



Supply chain lessons from the catastrophic natural disaster in Japan

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Abstract While supply chain management has been approached from a variety of perspectives, the role of the global supply chain as a mechanism to overcome severe supply chain disruptions has not been explored adequately. This article discusses the ways in which Japanese manufacturing firms have responded to the recent earthquake, tsunami, and nuclear disaster. Based on case studies of Japanese manufacturing firms, this article presents a discussion of the supply chain restoration process after severe natural disasters and humanitarian disruptions, and reflects on supply chain lessons in terms of disaster planning and recovery responses. The critical capabilities of supply chain information design, portability, and dispersion are discussed.

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1. Disaster strikes

On March 11, 2011, an 8.9-magnitude earthquake struck the northeast coast of Japan. Even more devastating was the tsunami that followed the earthquake. Thousands of homes were destroyed, and numerous forms of social infrastructure, such as roads and dams, were destroyed. The death toll exceeded

86,000, more than 13,000 were listed as missing, and 550,000 people had to evacuate the region. The subsequent nuclear meltdown in Fukushima was another calamity that shook the nation and made the people and the economy suffer further.

Together, the massive earthquake in Japan and the tsunami that followed made up one of the most costly calamities caused by a natural disaster in modern history, and The World Bank estimated that the disaster left Japan with damages totaling about \$235 billion. The magnitude of these damages is quite obvious in comparison with other recent disasters. For instance, the U.S. National Hurricane

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Center estimated that in 2005, Hurricane Katrina cost the state of Louisiana \$81.2 billion in damage, and the 2010 Haiti earthquake cost \$8 billion (Nakamura, 2011). The 2004 tsunami that struck India, Indonesia, Sri Lanka, and Thailand was reported to have cost \$9.5 billion.

The earthquake and tsunami in Japan disrupted both domestic and global supply chains. During the 1960s and 1970s, Japan rose up as the world's second largest manufacturer, and it established itself as a major manufacturing hub in the world. For example, Japan provides 60% of the world's silicon, an important raw material for semiconductor chips. Japan is also the world's largest supplier of dynamic random access memory and flash memory—a form of memory that can retain data without a power supply. Flash memory plays an important role in supplying standard logic controllers, liquid crystal display (LCD), and LCD parts and materials. Right after the disaster, the prices for these components in the world market soared by 20%, showing the world's strong dependence on the Japanese supply chain.

These catastrophic disruptions have had serious impacts on firm performance. For example, global automakers—such as Ford, Chrysler, Volkswagen, BMW, Toyota, and GM—depend on Japanese suppliers and had to place a hold on some paint colors after the earthquake and tsunami (Schmitt, 2011). Renesas—a major automotive computer chip maker located in Japan—was badly damaged, representing a major blow to the automotive industry around the world. More specifically, a typical car contains about 100 different microcontrollers, which function as the car's brain, and 40% of the world's supply comes from Renesas (Pollack & Lohr, 2011). Additionally, the only production sites of Xirallic pigments (i.e., specialty paints used to give greater color intensity to automobiles' appearance) were badly damaged. Such supply chain disruptions resulted in critical component part shortages and thus subsequent operational shutdowns in GM, Ford, and Chrysler plants in the United States (Bunkley, 2011).

Supply chain management has been examined from a variety of process, legal, strategic, organizational, and competitive perspectives (Adobor & McMullen, 2007; Barker, Cobb, & Karcher, 2009; Duncan, Yeager, Rucks, & Ginter, 2011; Ketchen, Rebarick, Hult, & Meyer, 2008; Kim, 2006). However, the role of global supply chain responses as a critical linkage that overcomes severe supply chain disruptions has not been adequately explored. Therefore, this study discusses how Japanese manufacturing firms have responded to the recent earthquake, tsunami, and nuclear disaster in Japan. We identify critical supply chain challenges that manufacturing firms have faced in recent months on multiple levels

(Kleindorfer & Saad, 2005; Thun & Hoenig, 2011). More specifically, this article examines select Japanese manufacturing firms' global supply chain responses to enormous disruptions on every front, including the loss of component part plants, design disruptions to products, manufacturing stoppages, logistics breakdowns, and infrastructure and electric power rationing. These firms' supply chain lessons are noteworthy for disaster planning and recovery responses through global collaboration networks (Liao, Hong, & Rao, 2010; Maon, Lindgreen, & Vanhamme, 2009; Sawik, 2011).

Based on case studies of how firms coped with severe natural disasters and humanitarian disruptions, this research offers a model of supply chain robustness related to supply chain design information (SCDI) and business continuity planning (BCP) (Craighead, Blackhurst, Rungtusanatham, & Handfield, 2007; Fujimoto, 2011). In particular, as an alternative measure to make supply chains more robust and cost effective, this study proposes 'virtual dual supply chains,' which enhance SCDI portability. Based on case studies of Japanese manufacturing firms, the aim of this study is to examine strategic supply chain restoration and recovery processes and consider how firms can effectively prepare for and respond to massive disruptions.

2. The standard model

2.1. Supply chain models and risks

Turbulent environments with severe natural, humanitarian, and economic system disruptions subject firms to an enormous level of business risk. Unanticipated traumatic events impact all aspects of business processes and can cause component part shortages, product design change needs, manufacturing stoppages, logistics breakdowns, and humanitarian emergencies (Drummond, 2004; Duncan et al., 2011; Schmitt, 2011; Thun & Hoenig, 2011). In view of such critical supply chain impacts, researchers have investigated manufacturing firms' critical supply chain challenges on multiple levels (Braunscheidel & Suresh, 2009; Kleindorfer & Saad, 2005; Roth, Tsay, Pullman, & Gray, 2008).

2.1.1. Supply chain risk management processes

Disasters do not routinely occur; they happen in an unusual and extraordinary fashion. Thus, managing disasters requires useful risk management models. Along these lines, Hong, Huang, and Li (2012) identify four distinct crisis processes. First, in the crisis signal detection stage, early warning signals of

the crisis unfold. Second, the crisis occurs and inevitably results in tangible damage. Organizational responses to the crisis intend to minimize negative impacts and contain the scope and intensity of the crisis. Third, once the crisis event is over, organizations begin to enact procedures to resume normal business activities. Fourth, in the crisis resolution stage, firms examine their crisis management processes, review all their crisis management activities, and further develop their crisis management capabilities.

Similarly, Craighead et al. (2007) emphasize the importance of supply chain mitigation capabilities. They emphasize recovery capabilities and warning capabilities, and suggest a conceptual model for responding to supply chain disruption:

- Supply chain design characteristics include density, complexity, and node criticality. Each of these increases the severity of a supply chain disruption.
- Supply chain mitigation capabilities include warning signal detection and recovery. These moderate and reduce the severity of a supply chain disruption.

These supply chain risk management models identify supply chain risk processes; highlight the need to build dynamic supply chain capabilities; and explain the strategic, organizational, and management needs required to prevent and plan for various forms of supply chain disruptions. However, the standard model does not examine specific disaster responses in terms of information infrastructure development.

2.2. A revised supply chain management response model: Supply chain design information

In this section, we extend the standard model and present SCDI as an important mechanism for responding to supply chain disruptions. This model has three distinctive elements: (1) an integrative manufacturing information system (IMIS), (2) virtual dual sourcing (VDS) and a collaborative electronic database infrastructure (CEDI), and (3) portability provisions in supply chain information flows.

2.2.1. Design information through an integrative manufacturing information system

Extending the various process models of supply chain risk management, we now present a supply chain response model based on design information. The

concept of manufacturing (*monozukuri* in Japanese) can be defined in a broad sense as an integrative total system that combines all activities related to management, manufacturing production processes, development processes, sales and marketing, and services via an integrative information technology (IT) system. Adopting the concept of manufacturing in a broad sense, this article defines manufacturing as business processes that electronically transfer design information to media (e.g., materials like iron, plastic) to satisfy customers (Fujimoto, 2001; Park, Hong, & Park, 2012).

Figure 1 illustrates the IMIS concept. The primary focus of IMIS is to respond to customer needs through strategic business process integration and design information planning (Park et al., in press). The concept also identifies the key processes in terms of the following:

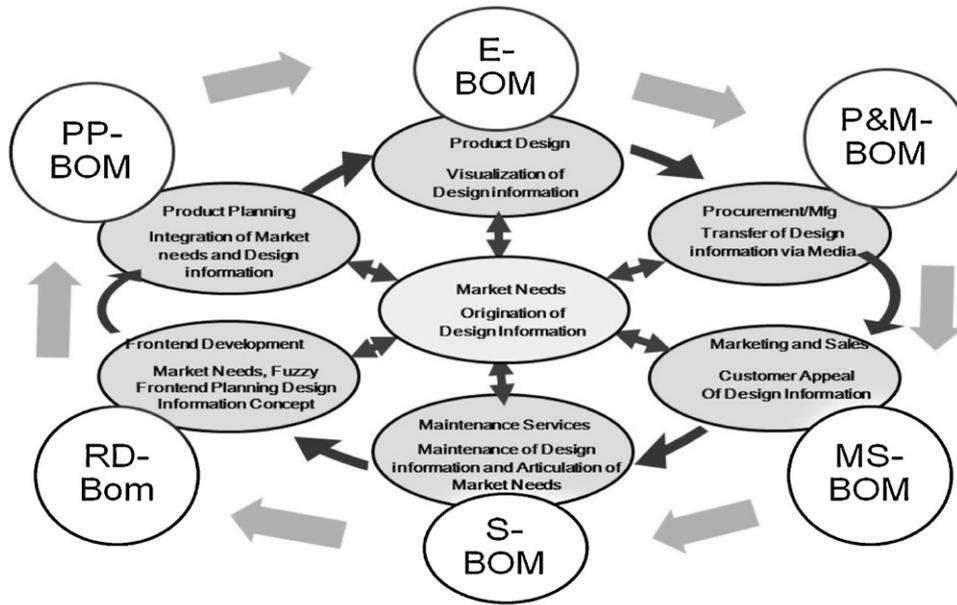
- A fuzzy front-end process for concept definition
- A product planning process for integrating customer needs—expressed or unspoken—and design information
- A product design process for visualizing design information
- A procurement and manufacturing process for transferring design information through media choices
- A sales and marketing process for customers by providing design information
- A maintenance process for managing design information

In particular, through a bill of material, all processes can be integrated. Figure 1 illustrates this process.

2.2.2. Securing and maintaining design information flows

From this design information point of view, supply chain disruption management further considers how to secure and maintain design information flows. Fujimoto (2011) suggests three methods to cope with such a situation. First, dual tooling is used to prepare multiple copies of equipment and molds that store design information. Second, dual sourcing is used to maintain production lines both inside and outside the factory. The third method is VDS, which obtains design information upstream in the line and rebuilds and relocates it during an emergency based on previously obtained information. Specifically, IT infrastructure is needed to respond to information

Figure 1. Supply chain management based on design information



Legend

Bill of Materials: BOM
Procurement and Manufacturing: P&M
Marketing and Sales: MS
Maintenance Services: S
Front End Development: RD
Product Planning: PP

Source: Adapted from Park et al. (in press)

needs in all crisis management stages (i.e., prevention, planning, response, and recovery). Protecting the identification as well as protecting and preserving the CEDI become critically important aspects of continuity of operations planning (Duncan et al., 2011; Schackow, Palmer, & Epperly, 2008). Furthermore, IT infrastructure is a high-performing supply chain instrument.

Figure 2 shows a typology of the four types of supply chains in relation to disaster responses. Effective SCDI requires portability and supply chain dispersion depending on the degree of portability and the extent of supply chain dispersion. A domestic supply chain leader (Type 1) has high portability (i.e., high information access flexibility) with low supply chain dispersion (i.e., supply chains are mostly focused on the domestic base). A domestic supply chain follower (Type 2) exhibits relatively low portability. A global supply chain leader (Type 3) is both flexible in terms of information success and capable in its supply chain network. On the other hand, a global supply chain follower (Type 4) has a widely dispersed supply chain but fairly constrained information access.

2.2.3. External integration with key suppliers through portability provisions

As Braunscheidel and Suresh (2009) insist, external integration with key suppliers is critical to maintaining supply chain integration when catastrophic events and disasters occur. When external services are required and materials are purchased, external integration with suppliers is necessary. In particular,

Figure 2. Framework for a robust supply chain to protect against disasters

Supply chain design information portability	High	Type 1 Domestic Supply Chain Leader	Type 3 Global Supply Chain Leader
	Low	Type 2 Domestic Supply Chain Follower	Type 4 Global Supply Chain Follower
		Low	High
		Supply chain dispersion	

contractor agreements are an important external integration method needed with suppliers when a disaster occurs (Altman, 2006; Cenicer0s, 2008). Furthermore, an effective supply chain disruption response requires flexible information flow that accommodates natural disasters and unexpected supply chain disruptions (Braunscheidel & Suresh, 2009; Fujimoto, 2011). The expanded model adds two new distinct components to the standard model: IMIS (Figure 1) and the four types of supply chains (i.e., domestic leader/follower, global leader/follower) (Figure 2). We now present four case studies of Japanese manufacturing firms affected by the earthquake, tsunami, and Fukushima disasters. In the next section, we discuss how each firm responded to these catastrophic natural disasters and why they have or have not been successful in responding to the disasters and recovering from them in timely manner.

3. Case studies: Disaster in Japan

3.1. Motivation for case study

These case studies are taken from companies that experienced supply chain disruptions because of the Japanese earthquake and tsunami that occurred on March 11, 2011. The earthquake exposed to the public three essential characteristics of Japanese automotive supply chains: (1) the complexity of vehicles' electronic controls, (2) the globalization of the supply chain, and (3) the heightened global competition (Fujimoto, 2011). These characteristics revealed that conventional responses to supply chain disruptions face serious limitations in coping with sudden, massive, and unexpected disasters. The cases aim to illustrate how firms responded to this enormous scale of disruptions from the SCDI perspective. We interviewed senior executives as well as middle managers who were involved in supply chain management and responding to the disasters. Based on in-depth interviews with structured questions, we attempted to uncover an effective way to prepare for and respond to such disruptions. The focus of the interviews was to understand the firms' contexts, disaster impacts, disaster planning, recovery plans, and key supply chain lessons. According to the case firms' request, we disguised their names.

3.2. Japanese cases

3.2.1. Iryou

Iryou is a representative Japanese medical device company. Iryou is the industry leader in Japan but is not one of the top 10 global medical equipment

manufacturers. Medical equipment requires highly skilled craftsmanship to execute, and detailed design and manufacturing requirements. Its supply chain is unique in terms of product lines at the plant level. Most of Iryou's products are not price sensitive and are entirely produced in Japan. Therefore, the company's dependence on a global supply chain is fairly low. The primary impact of the natural disasters was on price-sensitive commodity products, such as needles and syringes, which are produced in Japan and around the world.

While it experienced a surge in demand during the 2008 global financial crisis, supply shock hit the company in March 2011. Although there was initially a demand for Iryou products, the supply of components for the products came to a sudden halt. Due to the lack of raw and subsidiary materials, the shortage of components, and the power outage, the factory operated at a suboptimal level. The company spends a large amount on labor and fixed costs but little in variable costs, such as raw materials. As a result, the break-even point for the firm occurs when products are supplied in large quantity, so a low plant operation level results in low profitability. The firm attempts to run its plants constantly at a particular level.

Although the earthquake did not directly damage the plant, its suppliers suffered from damage, and chemical and electric components stopped being delivered to the company. In particular, special orders suffered from a serious bottleneck. Because the earthquake cut off the suppliers of components and raw materials from the supply chain, the company found an alternative way for suppliers to reach them with a transition period of about 2 weeks.

Immediately after the earthquake, production capacity was at half the normal level, but back up to 80% of the normal level within a week. In addition to its other adjustments, the company was able to find alternative sources to meet the shortage of raw materials. On the other hand, the company's overseas plants were minimally affected because they had maintained a certain amount of inventory. However, a daily 3-hour power outage imposed by the Tokyo Electric Power Company caused the production level to decrease by 50%. Iryou responded in the following ways:

- To establish power generation in the plants using natural gas, the company spent billions of yen to lay a gas pipeline to the plants.
- To facilitate communication and response to the natural and nuclear disasters, the company formed a 24-hour crisis center, which was later changed to a more permanent task force.

- To ensure prompt information sharing, the company flattened the organizational structure to Chief Executive Officer → Vice President in Production → Vice President in Sales. The flattened structure enabled the firm to share the disaster remedies more quickly with constituents.

3.2.2. Kenki

Kenki is a representative construction equipment maker. By the end of the 1980s, Kenki had successfully caught up with U.S.-based Caterpillar in terms of manufacturing and marketing capabilities and became the number two global construction equipment manufacturer. However, Kenki failed to diversify with a broader scope of product lines. By the early 2000s, Kenki was a below-average market performer. Faced with sinking performance, Kenki determined that its turnaround depended on building and implementing a strong IT system infrastructure. In particular, Kenki improved supply chain traceability by implementing global positioning systems (GPSs) for all construction equipment. At the same time, its investment in emerging markets (e.g., BRICs) has been more intensive. As of 2010, more than 60% of its total sales were from the emerging global market. Because Kenki's supply chains were more dispersed than Iryou's, the overall impact of supply chain disruption was somewhat more manageable. However, some core component parts were still deployed through its domestic Japanese suppliers, some of which were located in the earthquake regions.

Kenki experienced only minimal damage to its assembly plants, but its operations came to a halt for 2 weeks due to incapacitated suppliers. Integrated circuit components were in short supply, and the firm reacted to this by promptly diversifying its electronics vendors. The electric power shortage was also a concern for the company, and it planned to respond to the crisis by installing a self-generating system in the plant. As reconstruction activities increased, the demand for the company's products increased as well.

As part of its contingency plan, the company paid visits to its suppliers to see what their needs were and to help them get back on track. The disaster revealed the vulnerability of the semi-conductor supply chains located on the northeast coast. The company plans to find alternative supply chains within Japan and overseas as such diversification will help the company to absorb disruptions and shocks in the supply chains.

3.2.3. Sangyo

Sangyo is a large engineering company that produces industrial equipment and process-automation machines. Its main products are timers, power and

temperature control mechanisms, sensors, and programmable logical controllers. Before the earthquake hit in March, the firm already had been transferring its manufacturing capacity from Japan to China as an initiative to reduce its production costs.

Starting in the 1990s, Sangyo began moving its manufacturing facilities to China to take advantage of cheaper wages and lower production costs. Its primary customers have been Japanese firms, and starting in the mid-2000s, the largest share of sales has been to China. With the changing nature of its global market, Sangyo raised its portion of production in Chinese plants to be more responsive to the rapidly growing Chinese market. For Sangyo, a specific aspect of this type of supply chain strategy is implementing design information sharing between Japanese mother factories and overseas plants. It was a coincidence that Sangyo benefited from such a diversified manufacturing base and was better able to handle the potential damages of the earthquakes. The company was outside of the disaster region, but its domestic production line was still closed for 2 weeks due to the difficulties in procuring components. Like other companies, it looked for alternative suppliers, resolved part-shortage issues, and managed to resume operations, and the power outage imposed by the Tokyo Electric Power Company did not affect the company. Meanwhile, right after the crisis in Japan, the firm's plants in China saw their orders rise by 140%. In response to the disaster, the company did the following:

- To accurately and tightly manage parts supply, the company directly manages the inventories of supplier branches. The company aims to improve the transparency of each product's original costs.
- It is also conducting a corporate-wide risk analysis of earthquakes, fires, and other natural disasters.
- It has decided to maintain 1 month's worth of inventory stock to give itself time to recover from disruptions in logistics and supply chains.
- Besides increasing the inventory level, the company plans to increase its use of generic components as a long-term initiative.

3.2.4. Zyuden

Zyuden is one of the largest conglomerates in Japan and produces large-scale generators and vehicles. Its plants located on the northeast coast were directly affected by the earthquake and the tsunami.

When the earthquake hit, the plants shook violently. Although the tsunami did not reach the plants, the aftershocks following the earthquake repeatedly struck the plants, severely damaging the equipment, machines, lighting system, and air conditioners, causing chaos. The disaster cut off the plants from all forms of infrastructure, including electricity, communication, transportation, etc. Employees were ordered to evacuate the workplace, and when they returned to the production sites after a few days, they found them in a state of total collapse. Products ready to ship out had been damaged, and print production lines, painting lines, and precision machine facilities were broken. The tsunami swept away the facilities adjacent to the coast and destroyed the roads to the harbor. At the end of April, the facilities were still in reconstruction, and the company was having difficulties transporting a power plant turbine and transformers to the affected area.

The damage to the Zyuden supply chain can be divided into two domains: demand and supply. Demand shock caused the plants to change their production plans abruptly and reduce production considerably. As the production line came to a halt, repair parts for vehicles were not replenished in a timely manner, which in turn reduced transportation capacity and delayed order fulfillment and component replenishment.

Supply shock refers to disruptions caused by suppliers' own abrupt changes in production and delivery plans. The first-tier suppliers in the impacted region were disabled, and their collaborating companies had to stop or reduce their specialized operations. Because the impacted suppliers provided specialized, technology-intensive components, it was difficult to find alternative suppliers, so the company faced a bottleneck. In particular, the company fell into a panic when the final assembly system, total system, and final test process synchronization system ran into disruptions at the same time. The power outage imposed by the Tokyo Electric Power Company caused additional problems in terms of maintaining operations and mounting equipment machines, and involved concerns about production operation, electric overload on mass storage equipment, and computer malfunctions. As a long-term solution, the firm is pushing forward to develop manufacturing technology that can handle continuous and batch production lines together. It is also taking dual-process lines into consideration.

Among the companies discussed, Zyuden suffered the most serious damage and yet restored its production lines at the fastest rate. This is because the company used the design information system to cope speedily with supply chain disruptions. As the case describes, the company's operations stopped for 10

days while it attempted to restore its operations by restoring electricity, its communication network, and various equipment. However, the absence of real-time information about the status, condition, and progress of equipment and process line facilities in production made it difficult to promptly recover from the disruptions. When the electricity came on again, the company was still not ready to put the production line equipment to work.

After power resumption, the real-time information system Zyuden had implemented 6 months before the earthquake took over. Unlike the previous system, this system does not involve major requirements but instead possesses only the functions necessary to configure the information needed for production floor users. In this time of crisis, such functionality became quite useful. Several of the sensors that were attached to production lines remained undamaged. After the fallen sensors were reattached and the destroyed sensors were replaced, the field information system started operating again. The vital information derived from such a system has become the restoration roadmap for Zyuden's production lines.

The collection of real-time data by a field information system is the result of implementing an appropriate design structure. Any event (e.g., completing product processing by sensors on each product line) can generate automatic product processing information in real time. Thus, for Zyuden, except for the automatic facilities that required considerable restoration time, event information continued to include operator details and test process outcomes.

As a result of collecting such a broad scope of vital information, Zyuden was in a better position to handle plant disruptions and improve recovery speed. The visualization of real-time information enabled the firm to monitor its recovery speed through Excel graphs. Some slow-recovery plants have adopted real-time information sensors as the source of acquiring benchmark data from the accelerated line recovery plants. Such a field information system allowed the company's headquarters in Tokyo to monitor recovery status in real time through intranet arrangements. By utilizing this field information system, Zyuden has successfully integrated all sectors of its business, including those in the damaged region.

4. Supply chain lessons from the case studies

The highlighted case studies suggest several supply chain lessons in terms of what to do and what not to do in the event of a natural disaster. Based on the

cited case examples, we now discuss how firms can prepare supply chain restoration processes in response to natural disasters.

4.1. Information disruptions

Table 1 presents a comparison of the cases. Zyuden was housed nearest to the impacted region. Even though its plant remained intact after the earthquakes, its supply chain was dismantled as a result. Furthermore, the nuclear energy crisis in Fukushima made it very difficult for the companies to return their supply chains to normal levels. The power outage imposed by the Tokyo Electric Power Company also prevented the firms from fully committing to supply chain restoration. Thus, not only does a natural disaster directly disrupt the supply chain, but subsequent problems can also have a severe impact on the supply chain. As for Sangyo, it was able to successfully address the challenges raised by the earthquake and nuclear meltdown because it had been running both domestic and

international plants via integrated information systems that synchronized coordination. Such design information sharing enabled the firm to react to the disruptions flexibly.

In response to the increasing cost competitiveness for routine medical products, Iryou extended its global manufacturing network to the Philippines (for low manufacturing costs) and Japan and the United States (for market proximity and low logistics costs). When these natural disasters hit, Iryou increased overseas production and thus spread out the potential supply chain risks. Kenki focused on obtaining component parts for routine and commodity products using a global sourcing strategy while placing its strategic priorities heavily on domestic component parts suppliers for immediate damage assistance and technological support to recover quickly from natural disasters. Zyuden established an alternative manufacturing technology by integrating information systems. No firms, however, have realized the ideal status implied in the research, to which less attention has been paid.

Table 1. Comparison of case firms

Criteria	Iryou	Kenki	Sangyo	Zyuden
Products manufactured	Medical devices	Construction equipment	Industrial equipment and process-automation machines	Large-scale generators and vehicles
Cessation of production	No	Yes (2 weeks)	Yes (2 weeks)	Yes (10 days)
Effect of production levels	Yes (1 week: 50% → Two weeks: 80%)	Yes (2 weeks: 0% → 3-8 weeks: 50%)	Yes (2 weeks: 0% → 3 weeks: 100%)	Yes (1.5 weeks: 0% → 1.5-4 weeks: 50%)
Delay in component supply	Yes	Yes	Yes	Yes
Special/general parts	General	General	General	Special
Recovery response	Alternative suppliers (transition period: 2 weeks)	Alternative supply chain + supplier recovery support	Alternative supply chain + sharing design information with Chinese factory	Alternative manufacturing technology by IT
Direct effect of power outage	Yes	No	No	Yes
Response to power outage enforced by Tokyo power company	Establishing gas power generation (billions of yen)	Self-generation system	Self-generation system	Self-generation system
Organizational response	24-hour crisis center (3 weeks) → task force team	Recovery activity	Risk management task force	Crisis center

Table 2. Evaluation of supply chain of case firms

	Iryou	Kenki	Sangyo	Zyuden
Dependence on one supplier/factory	Middle	Middle	Middle	High
Supply chain design information portability	Low	Low	Middle	Middle
Substitutability of supply chain design information	Low	Low	Middle	Middle
Supply chain dispersion	Middle	Middle	High	Low
Virtual dual sourcing	No	No	No	No
Supply chain risk	Middle	Middle	Low	Middle
Business continuity planning	Middle	Middle	High	Middle

4.2. The cost of overdependence

The need for special or sophisticated components makes it difficult for firms to find alternative suppliers and worsens delays. It seems that companies need to prepare separate contingency plans depending on the complexity of the components they need. Table 2 shows the case firms' dependence on suppliers for components. Table 2 suggests that Zyuden was unable to manage the disruptions as well as the other firms because it depended heavily on specific suppliers. This dependence could be attributed to the fact that Zyuden took the complexity out of component design and thus exhibited high dependence on special parts. Furthermore, compared to the other firms, Zyuden had high visibility into the supply chain through an IT system, which enhanced its ability to get impacted facilities running again. However, the firm does not utilize virtual dual sourcing actively nor does it fully engage SCDI portability. This study predicts that a virtual supply chain supported by information systems will emerge as an important model in preparing for disruptions. Table 2 shows our evaluation of the case firms in terms of the portability and supply chain dispersion variables of Figure 2.

4.3. Portability and supply chain dispersion

Competitive advantage requires firms to implement supply chain integration, and SCDI is an important component of supply chain integration. Many firms have not yet achieved complete integration between all their internal functional units and their supply chains. The 2011 natural disasters in Japan (with a chance of occurring once in 1,000 years) showed how inadequately constructed SCDI can slow down the supply chain recovery process, as well as how critical SCDI is for the supply chain recovery process in the context of supply chain disruptions.

SCDI portability is vital for firms' competitiveness in the long run. The higher the degree of portability, the greater the chance firms will be able to find desirable SCDI substitutes. This high portability

makes it easier to effectively disperse key components. Conversely, the lower the degree of portability, the smaller the chance firms will be able to find satisfactory substitutes to SCDI and the more difficult it will be to widely disperse SCDI. When natural disasters strike a region, it is important to assess to what extent SCDI portability has affected the company's diverse product lines and the percentage of special parts damaged by supply chain disruptions. Such analysis is quite feasible using a product architecture matrix (Park, Abe, & Okuma, 2011). The more special parts a product requires, the more difficult it will be to disperse SCDI. Thus, dispersing risks become more difficult. In this sense, the most practical way to increase SCDI portability is to utilize an IT system (Duncan et al., 2011; Maon et al., 2009).

Among the case firms, Zyuden shows the highest dependence on complex special parts, so its issues with SCDI portability are somewhat more difficult to handle. However, Zyuden secured production visibility through its IT system, and its recovery process was much faster than the other firms as a result. Sangyo exhibited higher SCDI portability and more supply chain substitution possibilities than Zyuden. These increased capabilities resulted from Sangyo's implementation of design information sharing between its Japanese mother factories and overseas plants in the broad supply chain network. Neither Kenki nor Iryou have begun utilizing SCDI portability. However, it is evident that SCDI portability is a task that a small number of firms view as a strategic issue.

In a time of disaster, physical supply chain dispersion plays a large role in managing disruptions but requires firms to make large investments. When firms perform business continuity planning, embedding supply chain dispersion in every supply chain may not be a viable option for firms that have to stretch their resources thin to weather fierce global competition. Considering that some disruptions (e.g., an earthquake followed by a tsunami) occur very rarely, implementing dispersion on a global scale may not be a cost-effective method to mitigate supply chain risks (Knemeyer, Zinn, & Eroglu, 2009). An alternative to physical dispersion is virtual

supply chain dispersion (Fujimoto, 2011), and IT systems are crucial in implementing and executing virtual supply chain dispersion.

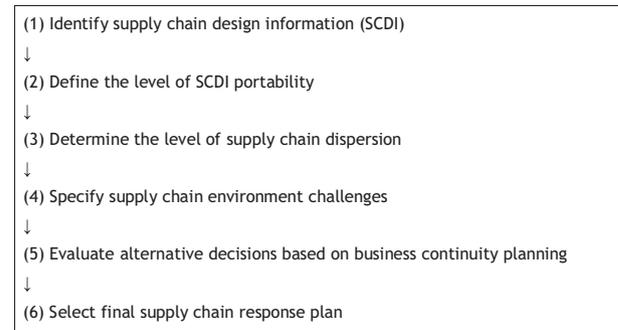
The case companies in this study show varying degrees of virtual dispersion. Most of the companies use physical dispersion to some extent but exhibit different levels of utilization. Although Sangyo practices physical dispersion through production dispersion to China, it only partially realizes virtual dispersion, such as sharing drawings and production process information. Zyuden utilizes supply chain recovery processes and virtual plant facility recovery but has not yet implemented virtual capabilities to remotely control plant facility recovery processes. Despite using its system to manage supply chain risks virtually from headquarters, Zyuden's capabilities seem to be limited. Meanwhile, Iryou and Kenki have achieved physical dispersion by transferring facilities overseas and enhancing responsiveness to the market. However, they should also consider implementing virtual dispersion.

Supply chain environment challenges must be considered in responding to disruptions. Infrastructure is often key to restoring supply chain robustness and business continuity planning. As shown in the case illustrations, Japanese companies have suffered from supply chain disruptions due to issues with receiving electricity. Because of the limited and intermittent electricity supply as a result of the nuclear meltdown, companies have had a difficult time recovering production capacity and maintenance. Such a disruptive power outage is an issue that can persist over a considerable length of time, thus making infrastructure access problematic. Although the cooperation among people and the well-developed infrastructure in Japan made the recovery process ramp up relatively quickly, it is unrealistic to always expect such a rapid recovery, especially when a supply chain is located in an underdeveloped region. For such cases, companies should develop reaction measures using different approaches. Thus, it is important for companies to understand what levels of infrastructure their supply chains deal with and then to set up reaction plans after taking their specific supply chain environments into consideration.

4.4. Supply chain evaluation decision processes

Companies need to assess supply chain disruptions from a business continuity planning perspective. As the research framework in this study suggests, SCDI portability and the extent of supply chain dispersion serve as important criteria. The most important principle is how to increase SCDI portability. From

Figure 3. Supply chain risk mitigation and restoration process



the manufacturing side, one way to improve SCDI portability is to reduce the number of special parts and increase supply chain robustness. This product architecture simplification strategy may decrease a focal company's global competitiveness and increase risks in business continuity planning because other rival firms can easily imitate its simplified product structure and parts. Therefore, physical supply chain dispersion is a better alternative when product architecture plays a key role in acquiring competitive advantage. Additionally, when it comes to special parts, external integration methods with suppliers are necessary. In the case of the 2011 Japanese earthquake, one external integration method with suppliers was contractor agreements for rapid recovery.

On the other hand, virtual supply chain dispersion is an ideal alternative plan for rare yet abrupt disruptions. The higher the SCDI portability, the better virtual supply chain dispersion is. However, when a company displays a low level of SCDI portability, it should consider not only product architecture but also physical supply chain dispersion and contractor agreements with suppliers.

Figure 3 shows six important steps to determine supply chain response. A company equipped with final supply chain response planning will be able to swiftly respond to abrupt disturbances and be able to turn a crisis into an opportunity to gain competitiveness and optimize its supply chains.

5. Conclusion

This article is unique in that it examines the impact of the recent supply chain disruptions in Japan. In response to potential major natural disasters, Japanese firms have naturally considered increasing their inventory levels, adopting standardized component parts, increasing the number of lines/facilities/suppliers, and relocating production centers. These timely case studies suggest that the

outstanding responses to these natural disasters are not produced by the above-mentioned normal options but by robust and responsive supply chain strategies.

Based on these cases, we believe that no Japanese firms have yet achieved SCDI portability in response to major natural disasters. Thus, it is important to further study how firms establish virtual global supply chains supported by increasing SCDI portability and virtual dual sourcing. Future research should explore design method details to construct virtual dual supply chains to deal with global supply chain disruptions.

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