeders for shipping lines, yard congestion and re-handling for terminal operators, longer waiting times for trucking companies and longer lead times for shippers (Park and Noh, 1987, David and Sichman, 2009). Thus the parties involved with the supply chain face losses. Secondly, because of capacity problems and for economic reasons, the larger ships tend to visit a specific number of ports (Henesey et al., 2009). For example, a mega ship that has a capacity of 18,154 TEU can cause capacity shortage in many ports (Grossmann, 2008). Hence, recently built deep-water ports can gain market share from the shallow-water ports (Baird, 2002). If an exporting country sends its containers to an importing country via a hub port, problems will occur: (1) the "transit time" will increase. (2) "cargo handling costs" and "risk of damaging the cargo" will increase due to multiple freight handling in each port during the course of transhipment**.** So, capacity shortage causes supply chains to be ineffective in many ways. Finally, capacity shortage causes a port to increase the price of its service. This, in turn, increases the transport costs for the use of some ports and, thus, other less congested ports look more attractive to shippers (Dekker, 2005).

4. OBJECTIVE OF THE STUDY

Academic research that addresses container terminal operations from a System Dynamics (SD) perspective is still remarkably scarce in contrast to the typical discrete event-driven simulation approaches. For examples of discrete event-driven simulation, see Steenken et al., (2004) and Stahlbock and Voß (2008). Conversely, papers aiming to provide a system dynamics perspective of seaport problems, have not been extensively published (for examples of system dynamics problem, see Yeo et al., 2013, and Carlucci and Cirà, 2009). Therefore, to further establish the maritime logistics field, by identifying the consequences of capacity shortage at seaports and the corresponding supply chains, the study of Islam and Olsen (2011) offers a conceptualization (as embedded in Figure 3) based on an extensive literature review of the academic and industry-related papers concerned with the factors influencing seaport capacity from a holistic point of view. Although Islam and Olsen (2011) have examined the capacity shortage problem by reviewing the literature to suggest a framework (since there is limited literature on the subject of factors affecting seaport capacity; studies carried out thus far on capacity improvement mechanisms have been partly constrained by the lack of an integrated view), they have ignored to show the managerial implications of the framework. Therefore, to quantify and measure the effect of the framework on seaport capacity improvement potential, this study further explores the usefulness of the suggested framework from both a micro and a macro perspective.

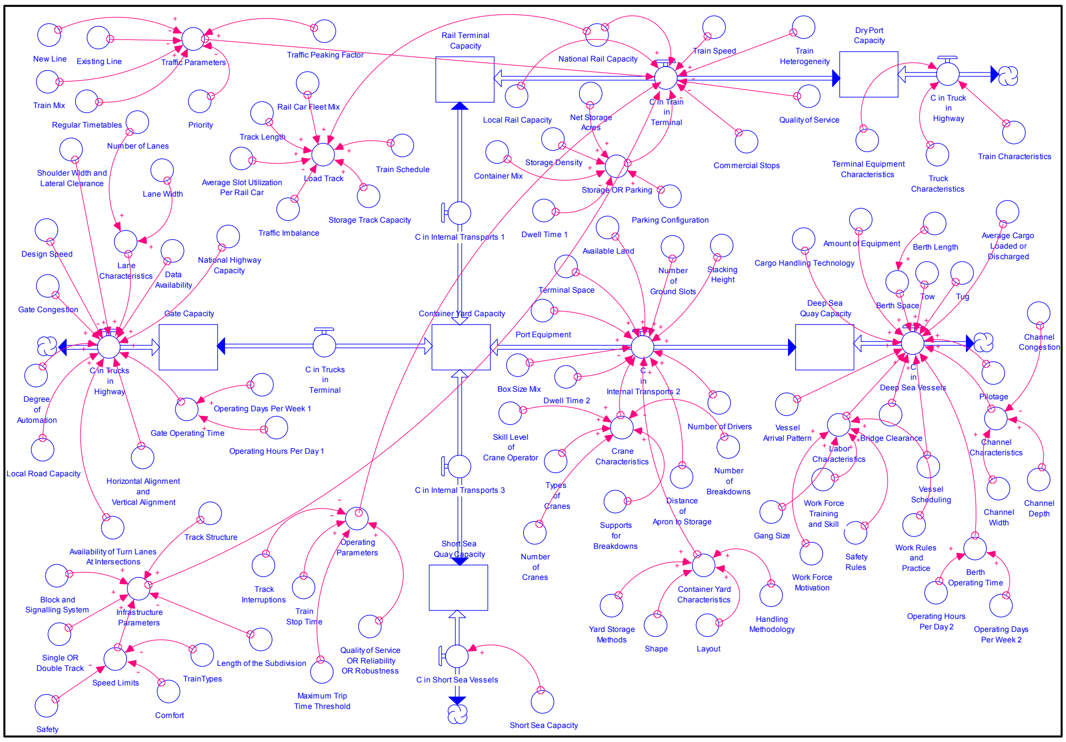

Figure 3: A review of factors affecting seaport capacity
Source: Islam and Olsen (2011)

5. MANAGERIAL IMPLICATIONS

System dynamics methodology is appropriate for the management of processes with feedback structures (Maani and Cavana, 2000). Taking the vital features of SD into account, this study has chosen the methodology to advance and showcase the application of the suggested framework (embedded in Figure 3). Kim (1998) also adopted a similar approach to develop a transportation planning model. Following a comparable approach, this research discusses the managerial implications from two perspectives, namely the micro and the macro. A description of the development of the SD model is outside the scope of this paper.

5.1 A Micro-level Perspective

A micro-level view looks into a capacity management problem at a port from a single dimension, such as, yard operations, which are important in the controlling of container inflows and outflows as terminal space is limited. To focus on yard operations by displaying a list of causes affecting the yard capacity and their interrelationship, a hypothetical Causal Loop Diagram (CLD) is created, as shown in Figure 4. The feedback loops in the CLD represent the complexity of the interconnected variables of the process and the stock element measures the yard capacity. The stock is the difference between the numbers of containers arriving at, or leaving, the yard. Therefore, the arrival of a truck adds to yard capacity and the departure of a truck does the opposite. However, in addition, variations in yard capacity are dependent on many other factors such as; number of truck lanes, degree of automation at the entry gate, and the availability of turn lanes at intersections. These factors also influence one another, for example, the required label of automation at the entry gate depends on the yard capacity that has been projected by the authorities, and the number of container trucks in a terminal depends on the provided degree of automation. Limited yard capacity may result in severe congestion.

The CLD can facilitate in the development of a capacity-management-related scorecard to monitor and manage yard capacity using performance indicators. The objective is to enable interaction between the port authority and the model. For example, the port authority may wish to see the impact of changes on yard capacity of a policy variable of interest (e.g., increasing the availability of turn lanes at intersections or investing in the degree of automation at the entrance gate). Using a slider tool (Figure 5 shows a sample user interface consisting of a diagram and three slider tools), the port authority can select one of the important variables and change the initial value by dragging the slider button during the simulation. The interface does not require the decision-maker to understand the complexity of the model.

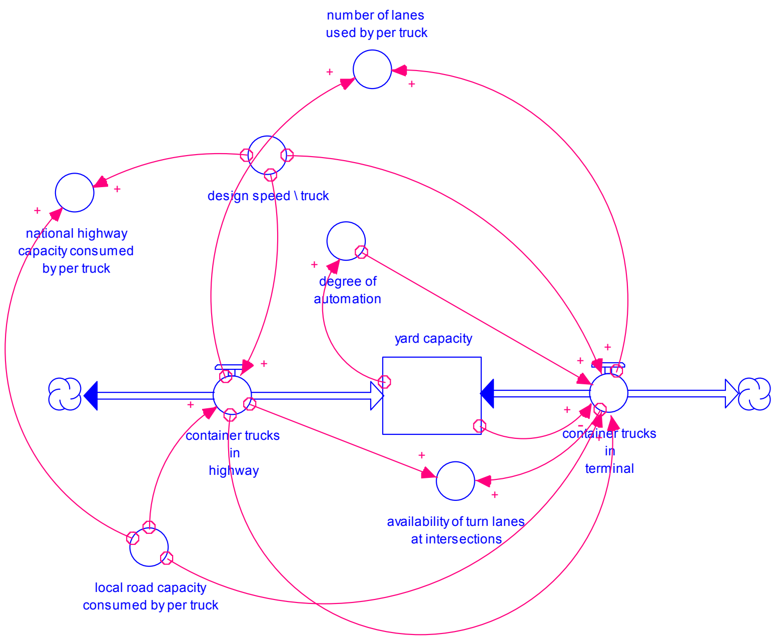

Figure 4. A simplified CLD for yard capacity management

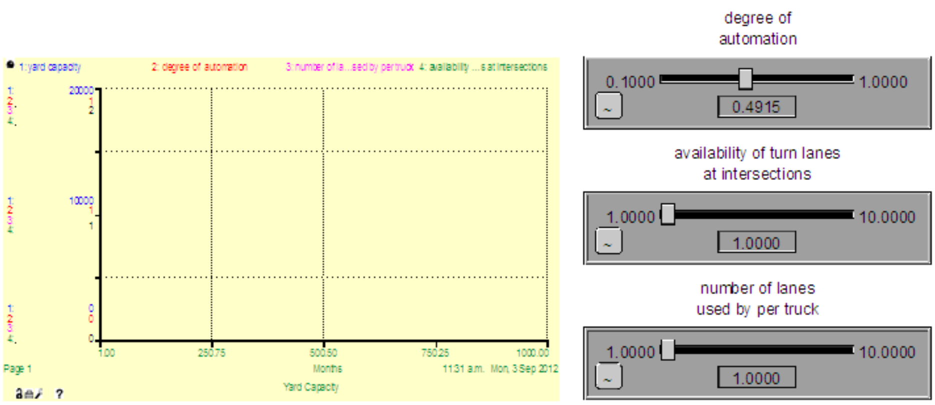

Figure 5. A sample user interface for yard capacity management

5.2 A Macro-level Perspective

The usual way of solving capacity management problems according to the literature is to divide a seaport into many dimensions and to focus solely on one dimension at a time, such as; gate operation, yard operation or container storage operation. Such a single-dimension-based solution approach focuses on one specific and disconnected dimension, whilst ignoring the application of the whole seaport-oriented approach. Thus, the system-wide capacity management method has received little attention in existing studies on seaport performance management and monitoring (Stahlbock and Voß, 2008). However, all components and processes need to work together to ensure the appropriate performance of a seaport as all elements are functionally and logically interconnected, and a capacity shortage in one dimension affects the service quality of the others. Hence, in order to provide for adjustments in capacity, the macro perspective suggested here considers all dimensions of a port from the operations at its gate to other facilities.

Gate capacity, short sea quay capacity, container yard capacity, deep sea quay capacity, rail terminal capacity and dry port capacity are some of the important stock-related elements of the macro-level CLD developed in Figure 6. Each of these stocks represents the capacity of the port system for each of the dimensions at any given time. One of these stocks is sufficient to be the cause of a bottleneck for the entire seaport; in addition, a small delay in any of the stocks can introduce significant disruption to the entire system as all of the stocks in the port are connected to each other. For example, the number of container trucks within a terminal depends on the number of container trucks on the highway or at the entry gate. Similarly, the entire container-carrying capacity of the container trucks in the yard is dependent on the loading capacity of the short sea vessels. These stocks are also connected to each other through feedback loops. A feedback loop occurs, for example, when the output of the yard capacity is connected back to the input of the same yard. The factors connected to a stock can also have links with many of the factors related to other stocks. Hence the making of another graphical interface can demonstrate the features of the macro perspective. The interface may include many types of diagrams for reporting and the sliders for taking inputs. Based on the requirements of the port authority, other parameters and reporting types may be added to the model.

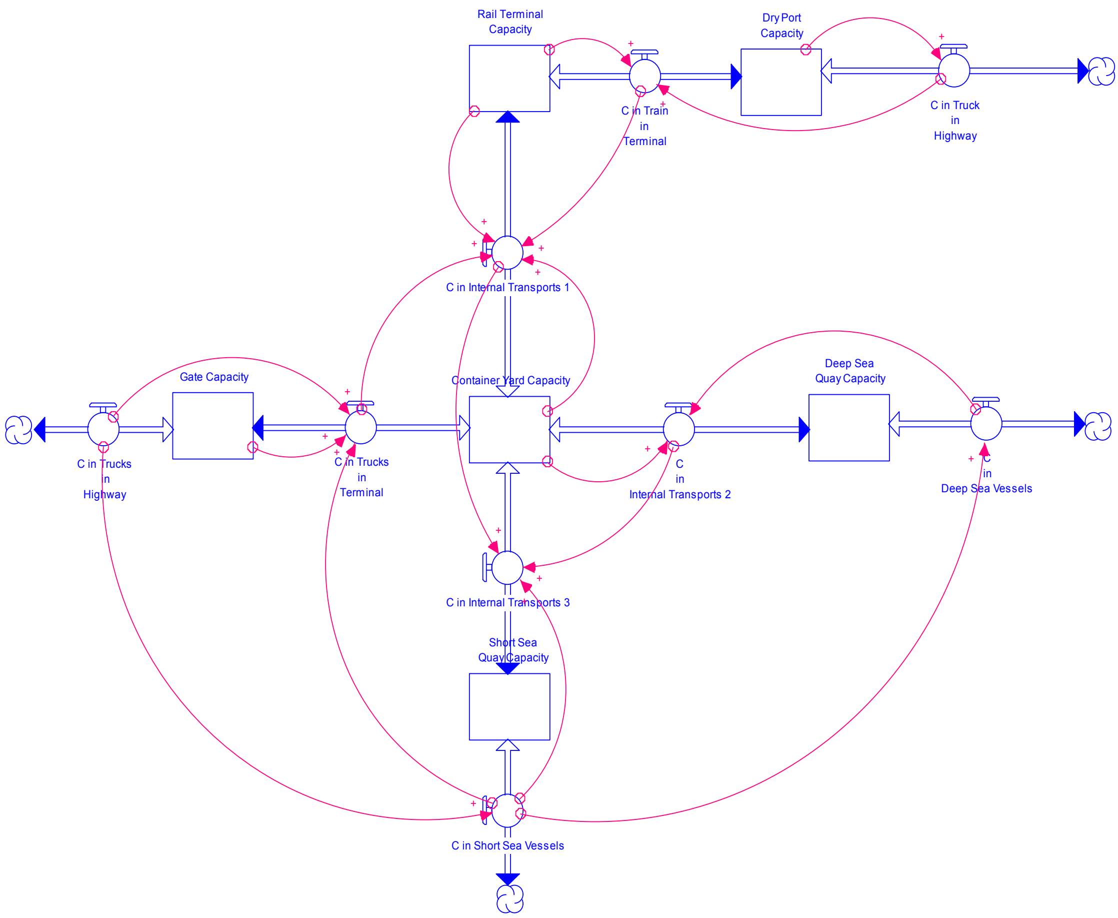

Figure 6. A simplified CLD for container terminal capacity management

6. CONCLUSION

The seaport of a country is an important link in its international supply chain as it facilitates in the moving of containerized goods from an exporting country to the importing nation. Hence the contribution of a port is imperative for both economic growth and national development. However, many ports of the world have insufficient capacity to handle the increasing number of containers (e.g., because of the exporting of Chinese manufactured goods worldwide) and the continuing growth in ship size. Due to the evolving capacity shortage and the further deterioration of the situation, port authorities are seeking opportunities that may lead to the resolution of the problem while, at the same time, turning the escalation of the problem into a competitive advantage. As a result of capacity shortage problem, port authorities look for efficient ways of expanding terminal capacity in order to remain competitive in the region of competition. As an approach to facilitate in capacity related problem solving by identifying the underlying capacity factors that are lacking in the literature, the study of Islam and Olsen (2011) reviews the literature concerned with the factors affecting seaport capacity from a holistic point of view, and offers a framework (embedded in Figure 3). Although Islam and Olsen (2011) have examined the factors affecting seaport capacity, they have omitted to suggest a promising solution for assessing the usefulness of the framework. By taking that limitation into account and suggesting the managerial implications for the proposed framework, the current study further explores the usefulness of the framework from both a micro- and a macro-perspective. The recommended perspectives should be applicable to most ports of the world given the customization of the framework to accommodate inevitable differences from port to port.

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