Transportation Research Part E 77 (2015) 198–214

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

Robust supply chain strategies for recovering from unanticipated disasters

Li-Ming Chen [a], Yan Emma Liu [b], Shu-Jung Sunny Yang [c,*]

[a] Department of Business Administration, National Chengchi University, Taiwan
[b] Leeds University Business School, University of Leeds, UK
[c] Southampton Business School, University of Southampton, UK

ARTICLE INFO

Article history:
Received 22 December 2013
Received in revised form 20 January 2015
Accepted 20 February 2015
Available online 27 March 2015

Keywords:
Emergency management
Supply chain disruptions
Supply chain vulnerability
Cellular automata
Complex systems
Behavioral game theory

ABSTRACT

Recovering from unanticipated disasters is critical in today's global market. This paper examines the effectiveness of popular recovery strategies used to address unpredictable disasters that derail supply chains. We create a formal model to portray dynamic operational performance among supply chain firms facing disruptions caused by natural and man-made disasters. Our analysis shows that a supply chain recovers best if member firms adopt a radical, rapid, costly recovery strategy that immediately resolves the disruption. This observation is robust to various resource consumption requirements. We apply our methodology in the case of Taiwan's 2011 food contamination scandal and provide managerial insights.

1. Introduction

Today's global business landscape is characterized by increasing uncertainty and vulnerabilities. Recent years have brought unforeseeable disasters – man-made and natural – including terrorist attacks, computer viruses and 'hackings', financial crises, earthquakes, tsunamis, the SARS and Ebola epidemics, and nuclear reactor accidents, etc. Anecdotal evidence about the global production plummet due to Japan's March 2011 earthquake and nuclear reactor semi-meltdown shows that most serious, unpredictable disasters can disrupt the normal flow of goods and materials within and across supply chains. Such unpredictable disasters expose firms enormous operational and financial risks (Kleindorfer and Saad, 2005; Papadakis, 2006; Xiao and Yu, 2006; Bueno-Solano and Cedillo-Campos, 2014). Motivated by these real-world observations this paper examines the effectiveness of popular recovery strategies when a supply chain faces unpredictable, hazardous events, and then provides managerial insights for supply chain managers.

Historical data indicate that the total number of natural and man-made disasters has soared dramatically over the last two decades (see e.g., www.cred.be; www.munichre.com). For instance, Thailand's 2011 massive flooding affected the supply chains of computer manufacturers dependent on hard disk drives and of Japanese auto companies including Honda, Toyota, and Nissan with factories in Thailand (BBC, 2011), among others. The 2010 eruption of an Icelandic volcano caused flight disruptions across Europe that severely affected supply chains dependent on air-freighted imports and exports, such as food and flowers. BMW had to suspend auto production at three plants in Germany due to the parts supply interruptions resulting from this volcanic eruption (DailyMail, 2010). Empirical studies indicate that most supply chains tend to collapse

* Corresponding author. Tel.: +44 (0)23 8059 1954.
E-mail address: s.s.yang@soton.ac.uk (S. S. Yang).

http://dx.doi.org/10.1016/j.tre.2015.02.015
1366-5545/

during disruptions caused by major unanticipated disasters and many of them never recover afterwards (e.g., Eskew, 2004; Tang, 2006). The detrimental effects of various catastrophic disasters (Hendricks and Singhal, 2005; Green et al., 2011) motivate us to identify robust supply chain strategies that promptly and effectively address them – strategies enable supply chains to maintain their operations during and closely after disaster-caused disruptions.

To explore supply chain dynamics in the presence of major disasters, we construct a behavioral supply chain model using the cellular automata (CA), a simulation method that considers strategic interaction among neighboring firms and the resultant impact on the entire supply chain (Davis et al., 2007; Harrison et al., 2007; Nair et al., 2009; Yang and Chandra, 2013). Using the aforementioned floods in Thailand and the volcano eruption in Iceland as examples, we employ CA to model how an unanticipated disaster in a supply chain firm places the entire supply chain's operational and financial performance at risk, following the forest fire model in physical science (see Robertson and Caldart, 2008). In essence, our model mirrors many real-world supply chain disruption cases.

Research that explores ways to mitigate supply chain disruptions has generally followed one of two streams: disruptions caused by anticipated and unanticipated disasters. In practice, a supply chain frequently faces disruptions with anticipated probability of occurrence and magnitude of impact, due to forecast errors caused by demand fluctuations, machine breakdown, and poor supplier performance (e.g., Hilletofth and Hilmola, 2008; Lättilä and Saranen, 2011). The first stream, anticipated disaster-caused disruptions, suggests that the disruption's adverse impact can be mitigated by taking steps to diminish the *likelihood* of a disruption (e.g., Chang et al., 2007); on this, Altay and Green (2006) offer a comprehensive literature survey. However, how can a firm reduce the chance of a disruption if the probability distribution of the hazards is *unknowable*, such as those caused by unpredictable, sudden-onset natural and man-made disasters? The first stream of research cannot address this thorny problem, which is important in global supply chain management of product production ranging from airplanes to consumer goods to chemicals (Sheffi, 2007; Simchi-Levi et al., 2014). But the second stream of research, unanticipated disaster-caused disruptions, attempts to address this problem of unforeseeable incidents.

In the past decade, managers of supply chains and operations have become much more concerned about the potential consequences of unanticipated disasters at their facilities and those of their supply chain partners (Sheu, 2007b; Kunz and Reiner, 2012). The increased concern is partly the result of greater inter- and intra-organizational complexity and increased exposure to unpredictable natural and man-made disasters. For instance, meteorologists are forecasting increased weather events – in terms of severity and incidence rates – due to global warming. These events will inevitably disrupt supply chains because shipping, air freight, trains, and other transportation modes along with fuel shortages, communication and electricity outages and electricity supply disruptions, will be greatly affected by increasingly extreme weather events. As noted earlier, in 2011 Honda had to cut its car production at six plants and postponed new model launches in the US and Europe due to a shortage of electrical and engine components from suppliers in flood-stricken Thailand; Kenyan farmers who relied on air-freighted exports to Europe had to destroy over 400 tons of flowers after two days of flights cancellations due to the eruption of an Icelandic volcano; and Japan's 2011 earthquake and tsunami halted Toyota's production at three plants for several days and damaged American dealerships (see Chopra and Sodhi (2004, 2014) for more details and examples).

To address the practitioners' and researchers' increased concern about unanticipated disasters, a second stream of research has recently emerged that explores the role of supply chain disruptions caused by unpredictable natural and man-made disasters (Sheu, 2007a). For instance, Bueno-Solano and Cedillo-Campos (2014) develop a system dynamics model to analyze the devastating effects of terrorist acts on global supply chain performance. Qi et al. (2004) examine a one-supplier-one-retailer supply chain experiencing demand disruptions and the resultant impacts on supply chain's coordination mechanisms in pursuit of maximizing supply chain performance. Xiao and Qi (2008) extend Qi et al.'s (2004) analysis of a one-manufacturer-two-competing-retailers supply chain under disruption. However, most studies in this stream explore the effects of supply chain disruptions but fail to consider recovery strategies – the major focus of this work (see, Altay and Green, 2006; Sheu, 2010). We extend this research stream by developing a formal model of supply chain dynamics under unanticipated disasters and their effects on member firms over time. Also, we summarize several observations by carefully analyzing extensive simulation outcomes.

Our key findings are as follows. An incremental recovery strategy mitigates disruptions from unanticipated disasters by incrementally improving the supply chain's recovery performance; this strategy performs well when bringing the entire supply chain operations from a poor to good state consumes considerable resources. However, with the incremental recovery strategy, the supply chain may not perform as well as expected if the above condition – high resource consumption requirement – does not hold. As Lee (2004) highlights, a good supply chain strategy for recovery must perform at "triple-A" job by employing agility, adaptability, and alignment. Our computational analysis demonstrates that a radical (the most rapid) recovery strategy – one that contains the impact of a disaster within the effected firms and strives to immediately fix the disruption – is most robust. That is, in most disruptive cases, the radical recovery strategy consistently performs reliably. In contrast, strategies using the state-of-immediate-neighbors as a reference point are not as effective as the radical strategy to inhibit the contagion effect of disasters across the supply chain, leading to relatively low recovery performance. Their lack of efficiency is more significant when the supply chain is relatively large (e.g., the supply chain has ten echelons). These findings and insights under the supply chain structure generally hold in a stochastic setting in which a firm's recovery strategy is altered over time and in an extended supply network structure where each member firm has multiple upstream and downstream neighbors. We describe those conditions and strategies in detail, and justify these insights and other results in subsequent sections.