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Estimating economic losses of industry clusters due to port disruptions

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ABSTRACT

Seaport operations are highly important for industries which rely heavily on imports and exports. A reliable evaluation of port risks is essential to govern the normal running of seaborne transportation and thus the industrial economies. The occurrence of a breakdown in the trade facilitators, such as ports, will disrupt the smooth flow of supply chains for the industries. The estimation of the economic loss for an industry when a port gets disrupted is a challenging task as the relationship between the port and industry clusters is complex. This study aims to develop a systematic framework for performing economic loss estimation of industry clusters due to port disruptions. The whole risk assessment is split into three stages focusing on the establishment of a network flow model, economic estimations and evaluating risk mitigation strategies. The proposed idea is demonstrated by a case study on Shenzhen port and its related manufacturing industries. A dynamic inventory control strategy used by manufacturers is found to be beneficial for mitigating port disruption risks.

1. Introduction

In an increasingly globalized economy, the scope of supply chains expands beyond national and regional boundaries. Seaports play a crucial role of facilitating international trade in both inbound and outbound supply chains. Any risks faced by ports affect not only port operations but also trade flows and various supply chain parties. Any changes in the port operation status could have a direct impact on cargo delivery, affecting regional and even global activities. Correspondingly, ports are required to be resilient and reduce expected/unexpected losses in order to continue serving the supply chains (Mansouri et al., 2010). This is particularly important for industries which rely largely on seaborne transport. However, ports and shipping are regarded as the most uncertain and volatile component within the supply chains (Sanchez-Rodrigues et al., 2010). Many potential risks could cause a halt in the functioning of ports. For example, Chopra and Sodhi (2004) classified supply chain risks into nine categories, namely, disruption, delay, systems, forecast inaccuracies, intellectual property breaches, procurement failures, system breakdown, inventory problems, and capacity issues. Among these risks, port disruption is recognized as one of the major threats that may happen due to various causes especially from environmental factors (Lam and Su, 2015; Zhang and Lam, 2014, 2015a). A port disruption is defined as an event that could cause a sudden interruption on material flow in the transport system, which may lead to a stoppage in cargo movement (Wilson, 2007). Such a risk event can be caused by natural or man-made hazards such as typhoon and fire and may result in long delays of cargo flows at ports and massive adverse impacts on multiple elements of a supply chain simultaneously.

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The need for risk based policies or management strategies has been articulated widely. Focusing on the safety and security of the port based transportation system, there have been several studies of port risk assessment. Svensson (2000) is one of the few pioneers who developed a conceptual framework for the analysis of port vulnerability within a supply chain. Merrick et al. (2002) established a risk model that was capable to assess the risks of accidents involving oil tankers in the coastal area. Yang et al. (2014) developed a risk quantification approach to assess port facility security. A fuzzy quantitative analysis was proposed by Pak et al. (2015) to evaluate the safety levels of ports. Similar techniques can also be seen in Beer et al. (2013). Although these former studies have greatly enhanced our understanding in port risk measures, they did not investigate the economic impact of port disruption. While port risk assessments are essentially required by policy makers including port authorities, terminal operators, and economics and trade authorities, the literature has not provided any generally accepted approaches to measure economic losses of industry clusters due to port disruption in a quantitative manner. Furthermore, port disruption risks are more than safety and security issues to cover other forms of interruptions like natural hazards. Hence, the demand for a systematic framework in performing economic loss estimation of industry clusters due to port disruption is very strong.

To address these research gaps, this paper aims to develop a framework of calculating the port disruption resulted economic losses for adjacent industry clusters. To analyze the propagation of port disruption within the industry cluster, a Petri Nets (Petri, 1962) model is utilized to model the relationship between the port and industries. The stepwise process and efficient environment characteristics of Petri Nets model are used for conducting simulations of cargo flows between ports and industry clusters. Moreover, based on the flows of cargo, an approach for the economic loss estimations of port adjacent industries is proposed. This covers both the inbound and outbound logistics. The study calculates the direct economic losses of industries resulted from a port disruption. Then in turn, an optimized risk mitigation scheme is aimed to be found from a scenario analysis.

After the introduction, the remaining of this paper is organized as follows. An overview of port disruption risk literature will be given. Then, the framework of the economic loss estimation for port adjacent industry clusters is elaborated. To demonstrate the proposed procedures, Shenzhen port is selected in a case study. Detailed steps in the economic loss estimations are then presented and explained. After which, a case study focusing on the printer industry is investigated. Next, based on the results, an investigation on how to utilize the loss estimation in a risk mitigation scheme is provided. The last section draws the conclusion.

2. Literature review

As globalization prevails, the world economy has become more intertwined and integrated. This imposes higher challenges on supply chain management as the members in supply chains become more interconnected (Lam and Dai, 2015). In a more interconnected global supply chain, a disruption at any stage of the chain could lead to a domino effect on the rest of the parties including shippers, consignees, shipping companies, intermodal transport providers and other ports. Although ports as vital trade facilitators and components of the supply chains are among the most significant causes for uncertainty (Sanchez-Rodrigues et al., 2010), there are limited researches on port related industrial risks and port disruptions' economic loss estimation.

Several studies related to port disruption can be found from the literature. Beside the direct impact on a particular supply chain node, disruption could also result in indirect impact on the rest of supply chain network. Chang (2000) studied the earthquake in Kobe, Japan which happened in 1995 and discovered that the disaster substantially affected Kobe port's performance in terms of losing a significant share of transhipment traffic. Other than natural disasters, man-made risks such as terrorist attack could affect port related industries greatly. Rosoff and von Winterfeldt (2007) and Park (2008) analyzed the impact of the shutdown of Los Angeles and Long Beach ports due to terrorist attacks. They found that such kind of major port disruption caused considerable economic losses and extensive interruptions to trade activities. Paul and Maloni (2010) conducted a more generic simulation study to include both natural and terrorism-related disasters at ports. Through the cases of the North American container port network, the study illustrated the effect of cost increases generated by port disasters. More recently, Kajitani et al. (2013) analyzed the economic impacts caused by a chemical explosion in the Straits of Malacca and Singapore. An explosion and fire will affect the associated ports resulting in a prolonged blockage of this critical navigation channel and the transhipment traffic. The literature also extended to focus on port disruption risk mitigation. Lewis et al. (2013) studied the macro effects of generic strategies of port disruption risk management including contingency plan, inventory management, and efficient capability. Lam and Su (2015) also examined the trend of port disruption and risk mitigation strategies for reducing the likelihood and severity of various types of port disruptive events.

To enhance the coverage and depth of the literature review, the more generic studies on port economic impact analysis are also referred to. Table 1 summarizes the three existing methods for port disruption economic impact analysis and overall port economic impact analysis. Firstly, the Input Output Model provides a detailed overview of the underlying relations between all parties involved in port activities, inside and outside the port area. However, the reliability of the data used need to be carefully examined and in many cases data about risk and economic losses may not be available (Coppens et al., 2007; Danielis and Gregori, 2013; Zhang and Cao, 2015). Secondly, the Gravity Model predicts trade flows and therefore economic developments between ports/countries. It can be used in disruptive events like mechanical breakdown of port machineries, natural disasters and terrorist attack. Despite the benefits, the estimation of the logarithm is infeasible due to the presence of heteroskedasticity in trade data and the existence of zero flows. Thus, different estimation techniques are required to be