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Literature Survey: Field-Based Studies of Supply Chain Robustness

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LITERATURE SURVEY: FIELD-BASED STUDIES OF SUPPLY CHAIN ROBUSTNESS [1]

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Abstract:
This paper points out the relative lack of field-based research on supply-chain disruptions caused by disasters. We show how field-based studies of supply chain robustness complements the existing literature on supply chain management (SCM) and business continuity planning (BCP), with its focus on real-world cases and analysis of firm responses to disasters through a lens that emphasizes firm capabilities. We also highlight the important role of information management, leadership, and coordination across the supply chain in disaster preparation and recovery.

Keywords:
Field-based studies, Supply chain robustness, Business continuity plan, Supply chain disruption, Risk management practices, Hurricane Katrina, Integrative manufacturing information system, Supply chain leadership

1. INTRODUCTION

1.1. Field-Based Studies of Supply Chain Robustness

Fujimoto (2019) presented the general framework and purpose of field-based studies of supply chain robustness, e.g., to shed light on how manufacturing firms and industrial sites (*genba*) improve both their supply chain robustness and resilience against major disasters when global competition is intense. In this paper, we will review the existing literature tackling this issue in the areas of business economics, organizational studies, supply chain management, business continuity planning, and so on.

To state our conclusion first, we think that, although ample existing literature has analyzed how firms and business organizations manage risks and uncertainties, including supply chain disruptions caused by disasters, there have been relatively few academic works that have explored principles and prescriptions regarding supply chain robustness and competitiveness based on empirical field studies of how actual firms behave and learn in such situations.

In recent decades, researchers have examined complex issues encompassing risks, vulnerabilities, and uncertainties in dynamic external environments and vast networks of suppliers (Cusumano and Takeishi 1991, Lambert and Cooper 2000, Oke and Gopalakrishnan 2009, Ellis et al. 2011, Sawik 2011, Schmitt and Singh 2012). Many of these studies on supply chain management (SCM) and business continuity planning (BCP) examine theoretical models of risk occurrence or discuss general risk management practices.

However, little is known about how firms come to a realistic understanding of field level (e.g., genba-based) needs before implementing top-down directives. Just as effective product development requires a clear understanding of final customers, so is the case with risk management implementation. Lack of appreciation of field level challenges too often results in unrealistic disaster risk planning execution. Hence, this volume presents “field-based (genba-based)” case studies regarding the risk management practices of firms in countries that have experienced frequent supply chain disruptions caused by natural disasters, such as certain Japanese manufacturing firms and factories facing intensifying global competition in the post-Cold War era.

For this purpose, recent studies on SCM risks and their mitigation or BCP strategies will be reviewed in this paper, mainly focusing on organizational responses to supply chain disruptions due to natural disasters (Altay and Ramirez 2010, Day et al. 2012, Park et al. 2013, Fujimoto and Park 2014).

1.2. Buffers or Capabilities

Our literature review suggests that there have been at least two main approaches to the issue of how organizations deal with environmental uncertainties and unpredictable changes. One focuses on buffers, or organizational slack, and the other concentrates on firms’ organizational capabilities. Let us discuss these two concepts in this order.

Slack and Buffers

Organizational slack refers to resources that exceed what is required for an organization that pursues efficiency to achieve its immediate goals, including buffer inventories, surplus production capacity, and excess personnel (Cyert and March 1963, Bourgeois 1981). This may be seen as inefficiency, but it may also be regarded as a source of effective adaptation to changes within the organization, including its own innovations. Organizational slack may have a negative impact on a firm’s overall performance, but it may also have positive effects if the level of slack is not disproportionate (Majumdar 1998, Tan 2003).

Another related concept is that of boundary spanning (Thompson 1967). Organizations as interactive systems respond to environmental uncertainty in both proactive ways (e.g., prudent efforts to reduce potential uncertainty in advance) and responsive ways (e.g., constructive initiatives for implementing information-processing capabilities to deal with normal uncertainty) and achieve organizational requirements for survival and growth (Penrose 1959, March and Simon 1958, Lawrence and Lorsch 1967, Galbraith 1973, Trkman and McCormack 2009). This requires an organization to develop central value-creating processes within its “technical core”, which supports its efforts to achieve productivity requirements based on stability and continuity of value creation and delivery processes (Thompson 1967, Harney 2004). Consequently, when facing uncertainties, an organization tries to insulate its technical core by setting up “boundary spanning units”, acting as buffers between said stable core and the fluctuating external environment, thus consistently achieving desirable levels of profit (Knight 1921, Aldrich and Herker 1977, Tushman and Scanlan 1981). This core-boundary view of organizations is useful to explain much of what we have observed in modern manufacturing firms and industries.

Capabilities

The second key notion regarding an organization’s adaptation to internal and/or external changes is that of organizational capabilities (Nelson and Winter 1982, Grant 1991, Fujimoto 1999), which are often described as a system of organizational routines to achieve stable and relatively high organizational performance against rivals in the long run. The concept includes both ordinary/static capabilities to reach a certain level of performance and dynamic/evolutionary capabilities to rapidly and effectively change structures and performance vis-à-vis competitors (Teece and Pisano 1994, Fujimoto 1999).

In this paper, we focus on organizational capabilities in manufacturing and supply chain management, or a system of organizational routines that govern flows of value added (e.g., the value stream) to the customers in the market (Schonberger 1982, Monden 1983, Goldratt and Cox 1984, Ohno 1988, Clark and Fujimoto 1991, Fujimoto 1999). The flow-oriented approach to manufacturing implies a broad definition of manufacturing (*monozukuri* in Japanese) as the creation and transmission of value-carrying design information to customers, which involves development, purchasing, production, distribution and sales of goods and services, because value is assumed to reside in design information (Clark and Fujimoto 1991, Fujimoto 1999, 2007). This design-based view of manufacturing stands in contrast to the narrow definition of manufacturing seen simply as transforming physical materials.

By adopting the aforementioned perspective, based on organizational capabilities in manufacturing that control and improve flows of design information to customers, researchers may analyze the competitiveness and robustness of manufacturing systems and supply chains in an integrated manner. That is, competitiveness refers to the effectiveness and stability of the flows in terms of speed, efficiency and accuracy, whereas robustness concerns the continuity of said flows when drastic environmental changes, such as a disaster, occur.

This design-information-flow-oriented approach leads us to infer that organizations or their units that are capable of improving supply chain competitiveness (e.g., *kaizen*) may also be capable of quickly recovering from supply chain disruptions, since the two capabilities are both related to enhancing the flow of value-carrying design information from suppliers and assemblers to customers.

In a sense, daily shop floor improvements, or kaizen, deal with numerous microscopic disasters and flow disruptions. Likewise, a large-scale project to recover even from an unprecedented supply chain disruption, when broken down into a series of tasks, may be regarded as a large-scale kaizen process. Thus, our flow-oriented capability perspective leads us to the hypothesis that supply chain competitiveness and robustness can be improved simultaneously, as they stem from a similar kind of flow-building capability.

Supply Chain Robustness

In this context, supply chains are essentially interpreted as design information flows of tangible materials and intangible value components between firms and customers. By combining the core-boundary view of organizations and the design-based concept of manufacturing, this paper aims to explore previous research on supply chain disruptions (Fujimoto and Park 2014), focusing mainly on the Great East Japan Earthquake of 2011.

Indeed, a recent study by Gupta et al. (2016) shows that earthquakes (33 papers) and hurricanes (22 papers) are the two most frequently investigated types of disasters, followed by terrorism (12 papers), accidents (8 papers) and floods (6 papers). Our analysis also rests on the assumption that the technical cores of firms (e.g., plants/factories, support facilities, transportation systems) require timely design information flows.

Disasters are by nature severe and unpredictable and providing reasonable estimates of their probability is extremely difficult (Knight 1921, Chakravarty 2011). Supply chain disasters temporarily shut down parts of the design flows to customers (Park et al. 2013). Such supply chain disruptions are extraordinary for two reasons: (i) instead of playing their normal stabilizing role, the technical cores of firms may become a source of increasing costs; and (ii) rather than retaining their normal function of insulating the technical core, the buffers in the boundary-spanning units are redirected toward maintaining the functionality of the whole chain (Fujimoto and Park 2014).

Supply chain disruptions caused by disasters force manufacturing firms to choose between *robustness*, e.g., preparing for rare but real future disasters, and *competitiveness*, e.g., striving to outperform their current rivals. Heavy investments to achieve robustness against possible disasters may lead to a reduction in the allocation of normal resources to enhance competitiveness. Robustness is needed in exceptional situations, whereas competitiveness is an everyday requirement. This was definitely the case with the Great East Japan Earthquake, which occurred in a period of moderate domestic performance and intense global competition. Harney (2004) discusses theoretical models of business continuity planning (BCP), or mitigation responses to possible disasters. Conversely, we examine the actual practices of better-performing firms after recent disasters occurred in Japan. Our analysis focuses on how manufacturing firms that have suffered serious damage to their technical cores balance the complex requirements of supply chain robustness and global competitiveness (Fujimoto 2012a, Park et al. 2013, Fujimoto and Park 2014).

2. EXISTING WORKS ON SCM AND BCP

Keeping in mind the aforementioned competitive situation and technological evolutions during the post-Cold-War period and early 21st century, let us briefly analyze the parts and materials most affected by the Great East Japan Earthquake – the weak links in the supply chains. Three industries whose recovery was particularly slow and had a rather strong impact on the operations of assembly manufacturers are discussed in this section: (i) semiconductors, such as on-board microcontrollers for controlling devices, (ii) functional chemicals, such as synthetic rubber, and (iii) high value-added, simple piece parts containing advanced materials technologies.

2.1. Views from Supply Chain Management (SCM)

Manufacturing firms face frequent disruptions in their supply chains because of a variety of man-made and natural threats, which expose them to significant business risks (Park et al. 2013). Unexpected but devastating events disrupt business processes in numerous ways, among which: component parts shortages, product design changes, manufacturing stoppages, logistics breakdowns and humanitarian emergencies (Drummond 2004, Duncan et al. 2011, Schmitt 2011, Thun and Hoenig 2011). In general, three broad categories of supply chain risks are identified in the value chain in relation to: supply, demand, and miscellaneous dimensions (Oke and Gopalakrishnan 2009). The risk of disruptions ascribable to natural disasters is regarded as a supply-related risk. Table 1 summarizes value chain risks and disruptions.

In view of these considerable supply chain challenges, researchers have investigated the critical responses of manufacturing firms at multiple levels (Kleindorfer and Saad 2005, Braunscheidel and Suresh 2009, Roth et al. 2008). After careful review, four streams of supply chain disruption responses can be identified.

The first stream concerns risk management models aimed at promoting system flexibility and dynamic capabilities to boost competitive advantage (Sawik 2011, Liao et al. 2010, Maon et al. 2009). Mitroff (1988) and Mitroff et al. (1996) present crisis response models in cases of disaster. Craighead et al. (2007) underline the importance of supply chain mitigation capabilities (SCMC). Their conceptual model of supply chain disruption responses suggests that: (1) Supply Chain Design Characteristics—such as density, complexity, and node criticality—increase the Severity of Supply Chain Disruptions, (2) Supply Chain Mitigation Capabilities—such as recovery and warning—reduce the Severity of Supply Chain Disruptions. In particular, after examining recent studies dealing with the decision-making process for managing disasters, Gupta et al. (2016) identify the following eight subcategories: (1) Decision support systems (DSS), (2) Multi-agency decision making, (3) Information processing, (4) Systems modeling, (5) Supply chains, (6) Equity and public risk, (7) Near-miss events and (8) Fund raising.

The second stream provides management insights into coping with disaster events (Maon et al. 2009, Ellis et al. 2010, Ellis et al. 2011). In particular, a dual-cycle model analyzes the practices of agencies offering aid in case of supply chain disruptions, in terms of: (1) prevention and planning and (2) response and recovery (Park et al. 2013). Three major contributions are offered: a concise account of current practices and the particularities of disaster relief supply chains compared with commercial SCM; challenges and barriers to the development of more efficient SCM practices, classified into learning, strategizing and coordinating, and measurement issues; and a simple, functional model for understanding how collaboration between corporations and disaster relief agencies might help relief agencies meet SCM challenges. In addition, Ellis et al. (2011) suggest that sense-making processes impact on the actions that firms take to mitigate supply chain disruption risks, and they develop seven propositions that advance the social and psychological factors that drive the idiosyncratic nature of supply chain disruption response decision-making.

The third research stream identifies the key stages of crises. According to Hong et al. (2012), in the first stage, *detection*, early warning signals of a crisis are detected in the unfolding reality. The second stage, *occurrence*, inevitably results in tangible damage. Organizational responses aim at minimizing negative impacts and containing the scope and intensity of the crisis. In the third stage, *recovery*, firms begin to enact procedures to resume normal business activities. The final stage, e.g., crisis *resolution*, involves reviewing all crisis management activities, assessing outcomes and developing plans for improving crisis management capabilities. Fink (1986) also pinpoints four stages in crisis situations: (1) the prodromal stage identifies looming disasters through internal indicators and external warnings (e.g., government sources); (2) the acute stage reveals tangible and measurable damage; (3) the chronic stage requires facing the aftermath of a crisis in terms of repair and recovery needs assessment; (4) the resolution stage has to do with examining the outcomes of the specific disaster, deriving lessons and implementing actionable changes.

Table 1. Classification of value chain risks and disruptions

Category	Type Classification	Example of Classification	Mitigation Response Strategies
Supply risks and disruptions	Import Restrictions (High likelihood, Low impact)	Temporary import restrictions on steel components or other raw materials	Better planning and co-ordination of supply and demand; flexible capacity building
	Climate Change (Low likelihood, Low impact)	Global warming	Better planning and co-ordination of supply and demand; flexible capacity
	Man-made Disasters (Low likelihood, High impact)	2010 BP Oil Spill	Identifying supply chain vulnerability points and having contingency plans
	Natural Disasters (Low likelihood, High impact)	2011 Japanese Tsunami; 2005 Hurricane Katrina	Identifying supply chain vulnerability points and having contingency plans
	Loss of Key Suppliers (Medium likelihood, Moderate impact)	Disappearance of suppliers through mergers and downsizing	Multiple sourcing strategy
Demand risks and disruptions	Demand Variability (High likelihood, Low Impact)	Changing customer tastes and preference for affordable and quality products (e.g., frugal innovation)	Better planning and co-ordination of supply and demand; flexible capacity
	Product Hazards (Low likelihood, High impact)	Toyota recalls due to accelerator failures	Educating customers
	Epidemic Outbreak (Low likelihood, High impact)	2002-2004 SARS (severe acute respiratory syndrome) outbreak in China	Educating customers
	Consumer Fads (Medium likelihood, Moderate impact)	Cabbage Patch Dolls	Better planning and flexible capacity
	Ban on Ingredients (Medium likelihood, Moderate impact)	Ban on toy components containing lead	Multiple sourcing strategy
	Forecasting Errors (High likelihood, Low impact)	Unanticipated demand changes in emerging markets	Better planning and co-ordination of supply and demand; flexible capacity
Miscellaneous risks and disruptions	Fluctuating Gas Prices (Medium likelihood, Moderate impact)	1970s Oil Crisis; 2015-2016 Low Gas Prices	Cost reduction/ competitiveness in operations; managing demand-promotion, incentives for customers
	Changes in Regulatory Rules (Medium likelihood, Moderate impact)	Changing Trade Regulation Policies (USA, China)	Cost reduction in operations; lobbying
	PETA (People for the Ethical Treatment of Animals) (Medium likelihood, Moderate impact)	International Animal Rights Movement	Cost reduction in operations; lobbying

Source: Adapted from Oke and Gopalakrishnan (2009).

The fourth stream emphasizes the constructive planning of supply chain disruption responses (Park et al. 2013, Fujimoto and Park 2014, Brandon-Jones et al. 2014). Duncan et al. (2011) present a framework, Continuity of Operations Planning (COOP), to plan for man-made or natural disasters, along with some concrete examples. COOP is a tool that aids organizations in staying in business under extreme circumstances. Knemeyer et al. (2009) develop a process to proactively plan for catastrophic risk events. They introduce an innovative methodology used by the insurance industry to quantify the level of risks according to the types of catastrophic events and the locations of supply chain partners. Braunscheidel and Suresh (2009) show that internal cross-functional collaboration, external integration (involving key suppliers and customers) and external flexibility have an extremely strong and positive influence on a firm's supply chain agility.

In brief, these SCM risk management models concentrate on strategic, organizational and management practices to prevent and plan for various forms of supply chain disruptions. However, these studies do not take into consideration the interdependent nature of global production networks and the complexity of evolving technologies. Beyond these theoretical disruption response models, there is a need to better assess vulnerability to supply chain disruptions and discover effective response mechanisms based on actual fieldwork (Wagner and Neshat 2010, Fujimoto and Park 2014).

2.2. Views from Business Continuity Planning (BCP)

In relation to managing natural disasters, the idea of business continuity planning (BCP) has received much research attention (Zsidisin et al. 2005, Lindström et al. 2010, Czinkota et al. 2010, Brandon-Jones et al. 2014, Gupta et al. 2016). However, most studies deal with supply chain disruptions and a large portion of these examine the relation between BCP and the effects of terrorism. For example, Czinkota et al. (2010) discuss the relation between terrorism and global supply chain disruptions. Supply chains can be affected by terrorism via both direct attacks and indirect effects, such as security measures imposed by governments and private interests. Important components of global supply chains potential vulnerability to attack include systems used for warehousing, transportation, and communications. Terrorism is primarily studied using game theory, assuming that the terrorists are one player and the government is another player. Earthquakes and hurricanes have mostly been investigated using mathematical programming (Gupta et al. 2016). Studies on epidemics, floods, and accidents have used real data, as they can be easily collected for these disasters. Thus, Czinkota et al. (2010) insist that research should address how to strike the right balance between ensuring secure operations, the cost of security and the efficiency of said operations. For BCP, they also suggest that the benefits and drawbacks of using multiple suppliers should be reviewed anew.

These BCP-related works reflect the renewed emphasis on how firms can continue their business operations despite a variety of disruptions, trying to minimize their impact, achieve fast recovery of operations and maintain normal business activities even in times of disruptions. Based on past experiences with lean systems, total quality management (TQM), time-based competition and other supply chain improvement initiatives, firms approach disaster planning with a collaborative and integrative perspective. In the increasingly information-intensive business environment, protecting strategic and routine information has become a crucial business priority.

2.3. Piece Parts and Consumables

The third example of automotive products affected by the 2011 Earthquake is simple piece parts, such as screws and small springs, used in the roughly 30,000 parts of which an automobile is composed, as well as materials, such as washing fluids, that are consumables used in the manufacturing process. In general, automobile makers pay little attention to these suppliers at the far end of the supply chain (fifth tier or lower), but quite a few of these small to medium enterprises operated in the Tohoku area and suffered heavy damage, especially suppliers for Toyota, which had opened a new assembly plant in the Tohoku region in 2010.

For very small suppliers such as these, the main challenge is not so much substitutability or concentration but visibility to the automobile assemblers. In short, regardless of how powerful Toyota's supplier recovery assistance might be, if the locations of these damaged suppliers are not identified, their recovery cannot be assisted.

The automobile supply chain is extremely complex; hence, it is difficult to comprehend it in its entirety, all the way down to the manufacturing of simple piece parts. In addition, during normal periods without disasters, there is no need, contractually as well as technologically, for automobile manufacturers to know about the product-process details of second-tier and lower-tier suppliers, because first-tier suppliers will take care of detailed component designs and purchases from sub-parts suppliers. In fact, this decentralized system—in which the first-tier suppliers handle the second tier, the second tier handles the third, and so on—functions very well at times of routine operations.

However, in an emergency such as this, when wide-area disruption of the supply chain is caused by a disastrous earthquake, it is crucial for automobile assemblers to gather accurate information on which suppliers are making what and where, all the way down to the 8^{th} or 9^{th} tier, so that they can be helped directly, if necessary, to avoid stoppages of vehicle assembly lines. Besides, some consumables, such as washing fluids for the heat treatment of a tiny spring, are even less visible, since they are not even listed in the product design information (e.g., bill of materials) of the assemblers or suppliers.

In previous disasters, automobile assemblers like Toyota could provide effective recovery assistance by being able to identify quickly which suppliers were damaged, because the disaster-affected areas were rather concentrated. However, this time, due to the huge scale of the disaster, even a month after the earthquake, the complete picture of exactly which suppliers suffered damage was not yet available to the assemblers. For example, one month after the earthquake, Toyota's headquarters reported that more than 100 parts manufacturers had been hit by the disaster, but they could not tell exactly how many, although they eventually calculated the accurate number within two months. This was certainly a weak spot in Toyota's supplier system, known as one of the most competitive in the world in periods without disasters of this magnitude. Nonetheless, Toyota moved quickly and improved its supply chains in terms of visibility.

To sum up, the 2011 Tohoku Earthquake's heaviest repercussions on global supply chains were due to the following aspects: products and parts with high technological complexity requiring longer recovery times; higher concentration of production; lower substitutability of supplies; lower portability of design information; and lower visibility of the suppliers themselves.

3. Countermeasures and Infrastructures for Supply Chain Disruptions

3.1. Major Disasters in Japan and the USA – A Comparison

Broadening the Research Scope

The literature on supply chain risk management has discussed various types of disruptions (Whybark 2007, Trkman and McCormack 2009, Oloruntoba 2010, Hong et al. 2012, Schmitt and Singh 2012, Park et al. 2013, Fujimoto and Park 2014, Brandon-Jones et al. 2014, Gupta et al. 2016), as the number of studies on supply chain risk and disruption management has substantially increased after the beginning of this century. Prior to 2000, most research in this area tended to focus on discrete aspects of supply chains. For example, research discussions included: (1) time-phased resource allocation for production/distribution systems (Carlson 1982, Monden 1983), (2) implementation of the just-in-time concept and inventory management (Wildemann and Carlson 1987, De Smet and Gelders 1998, Whybark 2007), (3) supporting innovative problem-solving with strategic sourcing and agile manufacturing (Nishiguchi 1994, Nishiguchi and Beaudet 1999), (4) scheduling in recoverable manufacturing systems (Daniel and Guide Jr. 1997), (5) controlled manufacturing environment practices (De Smet and Gelders 1998) and (6) stochastic lot scheduling problems (Sox et al. 1999).

In recent years, the scope of research has been extended to cover both macro- and micro-level supply chain disruptions. In particular, since supply chain disruptions occur with few or no warning signals, contingency planning and recovery measures require strategic and operational flexibility and robustness in competitive markets (Liao et al. 2010, Chakravarty 2011, Wallace and Choi 2011, Park et al. 2013, Fujimoto and Park 2014, Brandon-Jones et al. 2014, Gupta et al. 2016). National disasters often destroy regional and national infrastructures and disrupt national and global supply chain networks. Roth et al. (2008) highlight the serious damage to global food supply chain flows due to recent natural disasters. Ellis et al. (2011) review 79 supply disruption risk (SDR) studies and examine three stages of the decision-making processes (e.g., enactment, selection and retention) that involve social and psychological factors. In response to serious natural disasters (e.g., floods, earthquakes and tsunami), considerable research addresses logistic issues in immediate disaster areas (Altay and Ramirez 2010, Day et al. 2012).

The Great East Japan Earthquake

One of the turning points in the study of supply chain disruptions and recoveries was the 2011 Great East Japan Earthquake (GEJE), among the largest in modern history and, in many respects, quite extraordinary. The combined impact of the earthquake, tsunami and aftershocks—and of the related accidents at the Fukushima Daiichi Nuclear Power Plant—on domestic and global supply chains across industries was serious. Surprisingly, consumer sales remained steady and strong, thanks to the rapid reconfiguration of supply and distribution networks (MacKenzie et al. 2012). However, in the aftermath of the disaster, there was a great deal of debate over realistic approaches to improve the robustness of supply chains in case of rare but possible future disasters (Park et al. 2013, Fujimoto and Park 2014, Olcott and Oliver 2014). The GEJE struck areas with a high concentration of facilities that supplied components, parts and materials across the globe. For a while, the interconnected global supply chains predictably experienced major disruptions. At the time of this disaster, the exchange rate was about 80 yen per USD, compared with 360 yen in 1970, around 240 yen in 1985, and about 120 yen in 2000. In this sense, the GEJE has been called the first huge and wide-area disaster to happen in a high-cost country facing global competition (Fujimoto 2012a).

Then, how did Japanese firms and factories respond to this unprecedented disaster? Given the magnitude and complexity of the aggregate damage, it is worth analyzing the nature of the responsive measures implemented, as these may teach us some important lessons. For this purpose, immediately after the GEJE, the Manufacturing Management Research Center (MMRC) of the University of Tokyo began a series of studies, whose most significant findings are reported in field-based studies of supply chain robustness.

Hurricane Katrina

Recent natural disasters in the US have occurred in fairly stable geological conditions and emergency needs were mostly addressed from socio-economic and public policy perspectives (Comfort et al. 2010, Oloruntoba 2010, Dave 2015, Parsons 2016). Several differences between Japanese and US disaster cases can be pinpointed.

First, natural disasters—Hurricane Katrina, in particular—involve both short-term disruption and long-term recovery in the economic, social and political spheres. The damaging impact from natural disasters on the needy is far greater than on the affluent. The extent of community life disruption and ecosystem destruction has had much heavier repercussions on the vulnerable at the time of the disaster and during the post-disaster recovery process (Fussell 2015). From a political economic standpoint, the focus is primarily on restoring normal cultural, social and economic activities. Policy priorities concern building innovative public-private partnerships, implementing timely response mechanisms (e.g., privatization of government services and crisis communication network capabilities) and providing affordable housing and job opportunities (e.g., massive federal- and state-level support) to people in the disaster-stricken regions (Kapucu 2006, Garnett and Kouzmin 2009, Rockwell and Block 2010, Mancuso et al. 2011, Obama 2015).

Second, recent natural and man-made disasters (e.g., BP Oil Spill) have occurred in the southern part of the US, far away from the major manufacturing centers of the Midwest, East and West. Also due to vast outsourcing of supplier activities to Mexico, China and other cost-competitive countries, the long-term impact on manufacturing has been fairly minimal. Additionally, in most cases, after a brief period of import restrictions, business life normalcy is soon recovered (Parsons 2016).

Third, some of the disasters that have affected the US in recent years are expected to recur somewhat regularly (cyclone seasonality), whereas the 2011 Japanese earthquake was a much less common type of catastrophe. Hence, in the US the strategic management of disasters is generally discussed from the standpoint of diverse stakeholders from governmental entities, business organizations, and individual communities in terms of building cognitive disaster responsive mindsets and physical infrastructure network mechanisms (McGuire and Schneck 2010, Thévenaz and Resodihardjo 2010). The role of humanitarian logistics has also been reviewed to implement effective disaster coping mechanisms (Tatham and Kovács 2010, Day et al. 2012, Chakravarty 2011). As for fast business recovery, routine and ordinary preparations (e.g., emergency response plans, storm preparations, staff communication) have had little impact on organizational performance.

On the other hand, external factors (e.g., severity of disasters, extreme population dislocation), post-disaster problems (e.g., loss of customer base and staffing inadequacy) and swift responses (e.g., high level of coordination among private and public organizations, improved preparedness and collaborative community culture) are crucial to organizational performance (Corey and Deitch 2011, Chakravarty 2014, Paul and MacDonald 2016). These studies suggest that disaster planning requires a realistic understanding of field level needs in all phases—prior disaster planning, disaster coping responses, and post-disaster recovery. In this sense, the real issue is not how to implement top-down disaster planning directives but how to strengthen bottom-up need translation processes.

3.2. Digital Manufacturing and Supply Chain Disruptions

Integrative Manufacturing Information Systems

As is argued in field-based studies of supply chain robustness, firms have to prepare for the fact that today's major disasters occur amidst intense global competition—yet, this is also the era of digitization. Thus, an area of research that needs to be developed further is that of digital information systems, such as ICT, big databases and digital manufacturing.

As an example, we propose the design information view of the whole supply chains as a means to respond to disruptions (Fujimoto 2012a, Park et al. 2013). There are at least three elements in this framework: an integrative manufacturing information system (IMIS), virtual dual sourcing (VDS) and collaborative electronic database infrastructure (CEDI). Extending the various process models of supply chain risk management, the supply chain design information perspective adopts a design-information-flow-based view of manufacturing (*monozukuri* in Japanese) that includes not only production but also development, procurement, sales, marketing, and services that are connected via an integrative IT system, or IMIS (Park et al. 2012a).

IMIS aims at linking not only physical flows of products and materials but also their upstream and downstream activities (Clark and Fujimoto 1991, Park et al. 2012, Youn et al. 2012, Park et al. 2013). We define the key processes that are connected by IMIS as follows: (1) fuzzy front-end process for concept definition and product architecture (Ulrich 1995, Hong et al. 2004, Reid and Brentani 2004, Hong et al. 2005); (2) product planning process for integrating customer needs—expressed or unspoken—and design information (Karsak et al. 2002, Doll et al. 2010); (3) product design process for visualizing design information (Park et al. 2011, Park et al. 2012a); (4) lean procurement and manufacturing for transferring design information through media choices (Womack and Jones 1996, Wallace and Choi 2011); (5) sales and marketing processes for providing design information to customers (Jayachandran et al. 2005, Hong et al. 2005); (6) maintenance process routines for managing design information (Tsang 2002).

Park et al. (2013) show how of these all processes can be integrated through the BOM (Bill of Materials). Namely, RD-BOM (Research and Development BOM), PP-BOM (Product Planning BOM), E-BOM (Engineering BOM), P&M-BOM (Procurement and Manufacturing BOM), MS-BOM (Marketing and Sales BOM) and S-BOM (Service BOM) must be integrated so that design information can circulate from market needs into product development, manufacturing, sales, etc.

Virtual Dual Sourcing

From this design information point of view, supply chain disruption management further considers how to secure and maintain continuity of design information flows to customers (Park et al. 2013). Following this design-based framework, Fujimoto (Fujimoto 2011, Fujimoto and Park 2014) suggests *virtual dual sourcing*, an approach that involves quick design information transfer from damaged production lines to substitutive lines that may be as effective as actual dual tooling/sourcing with lower costs. Virtual dual sourcing is also discussed in field-based studies of supply chain robustness including Fujimoto (2011) and Fujimoto and Park (2014).

Maon et al. (2009) explain the utility of IT for fulfilling the mission of disaster relief agencies in terms of: (1) prevention and planning and (2) response and recovery. Specifically, information technology infrastructures are vital to respond to information needs in all crisis management stages (prevention, planning, response and recovery). Identification, protection, and preservation of collaborative electronic database infrastructures (CEDIs) becomes one of the most important aspects of continuity of operations planning (COOP) (Schackow et al. 2008, Duncan et al. 2011). Furthermore, information technology infrastructures represent a potentially high-performing supply chain instrument.

An actual large-scale database developed by Toyota for improving the visibility of damaged suppliers will also be discussed elsewhere in this volume. Overall, the effective application of advanced ICT and the use of databases are becoming invaluable tools to prepare for and respond to supply chain destructions caused by major disasters.

3.3. Supply Chain Leadership and Coordination

Leadership

Another important aspect of supply chain recovery and restoration is leadership within the whole supply chain. Not only do firms in a given supply chain possess different levels of transactional power, financial/productive resources, manufacturing capabilities and knowledge, but they also have different levels of capabilities and knowledge as to how total supply chains can recover from disruptions. Companies with more abundant resources and capabilities, such as Toyota in the following case studies, will be more likely to help other firms in the chain recover from damage. We call them supply chain leaders or "leading firms" in recovery assistance.

For example, Park et al. (2013) identify four types of firms in supply chains in terms of their capabilities for design information transfer (e.g., leaders or followers) and the geographical dispersion (Mitchell 2007, Duncan et al. 2011) of the supply chain in question (e.g., global or local). The four types are: Domestic Supply Chain Leader; Domestic Supply Chain Follower; Global Supply Chain Leader; Global Supply Chain Follower. Park et al. (2013) then describe how the abovementioned four types might respond to supply chain disasters in relation to design information portability, substitutability, supply chain dispersion, supply chain disruption response cost and supply chain risks.

Coordination and Integration

Coordination and integration between firms in the damaged supply chains are also crucial for effective supply chain recovery and restoration. Braunscheidel and Suresh (2009) argue that external integration with key suppliers is important to maintain supply chain functions even in case of catastrophic natural disasters, since it helps secure essential services and timely acquisition of strategic materials.

An effective method is to have contractor agreements for rapid recovery in case of sudden disasters (Altman 2006, Ceniceros 2008, Duncan et al. 2011, Hong et al. 2012, Park et al. 2013). Arranging flexible information flows with key suppliers may help meet pressing needs during natural disasters and unexpected supply chain disruptions (Braunscheidel and Suresh 2009, Fujimoto 2011). A number of studies also examine the role of IT systems that make virtual dual sourcing feasible (Mitchell 2007, Schackow et al. 2008, Maon et al. 2009, Duncan et al. 2011, Fujimoto 2011, Park et al. 2013, Fujimoto and Park 2014).

CONCLUSION

Effective risk management during catastrophic natural disasters requires drawing on lessons and considering implications based on actual field experiences. A firm's top managers may not necessarily have a good understanding of the actual realities associated with natural disasters. By virtue of their positional status, they may take a leading role in formulating and implementing risk management practices based on an "ideal" understanding of what the world should be. Thus, the discrepancies between upper-level planning and lower-level implementation are too often the result of a failure to understand the real field level needs. Such gaps may include:

(1) Contrasts between senior management intentions/goals and operational program efforts. Senior managers tend to understand risk management from a much more philosophical and strategic perspective, whereas operation plans focus on task/process specific details.
(2) Divergence between OEMs' stated expectations and the actual requirements met by suppliers. Expectations are initially set in broad terms, while suppliers tend to direct their efforts toward specific requirements.
(3) Incongruity between operational program goals and floor level execution. Operational program level goals also tend to be quite broad but floor level execution has to do with much simpler task-specific details.

The ineffective integration of upper-level goals/expectations and lower-level process efforts may explain why risk management implementation has yielded inconsistent results.

The likelihood of serious risk events—either natural or man-made—may be rare but it is very real. Field level managers are much more aware of the realities of disruptions than the senior managers. Thus, it is crucial to achieve greater harmonization between top-down leadership processes (e.g., planned goals/intent at the upper level vs. implementation details at the field level) and bottom-up empowerment processes (e.g., realistic assessment of needs at the field level vs. formulation of strategic, planned goals).

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