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Developing a model for measuring the resilience of a port-hinterland container transportation network

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ABSTRACT

The ongoing development of world trade has increased the demand for safe and resilient container transport. In this paper, we apply the concept of resilience to the context of a port-hinterland container transportation network. We first propose our definition of resilience within this context, and then build an integer programming model to obtain a quantitative measure of resilience from the perspective of shippers. The model is tested using a numerical simulation based on the specific case of Gothenburg Port and part of its hinterland. Finally, the validity and reliability of the model are tested.

1. Introduction

As the transportation hub linking shipping and inland transport, seaports are critical to the efficiency of international logistics and the globalization of the world economy (Cullinane et al., 2006) and, in consequence, to local, regional, and national economic development. While engaged in global trade, shippers and carriers constantly seek to reduce transportation cost by focusing beyond the costs incurred in deep-sea shipping or in ports. More than ever before, the efficiency of hinterland transportation has become equally important to that of port operations and shipping (Notteboom and Rodrigue, 2005; Rodrigue and Notteboom, 2006; Wilmsmeier et al., 2011; Kramberger et al., 2015; Wang and Cullinane, 2016).

Safety and security are prerequisites for efficient hinterland transportation. However, ports and their hinterlands are vulnerable to various disturbances that are often unexpected and severe, which induce the breakdown of the container transportation network between ports and the hinterland. For example, in March 2011, an earthquake of magnitude 9.0 on the Richter scale hit Japan near the northeast coast of Honshu. This was followed by a series of massive tsunamis. During this severe disaster, almost all of the ports on the northeast coast of Japan were shut down, including Hachinoe, Kashima, and Sendai. Numerous other ports in the east, for example Miyako and Hitachi, were damaged to different degrees. A total of 19.4 million TEUs were handled in Japan in 2011, and approximately 7% of this volume was affected in some way by the earthquake and the subsequent tsunamis (Reuters, 2011).

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In addition to natural disasters, ports and their hinterlands are also vulnerable to man-made events, such as strikes and terrorist attacks. For example, the negotiation between the International Longshore and Warehouse Union and the Pacific Maritime Association on the U.S. West Coast lasted for several months starting from June 2014. Five months later, strikes occurred separately in the ports of Los Angeles, Long Beach, and Oakland. These strikes resulted in the total breakdown of port operations, causing severe backlogs and significant delays to the movement of containers. The economic loss was estimated at approximately US$2.5 billion (ISSC, 2014).

As these real-life examples illustrate, ports and their hinterlands can be affected by various natural and man-made disasters, which, for the purposes of this paper, are termed as "unconventional emergency events" (UEEs). The first keyword, "unconventional," refers to events that are abnormal, devastating, and unpredictable. It differs from the more mundane, but probabilistic "conventional" events, such as theft and power outage. People are commonly ill-prepared for these "unconventional" events and are sometimes even unable to anticipate them. We propose that a vital attribute of any port-hinterland container transportation network (PHCTN) is its capacity or ability to react appropriately to the risk of UEEs and sustain, or at least regain as quickly as possible, its normal performance level. The importance of this attribute is such that it constitutes an aspect of the competitiveness of transportation service suppliers within the network and an essential criterion for shippers in evaluating the network's level of service against potential competitor networks.

Over the years, the concept of resilience has been addressed in numerous studies on disasters. From an academic perspective, resilience measures the capacity of a system to cope with changes that occur inside or outside the system (Holling, 1973). Its focus is to maintain the performance of a system or achieve a more desired outcome (Christopher and Rutherford, 2004). Resilience comprises two dimensions, namely, inherent and adaptability (Rose, 2006). Building resilience into a system relates to attempting to ensure its recovery from the adverse effects of a UEE within an acceptable period of time and at a suitable cost while reducing the adverse effects of the changes as much as possible (Carvalho and Cruz-Machado, 2009).

In this study, resilience is investigated within the concrete context of a PHCTN, focusing on container flows. In particular, the intention is to answer the following research questions:

(1) How can resilience be defined within the context of a PHCTN?
(2) How can this definition of resilience be measured quantitatively?

In conducting this research, the following assumptions are made about the targeted PHCTN context:

(1) The study is constrained to the case where only a single seaport in the network plays a critical role in container transportation.
(2) This single seaport within the network has developed to a level where the "port regionalization" development phase is applicable (Notteboom and Rodrigue, 2005). This level indicates the existence of a discontinuous hinterland (Notteboom and Rodrigue, 2007) where numerous discrete areas of demand are served by their associated "dry ports" and without any overlapping of areas of demand among these dry ports.
(3) Intermodal transport in the hinterland is fully developed and, specifically, by default the container flow between shipper locations and the dry ports is transported by road, whereas that from/to the seaport to/from the dry ports is by train. In building the measurement model for network resilience, the focus rests on the rail transportation component.
(4) The dry ports in the network function as points of consolidation and deconsolidation, as well as intermodal terminals that offer intermodal services. Fig. 1 illustrates a typical PHCTN, which forms the basis of this study.

From a mathematical perspective, the probability of a UEE occurring is extremely small. These events are not only "unconventional" but also "emergent," which signifies their unpredictability. People have difficulty in approximating the probability distribution function that applies to such events. Therefore, we exclude pre-UEE (i.e., pre-event) preparedness activities from our measurement model, because the inherent unpredictability of UEEs undermines the possibility of achieving a high benefit–cost ratio from investing in such measures for the players within a network. After damage has been incurred following a UEE, the network should react immediately to reduce the loss as much as possible. For this reason, only immediate recovery activities, rather than post-event rebuilding and other longer-term aspects, are considered in this study.

The analysis contained in this study constitutes an original contribution to the literature in two respects. First, although there have been previous studies that address network resilience (e.g., Wang and Ip, 2009; Nair et al., 2010; Ip and Wang, 2011; Miller-Hooks et al., 2012; Faturechi and Miller-Hooks, 2014), particularly the work of Chen and Miller-Hooks (2012) in dealing with the resilience of intermodal transportation networks, no focused and concrete analysis of the resilience of a port-hinterland container transportation network exists, especially where an empirical application is involved. This study fills this gap.

Second, this paper provides a new perspective on quantitatively measuring the resilience of a transportation network. As presented in Section 3, rather than adopt the social welfare or supplier perspective typical of previous studies, this work adopts the perspective of network users because multiple suppliers (local municipalities, rail operators, dry port terminal operators, etc.) are usually involved in a PHCTN. As these suppliers aim to maximize their own profits, issues like "free riders" in the Boxed Pig Game (Baldwin and Meese, 1979) become a concern when implementing recovery activities. The same problem occurs under the social welfare perspective, in that accountability for the costs of recovery activities and the setting