Optimal Strategies for Improving Resilience of Global Marine-based Freight Distribution Networks

Elise Miller-Hooks [1]
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Introduction and Motivation

Intermodal (IM) freight transport systems and their components play a significant role in world economies. Maritime transport operating within an IM system involving land-water interfaces remains the dominant mode for international trade. Ports and other terminals are critical components of these systems. Many of these components, as well as supporting rail and roadway system infrastructures, however, are by the nature of their designs and locations inherently vulnerable to rising sea levels, significant precipitation events, storm surges and consequent coastal flooding. Caldwell et al. (2002) describe potential impacts on freight transport due to climate change. The costs of such impacts can be excessive. For example, direct and indirect costs due to weakened infrastructure at ports and the like resulting from increased storm intensity and higher sea levels can lead to losses in the billions of dollars per day (Haveman and Shatz, 2006).

The IM system is a complex system of modal networks and IM interfaces with trade routes that cross the globe. Coordination that is enabled through the formation of such a system is required for national and international cargo movements, including raw materials, parts and finished goods. Production facilities are often located at or near IM terminals. Together these systems and related facilities form Global Commodity Chains.

The operation of such an international IM system involves a broad range of stakeholders, including national and private parties, with differing goals. In the context of marine-based freight distribution, these stakeholders include freight forwarders, transport companies, terminal operators and third-party logistics providers. While each terminal, link or set of links may be owned or operated independently, disruptions, backups, labor strikes, or physical, administrative or operational changes that arise in any single element can affect the performance of other elements within the Global Commodity Chain. Consider for example an event arising at a single port that impacts ship unloading times. In addition to creating a shortage in berth space for incoming vessels, the vessel will be delayed from moving to the next location creating queues and additional upstream backups. The initial disruption, thus, causes delays that ripple through the IM system, decreasing system-level productivity. Disruptions in pickup and delivery schedules will drive up the costs to shippers, producers, sellers and ultimately consumers. They may also cause permanent losses to perishable goods as well as vulnerable consumers who depend on life-sustaining supplies.

[1] Department of Civil, Environmental, and Infrastructure Engineering, George Mason University, miller@gmu.edu

Investments, thus, are needed to protect the IM system from such disruptive forces. Benefits derived from investments made in one portion of the system may carry over to the rest of the system. Since the IM system is an amalgamation of components and links with differing stakeholders, varying governing principles and investment sources, their interconnections and interdependencies must be taken into account when determining an optimal investment strategy. The strategic importance of ports in global trade flows was recognized in (Becker et al., 2013), wherein the importance of port interdependencies in predicting the potential impact of a local failure on global operations was purported. Becker et al. further noted the need for collaboration among a broad range of public and private stakeholders in implementing climate adaptation strategies.

Problem Conceptualization and Solution methodology

Optimization and equilibrium techniques will be presented for improving and examining the performance of both a single port and a network of ports that support Global Commodity Chains. The involvement of multiple stakeholders, owners and operators oftentimes involves competing objectives and differing roles. Thus, capital investment strategies involving multi-investor schemes are formulated and their potential will be studied. For this purpose, the techniques will be designed to support decisions pertaining to: (1) in which portions of the system (which ports, terminals or lines) to invest, and (2) to what level each stakeholder should or would need to invest. Stakeholders seek to maximize their own profits while seeking an equilibrium among the different stakeholder objectives that may involve the performance of different, overlapping trade routes. This work utilizes concepts of complementarity and multi-actor equilibrium modeling for the conceptualization of this multi-stakeholder investment problem. It accounts for the impact of investment decisions and related improvements to reliability in route choice thus demand at the ports or other intermodal facilities.

Application

Proposed techniques will be illustrated on a network representation of a worldwide IM freight system.

References

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