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Strategic investment in enhancing port–hinterland container transportation network resilience: A network game theory approach

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ABSTRACT

China's "Belt and Road" strategy emphasizes the significance of maritime logistics. To ensure the efficiency and safety of landside maritime logistics, this study aims to investigate the strategic investment of players in a port–hinterland container transportation network to enhance network resilience to man-made unconventional emergency events by reducing vulnerability. Given the complexity of the involvement of multiple players and their interacting complementary and competitive business relationships, network game theory is adopted. Results show that the complementary influence Bonacich centrality of players plays a critical role in determining their investment decisions and serves as basis from which useful managerial insights can be derived.

1. Introduction

Maritime transport plays a pivotal role in world trade, wherein approximately 80% of the world's merchandise trade volume and 55–67% of the world trade value are transported through shipping (UNCTAD, 2016). The new Chinese national strategy of "Belt and Road" (B&R, that is the Silk Road Economic Belt and the 21st Century Maritime Silk Road) emphasizes the significance of maritime logistics. A safe and resilient maritime logistic chain is a prerequisite for connecting the East Asia economic circle with the developed European economic circle and for boosting economic development of inland countries. Within the entire maritime logistic chain, the landside portion between ports and hinterlands serves as an essential link. This side includes various transportation modes involving multiple stakeholders who deal with complex legal and customs issues (Mansouri et al., 2009a; Lam, 2012). For example, from the perspective of transportation cost, in transporting containers from UK to Canada, approximately 50% of expenses are spent on landside transport (Stopford, 2008).

Thus, this study targets on a port–hinterland container transportation network (PHCTN). It gives a special attention to container transportation because approximately 90% of cargoes are transported in this manner (Van de Voort and O'Brien, 2003). Further, this study centers on intermodal transportation, as an increasing trend of intermodal transportation market share worldwide is witnessed due to its advantages on environmental issues, costs, and safety aspects (Konings et al., 2013; Lam and Gu, 2016).

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Table 1
Selected world-shocked catastrophic accidental explosions related with PHCTNs from 1900 to the present.

Event	Type	Direct cause	Consequence
1917.12.6, Halifax explosion, Canada	Port explosion due to ship collision	A French ammunition ship, *SS Mont-Blanc*, collided with a Norwegian vessel of *SS Imo* at a strait connecting the upper Halifax Harbor to Bedford Basin.	The Richmond district of Halifax was devastated. Approximately 1600 people were killed instantly, 9000 others injured, and more than 300 of whom died later. 12,000 buildings within a 2.6-kilometre radius were destroyed or badly damaged. The entire city blocks were caught up in the inferno, resulting in an estimated C$ 569 million in damage. The reconstruction took about 25 years.
1944.4.14, Bombay docks explosion, India	Ship explosion at the port	The freighter *SS Fort Stikine*, carrying a mixed cargo of cotton bales, gold and ammunition with 1400 tons of explosives, caught fire and was destroyed in two giant blasts.	About 800 to 1300 people were killed. More than 2500 were injured and 80,000 people were made homeless. More than 50,000 tonnes of shipping were destroyed and another 50,000 tonnes of shipping were damaged. Besides, an estimated of 6000 firms were also affected and 50,000 people lost their jobs. The reconstruction of the port took about seven months.
1947.4.16, Texas City disaster, USA	Ship explosion at the port	The French-registered vessel *SS Grandcamp* caught fire with approximately 2200 tonnes of ammonium nitrate detonated, causing subsequent chain-reaction of fires and explosions in other ships and nearby oil-storage facilities.	It is the worst industrial accident in American history. At least 581 people were killed, more than 5000 were injured. The seaport was destroyed with many businesses flattened or burned. About 1100 vehicles were damaged and 362 freight cars were obliterated. The property damage was estimated at $ 1.07 billion in today's terms.
2005.12.11, Buncefield fire, UK	Oil storage terminal explosion	A fuel-air explosion in a vapor cloud of evaporated leaking fuel. Further explosions followed, which eventually overwhelmed 20 large storage tanks.	43 people were injured. The explosion caused black smoke cloud that was visible from satellite photographs. Hundreds of homes in the Hemel Hempstead area were evacuated. The motorway was shut down between junctions 12 and 6a. Other roads in the vicinity were also closed. The flames were extinguished by the afternoon of the next day. The direct economic loss was 250 million pounds back then.
2010.7.16, Dalian oil spill disaster, China	Oil pipe explosion at a port terminal	An oil pipe exploded because of continuously pouring in the desulfurizer when a tanker had already finished the unloading operation.	Approximately 1500 tons of crude oil spilled, polluting at least 50 km^2 of nearby sea surface. The soaking up operation took about 10 days with a firefighter died doing the cleaning up. The oil product pier was temporarily shut up. The operation at the container terminal of Dalian Port Group was suspended for five days. Besides, the grain and iron ore terminals, which were close to the oil product pier, were also affected on certain degrees.
2015.8.12, Tianjin port explosion, China	Container explosion at port	The spontaneous combustion of nitrocotton stored in containers due to evaporation of wetting agent.	165 people were killed, 8 were missing, and 798 were injured. 304 buildings and 7533 containers were destroyed or damaged. The direct economic loss was 6.8 billion RMB. The traffic control around the explosion area was took place during rescue operations, which seriously impeded container traffic in and out of the port. The cleaning-up work took about one month.

Source: Summarized by the authors from various sources.

However, a PHCTN shows vulnerability to various unexpected and often severe disturbances (Marufuzzaman et al., 2014), causing considerable economic losses and damages to social welfare. The events that may cause such disturbances could be either natural or man-made. This study focuses on the latter, and terms it as man-made unconventional emergency event (MUEE). In this paper, MUEE specifically refers to three types of events, namely, catastrophic accidental explosions, labor strikes and terrorist attacks. Compared with daily operational risks, such as theft and fire, MUEEs present relatively low probability but enormous consequences to freight transport services of PHCTNs (Cox et al., 2011; Jabbarzadeh et al., 2016).

In specific, first, catastrophic accidental explosions are unintentional disasters. It often happens as explosions of hazardous chemicals due to reasons such as skill-based errors, lack of safety awareness, failure of safety inspection, and so on (Griffin and Neal, 2000; Lam and Su, 2015). Table 1 lists selected world-shocked catastrophic accidental explosions related with PHCTNs from 1900 to the present. The consequences were terrible. Nevertheless, it is both practically and theoretically proved that catastrophic accidental explosions can be well prevented through effective preventive investments. In practice, for example, the official investigation report of Tianjin Port explosion (August of 2015) claims that the explosion would not happen if the responsible logistic company (referred to Ruihai Logistic Ltd.) could have realized its duty on production safety with proper investments, such as giving the employees proper safety trainings, conducting regular safety inspection, making contingency plans, etc. In theory, similarly, Lam and Su (2015) proposed two major approaches to mitigate such risk through interviews with port terminal operators, shipping lines and insurance companies. One is to enhance proactive safety management, including improving safety awareness, enhancing the execution of organizational processes, formulating specific guidelines for safety supervision and management, giving proper trainings to staffs, conducting regular and stringent checks on the daily operation, and so on. The other is to make contingency plans and conduct drills. Therefore, an effective investment is a pre-requisite in PHCTN resilience.