MMRC
DISCUSSION PAPER SERIES

No. 509

Balancing Competitiveness and Robustness

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June, 2019

東京大学ものづくり経営研究センター
Manufacturing Management Research Center (MMRC)

BALANCING COMPETITIVENESS AND ROBUSTNESS[1]

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[1] This discussion paper is a reprint of the content, but not the formatting, of chapter 1, "Introduction: Balancing competitiveness and robustness" in Fujimoto, T. and D. A. Heller (eds.) (2018), Industries and Disasters: Building robust and competitive supply chains, Hauppauge, NY: NOVA science publishers, PP. 1-30. ISBN: 978-1-53612-905-2, Based on the Agreement Between the authors and NOVA science publishers.

Abstract:

This chapter presents the overall theme of the book, *Industries and Disasters* – that supply chain robustness and competitiveness can and must be balanced in this age of global competition – by describing the huge Tohoku earthquake that struck Japan in 2011 and the actual responses of some Japanese companies. The chapter also introduces the core theoretical issues addressed in the book. When should firms pursue: Buffers or capability building? On-the-spot recovery or substitutive production elsewhere? Bottom-up continuous improvement (*kaizen*) or top-down solutions?

Keywords:

The 2011 Great East Japan Earthquake, supply chain destruction, capability building, buffers, on-the-spot recovery, substitutive production, automobile industry, globalization

1. THE GREAT EAST JAPAN EARTHQUAKE AND SUPPLY CHAIN DESTRUCTION

1.1. Building Capabilities or Adding Buffers

Motivation and Purpose of the Book: The 2011 Great East Japan Earthquake (Tohoku Earthquake), with its main shocks, tsunami, aftershocks, as well as the accident at the Fukushima Daiichi (Number 1) Nuclear Power Plant, disrupted and destroyed numerous domestic and international supply chains across several industries. During and after their recovery/restoration period, there was much debate among practitioners, the media, the government and academics regarding how the Japanese and overseas supply chains should be changed and improved, to increase their robustness or resilience against the next big earthquakes, which seem inevitable in this country of frequent natural disasters.

This book is motivated by such a debate and thus consists of various first-hand academic studies on how firms, factories and facilities responded to the 2011 Earthquake and other large-scale disasters, including floods and big fires, learned from them, and enhanced their preparedness and robustness against them.

Special attention will be paid to the organizational capabilities of firms, factories and other industrial sites (called *genba* in Japanese) to achieve a difficult balance between robustness against disasters and competitiveness against rivals. Various Japanese firms and genba have already made capability building efforts toward greater robustness, more accurate initial reactions and shorter production and supply recovery times, by learning from the bitter lessons of past natural disasters. Many of them have also been building capabilities to improve their industrial performance vis-a-vis intensifying global competition. Indeed, the 2011 Earthquake occurred at a time when firms and genba were simultaneously preparing for global competition, which is present every day, and big disasters, which may come someday. We will thus emphasize capabilities, rather than buffers, as the most basic element of disaster-robustness of firms and industries. In other words, the recommendations proposed in this book will be capability-oriented, rather than buffer-oriented, although we will try to strike a certain balance between the two (Fujimoto and Park 2014).

The 2011 Earthquake and the Robustness of Genba: Let us go back to what happened during the 2011 Great East Japan Earthquake. The damage caused by this earthquake, one of the largest in the world's modern history (moment magnitude scale: 9.0[2]), was in many respects beyond anyone's imagination. Its main shocks and aftershocks destroyed numerous buildings and facilities and a tsunami—over 10 meters high and reaching 30-meter-high points in some areas—wiped out cities and communities across more than 500 km^2 of coastal areas in North-Eastern Japan (Tohoku). The toll of dead and missing was over 15,000 and, at the peak time, nearly half a million people were evacuated from their damaged or destroyed homes. In addition, the accidents at the Fukushima Daiichi Nuclear Power Plant will seriously affect the surrounding areas for several decades, at least.

The earthquake's enormous destructive power also hit local industries. The government estimated direct damage to be 200 billion USD or more. Besides, production stoppages in the Tohoku region had significant repercussions on overseas facilities through global supply chains. Production lines for global standard components (e.g., microcomputer chips) were shut down, seriously affecting multiple industries worldwide, and other impacts of industrial globalization and digitization in the post-Cold-War era made the recovery and restoration tasks more complex and unpredictable.

There were sharp contrasts in how the government, firms, factories and communities responded to this unprecedented natural disaster. On the one hand, misjudgment and mismanagement in the early stages and the subsequent slow response to the Fukushima

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[2] Magnitude 9.0 according to Japan Meteorological Association; In 2016, the US Geological Survey revised its estimation of the earthquake's magnitude from 9.0 to 9.1.

Daiichi Nuclear Power Plant accident by the government and the electric company were harshly criticized. On the other hand, the tenacity and orderly behavior of the people in the damaged communities were praised by the media and observers worldwide. Another group of organizations that was evaluated positively in relation to its robustness and teamwork were the numerous genba and other sites operated by people in the affected areas. Many of them, including large and small factories, shops, service centers, public transportation systems and power supply networks restored their supply chains and facilities significantly faster and more effectively than expected by many industry specialists and journalists, given the size and severity of the damage. For example, most of the disrupted genba of Japan's automotive supply chains (except for some critical parts and devices) reopened within two weeks of March 11, 2011, or substitutive production was started elsewhere, demonstrating rather high levels of anti-disaster robustness.

Disasters and Global Competition: And yet, the 2011 Earthquake left behind numerous lessons, concerns and problems for practitioners, administrators and academics, who realized that they need to prepare for the next 'Big Ones,' which seem inevitable, wherever or whenever they may happen. Thus, in the aftermath of the disaster, there has been a great deal of debate over possible approaches aimed at improving the robustness of supply chains against future natural threats.

The debate was complicated, however, by the fact that it had to take into account the industrial transformations of the early 21st century. For instance, economic globalization has expanded the supply network worldwide and the design of weighty and highly functional products such as cars—facing socio-technical constraints in terms of safety, energy conservation and environmental protection—has become increasingly complex, with integral product architecture and many product-specific components which are not easily substitutable. Moreover, revolutionary digital innovations in relatively weight-free products and devices with open-modular architectures have resulted in highly concentrated production of the key components on which they depend across industries worldwide.

In addition, factories of tradable goods (e.g., cars and electronic products) in relatively high-wage countries like Japan have had to face intense global competition from low-wage, emerging countries, such as China in the post-Cold-War era. Besides, in the case of Japan, the yen rose in value to around 80 yen per USD in the early 2010s, compared with 360 yen in 1970, around 240 yen in 1985, and roughly 120 yen in 2000. This meant that the Japanese factories, or genba, had to find ways to avoid not only temporary plant shutdowns due to disasters but also permanent shutdowns due to overwhelming competition. Thus, the 2011 Earthquake may be regarded as the first huge and wide-area disaster that happened in a high-cost country facing global competition.

All of the aforementioned developments have made the problem of minimizing damage to supply chains caused by major and unpredictable disasters more complex and difficult to solve. And this can certainly happen anywhere in the world, not only in high-wage, advanced countries but also in newly industrialized areas where wages are increasing rapidly.

Business practitioners and academics have already started discussing measures such as BCPs (Business Continuity Plans) to deal with disaster situations. The main purpose of this book, however, is not to present general procedures for coping with natural disasters, but to provide empirical studies on how specific firms and factories have responded to actual disasters and the lessons they have learned from them. These case studies will focus mostly on one of the countries and periods in which disasters were frequent and competition was, at the same time, rather tough, *e.g., Japan in the post-Cold-War period.* We will analyze various cases of Japanese firms and genba facing the potential dilemmas ensuing from disasters and competition, as well as the theories and logic that may be derived from them.

Design Information Flow View of Manufacturing: From a theoretical point of view, in order to analyze the destruction and restoration of industrial supply chains, we adopt a broad concept of *manufacturing*, seen as creating, improving and managing the flow of value-carrying design information to customers in the market. This is also called *monozukuri* in Japanese. We consider the value added of goods and services to reside in *design*, which refers to information about the functions of the artifact in question, as well as its structures and their relations. Hence, our concept of monozukuri (manufacturing in a broad sense) is design-flow-based, in that its mission is to produce total flows of value-carrying design information to and from customers and firms by integrating engineering chains and supply chains (Clark and Fujimoto 1991, Fujimoto 1999).

Here, the *competitiveness* of a product or factory is its ability to attract and satisfy customers and firms, as it is continually selected by them. *Organizational capability* in manufacturing refers to a system of organizational routines which enable genba (e.g., factories) to achieve stable, fast, efficient and accurate flows of design information to customers. Distinctively strong manufacturing capabilities, such as the Toyota Production System, tend to have a positive impact on the competitiveness of the product and genba in question, other things being equal.

Another important concept in the design-based framework of manufacturing is product-process architecture (Ulrich 1995, Baldwin and Clark 2000, Fujimoto 2007, 2012). In this context, architecture means patterns of connections between functional and structural elements of an artifact, such as a product or production process. If there is a simple, one-to-one correspondence between a product’s functions (e.g., performance specifications) and structures (e.g., components), its architecture is design-coordination-saving and is called modular. If there is a complex, many-to-many correspondence between them, its architecture is design-coordination-intensive and is called integral.

Modular products tend to consist of common parts that can be shared among different product variations. When these parts have industry-standard interfaces, the products have open (modular) architectures, in which standard components and interfaces are shared across many firms. On the other hand, integral products require a high level of design optimization and coordination and are often composed of product-specific parts. Many digital products and services (e.g., computers, the Internet) tend toward the open-modular architecture, while high-performing physical products (e.g., cars) tend to be more integral. The structural characteristics of the industries in question may differ depending upon the architectures of their products.

In this context, a supply chain can be regarded as the flow of design information about a particular product through multiple suppliers all the way to the end-point customers. It follows from this concept of monozukuri that the anti-disaster robustness of a given supply chain resides in its ability to make sure that the flow of design information to its customers continues or that its breakdown period is minimized. In other words, reconstruction of the supply chain after a disaster is nothing but the resumption of such design information flow. Since we define supply chains as flows of design information, we may conjecture that the nature of supply chains differs depending on the architectures and the design processes of their products. If a product is integral and its product-specific parts are co-designed by the customer and its suppliers, such parts may be difficult to substitute by other firms when their supply stops due to a disaster. If the product is open-modular and its standard design parts are available in the market, it will likely be relatively easy to find substitute suppliers. In the following analysis of actual cases, such differences in product architecture and design processes will be taken into account.

With these theoretical concepts and frameworks in mind, we will analyze how disasters affect supply chains as flows of design information, and how firms and genba facing disasters tackle the challenges of restoring and strengthening their supply chains, while maintaining and enhancing competitiveness at the same time.

Capabilities rather than Buffers: As mentioned above, the 2011 Earthquake may be regarded as the first vast disaster affecting a large area in a globally competing high-cost country, Japan. This implies that a supply chain must enhance its anti-disaster robustness without sacrificing its international competitiveness if it wants to avoid decline before the next large disaster strikes. Companies should not forget the fact that, while the next disaster will come somewhere someday, global competition is here every day.

Globally competing firms and genba have to try and strike a difficult balance between robustness against disasters and competitiveness against rivals, even when the overwhelming psychological impact of huge catastrophes like the 2011 Earthquake makes the “disaster-first mentality” prevail in the minds of those on site. More specifically, this book argues that building capabilities for anti-disaster robustness should be prioritized over adding buffers as seemingly easier countermeasures. This is because we believe that the former, if carried out effectively, can simultaneously enhance the supply chains’ robustness and competitiveness, whereas the latter may only strengthen robustness to the detriment of long-term competitiveness.

1.2. Impacts of Complexity and Globalization – The Case of the Auto Industry

The 2011 Great East Japan Earthquake showed how natural disasters impact on 21st-century industries and firms, particularly in higher-wage advanced countries like Japan in the post-Cold War era, characterized by product complexity and digitization, as well as global supply chains expansion and competition.

Special attention is paid here to the automobile and its parts industry, one of the sectors in which Japanese firms and factories have retained international competitive advantages in the early 21st century. The automobile is a complex physical product whose architecture is relatively integral or coordination-intensive and it consists of many product-specific parts. The Japanese automobile and parts manufacturers, with relatively high coordination capabilities, have enjoyed design-based comparative advantages in this coordination-intensive product for several decades (Womack et al. 1990, Fujimoto 1999, 2007, Heller and Fujimoto 2017).

Increasing Complexity and Electronic Controls: The first trend analyzed here is the rapidly increasing complexity of automobiles and their electronic control systems. Since the 1970s, with the introduction of electronic fuel injection, electronic control systems have progressed from managing individual functional parts to controlling subsystems and then the vehicle as a whole, thus becoming complex assemblies of many ECUs (electronic control units), in which semiconductors and discrete electronic components are mounted on printed circuit boards with embedded software controlling them.

The ECUs of higher performing automobiles contain semiconductor chips called microcontrollers. A microcontroller is a collection of processors and memory on a single chip. Companies using them, such as automobile manufacturers and suppliers, have to optimize the ECUs for each individual car by embedding product-specific software. As explained later, though, even before the embedded software is installed, the hardware of the microcontroller chip itself may also be product-specific (or customer-specific), as opposed to standardized, making it more difficult to substitute supplies.

Automobiles themselves, as physical artifacts, have become extremely complex products. The sheer fact that nowadays an average passenger car is roughly a 1-ton object which can move faster than 100 kilometers per hour makes the requirements for safety (accident prevention and mitigation), energy conservation and environmental protection imposed on it ever more stringent. Said requirements cause the design of a car, consisting of about 30,000 parts, as well as of its electronic control systems, to be extremely complex, with high levels of functional-structural optimizations and architectural integrality (Fujimoto 2014).

For example, as of the early 2010s, high-performance passenger cars were controlled by dozens of microcontroller units with embedded software having 10 million or more lines of code. Their production processes also became increasingly delicate, capital intensive and, consequently, difficult to resume if damaged or destroyed.

As a result, in the 2011 Earthquake, one of the damaged plants which took the longest to recover and affected the widest range of industries was a microcontroller factory located in the disaster area, namely, the Naka Plant of Renesas Electronics in the city of Hitachinaka, Ibaraki Prefecture. The case of this plant will be discussed later in this book.

Globalization and Localization of Supply Chains: The second trend is the expansions of global supply chains in both the automotive and other sectors. Consequently, the earthquake of March 11, 2011 caused production suspensions not only in vehicle assembly and component subassembly factories in Japan, but also in the overseas factories of Japanese firms (e.g., in Thailand). In addition, certain assembly plants for vehicles and components of non-Japanese firms using parts manufactured in the damaged area had to halt operations after exhausting their inventories (after May 2011 or 2 months later, in some cases), which, in turn, created supply shortage problems for Japanese firms purchasing such items. For example, despite buying certain functional parts from local suppliers, Toyota's European assembly plants were also forced to suspended production since their European suppliers imported sub-parts from earthquake-affected Japan.

Behind this evolution of global supply chains for automobiles and their components is a complicated process of both internationalization and localization of supplies. First, since the 1980s, Japanese firms have internationalized the locations of their large-scale vehicle assembly plants, due mainly to: cost advantages of low-wage countries in the Post-cold-war period, appreciation of the yen between the 1990s and early 2010s, protectionist pressures in some advanced automobile-producing nations, as well as other non-price advantages of local assembly plants. For example, while the Japanese automobile assemblers accounted for approximately 30% (about 27M units) of world automobile production (about 90M units) as of 2015, roughly two-thirds of their worldwide production came from overseas assembly plants.

Second, Japanese first-tier parts suppliers have quickly expanded their overseas production, following the aforementioned globalization of the Japanese assemblers. Once they enter a country or region where Japanese assemblers are located, many of them demonstrate competitive advantages in terms of quality, stability and flexibility vis-à-vis the local suppliers. At the same time, however, whenever they have competitive or technological advantages, Japanese first-tier suppliers have continued to export parts from their factories in Japan and other countries.

Generally speaking, bulky and technologically mature parts, such as many ordinary subassemblies and exterior-interior parts, tend to be produced locally in the countries where the vehicles are assembled, due mostly to savings in transportation and other distance-related costs. On the other hand, parts and materials which are technology-intensive, compact, with lower transportation costs, and have high value-added and/or strong scale economy effects tend to be exported from the home country if there are technological and scale advantages. The aforementioned microcontroller chips, discrete electronic components, and compact piece parts using highly functional chemicals and metals are typical examples of such export/import-oriented items, to the extent that they enjoy higher scale economies and lower transportation costs.

As a result, the automobile supply network is extremely complex and it is affected by two principles of international plant location: (1) closeness to the markets/users and (2) item-by-item comparative cost advantages. The former tends to result in compact supply chains in each country, whereas the latter leads to world-scale supply chains, with factories mutually linked through global trade networks of products and parts.

Third, the tendency toward both localization and globalization of supply chains can also be observed among Japanese lower-tier suppliers starting from the 2010s. In detail, whereas parts production is becoming more heavily localized in many emerging countries, involving not only internal production of the Japanese first-tier suppliers themselves and new entry of local lower-tier suppliers, the overseas production of Japanese lower-tier suppliers is also increasing. Yet, at the same time, the export of piece parts and sub-parts from the Japanese factories of lower-tier suppliers still remains significant.

As a result of all the above developments, complicated parts supply networks, characterized simultaneously by intense localization and wide globalization, had emerged in the auto industry as of March 2011. And wherever global supply chains of such complexity exist, a disaster causing suspension of operations in a given region may trigger worldwide chain reactions of plant shutdowns within and across firms.

Intense Global Competition: The third trend to be considered is the intensification of global competition in the post-Cold-War period. In the early 2010s, the international competitive environments were extremely tough for the Japanese auto industry's domestic factories due to a series of causes. The recession after the financial crisis that originated in the United States in 2008 resulted in weak domestic demand. US and European companies had been catching up with Japanese firms in assembly productivity and manufacturing quality since the 1990s, while Korean automotive manufacturers, such as Hyundai, were quickly expanding worldwide as fierce competitors. Furthermore, rapidly growing emerging markets like China were characterized by strong demand for cars with simpler technologies and design—a segment in which Japanese firms and factories did not excel. Lastly, the value of the yen continued to rise. Hence, the Japanese auto and parts manufacturers were dealing with a harsh competitive environment back in 2011.

Faced with these challenges, the Japanese automotive assemblers and suppliers (including the lower-tier ones) had no choice but to keep improving the competitiveness of their domestic genba in terms of manufacturing capabilities, productivity, quality, lead times and flexibility. Thus, even after the earthquake struck their network of suppliers, they did not have the luxury of strengthening their anti-earthquake robustness at the expense of competitiveness.

2. CRITICAL ITEMS FOR SUPPLY CHAINS RECOVERY AFTER THE 2011 EARTHQUAKE

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. Microcontrollers and ASICs

The first case concerns semiconductor integrated circuits for controlling machines and devices. In general, products such as automobiles, home appliances, electronic devices, office equipment and industrial machineries can be controlled by means of any of the following: a printed circuit board (PCB) with discrete electronic components hardwired onto it; a product-specific integrated circuit (ASIC) mounted on a single silicon chip for use by a specific customer; a more generic integrated circuit, or a microcontroller, with customer-product-specific software embedded into it.

Although a combination of the above three types is used in most actual cases, microcontroller chips, the third type, have become increasingly common in ECUs mounted in automobiles. In the early 2010s, nearly half of the Japanese manufacturers were utilizing microcontrollers. At the same time, however, various other types of electronic devices used the second type, i.e., ASIC, or a customer-specific semiconductor such as SoC (System on Chip), which has all the integrated circuit design information needed to control a given product built into the chip.

The 2011 Earthquake hit a large plant manufacturing semiconductors, microcontrollers and ASICs used for device control, the Renesas Electronics Naka Plant in the city of Hitachinaka, Ibaraki Prefecture. This semiconductor factory had two production lines: one for 200 mm wafers and the other for 300 mm wafers. At the time, the former was mostly producing microcontrollers for automobiles, while the 300 mm wafer line was producing customer-product-specific SoCs for digital products. Both lines were severely damaged and it was initially estimated that it would take one full year to resume production. Yet, intense recovery efforts by the inter-firm restoration team of Renesas and user companies enabled them to regain full production capacity within three months (at the beginning of June 2011). Also, substitutive production of the semiconductors in question gradually started in other Renesas factories in Japan and external foundries after April 2011. Despite these efforts to minimize the impact of its supply shortage, Renesas's Naka plant became one of the factories which affected the widest range of industries for the longest period after the disaster.

There were at least three factors which made the recovery of the microcontrollers supply chain difficult: production concentration, supply substitutability, and design information portability.

First, many user firms adopted almost exclusively chips from the Naka plant. Indeed, these types of leading-edge semiconductor technologies require minute processing on a scale smaller than 0.1 μ and involve the execution of more than 100 steps, utilizing extremely expensive semiconductor manufacturing equipment. Consequently, production of advanced semiconductors, with major entry barriers regarding technologies and capital investment, tended to rely on a limited number of suppliers.

In addition, production of microcontrollers was concentrated in Japan, partly because the Japanese manufacturing sites had some architecture-based comparative advantages in relatively integral and customized semiconductors, and partly because they were close to their main clients, e.g., Japanese auto manufacturers[3]. Consequently, Renesas Electronics held 30% of the world market share of microcontrollers (40% for automobiles) in the early 2010s.

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[3] It is true that production processes of such semiconductor types as DRAMs became modular, since the integral portion of the process was "capsulated" into semiconductor production equipment, which itself is highly integral. The coordination-rich Japanese firms and factories lost competitiveness in such coordination-saving, or process-modular, semiconductor products. In the case of advanced ASICs (SoCs) and microcontrollers, however, their internal and external product architectures tend to be relatively integral or coordination-intensive (to be externally integral means being customized), which fits Japan's development and production sites, with strong coordination capabilities and team collaboration among multi-skilled workers and engineers.

Second, substitutive supply of onboard microcontrollers for automobiles was not an easy task. Microprocessors are usually seen as generic semiconductor products, which user companies can buy off the shelf, thus making it easy to switch to substitutive supplies. However, the ones produced at the Naka Plant were developed using design rules (e.g., translation rules among functional-structural-process designs) and methods (e.g., development tools, design libraries, simulation equipment), which were unique to that plant, so those microprocessors were supplier-process-specific. As a rule, when a user company develops customer-product-specific embedded software which matches one of Naka's microcontrollers, that software takes on supplier-process-specific characteristics, causing the whole control system—software and hardware—to become Naka-Plant specific, making it very difficult to switch to other suppliers.

In general, if the structural design of a part (a microcontroller in this case) is either customer-product-specific (difficult to switch buyers) and/or supplier-process-specific (difficult to switch sellers), its substitutability decreases. In the case of the Naka Plant, the ASICs (SoCs) were more customer-product-specific, while the microcontrollers were more supplier-process-specific. Yet, in either case, from the point of view of the user companies, the semiconductors in question had relatively low substitutability, i.e., it was almost impossible to switch to other suppliers in the wake of the disaster.

Third, the design information embedded in semiconductor production equipment (e.g., circuit design information on the mask) is difficult to detach from its equipment hardware, unlike the cases of dies recovered from damaged press machines or NC programs moved from damaged machine tools. This implies low levels of design information portability, which leads to difficulties in switching production to other factories or suppliers.

To sum up, as a result of large market shares, low substitutability and low portability of its microcontrollers, the resumption of production at the Naka Plant was slower and its economic impact larger than in the case of other factories hit by the 2011 Earthquake.

Having grasped the seriousness of the situation, Japan's automobile manufacturers acted just like they had done during the production stoppage at Riken, an automobile piston ring supplier affected by the Chuetsu-oki earthquake in 2007 (see Chapter 4). All the companies which were members of the Japan Automobile Manufacturers Association deployed restoration assistance teams to the Naka Plant, while domestic and foreign semiconductor lithography equipment manufacturers commuted continuously between their factories and the Naka Plant to speed up the recovery process.

Hence, as mentioned above, Naka's complete recovery took merely three months rather than the original estimated time of one year. There were good developments also from the viewpoint of business continuity plans (BCPs). The design information controlling the equipment (recipe) for about half of the products manufactured at Naka was transferred to other plants and firms to facilitate substitutive supply of the affected parts. Despite major obstacles, as a result of all these efforts, the recovery of the Naka Plant and related supply chains was achieved much earlier than initially predicted by industry observers.

2.2. Functional Chemicals

Other key items used in the manufacturing of automobiles which were seriously affected by the 2011 Earthquake were functional chemicals, including: rubber for tires and brakes manufactured at JSR Corporation in Kashima, Ibaraki Prefecture; kneaded rubber at Fujikura Rubber in the city of Kodaka, Fukushima Prefecture; additives at Ouchi Shinko Chemical Industrial in the city of Haramachi, Fukushima Prefecture; paint pigments at Merck in the city of Onahama, Fukushima Prefecture; and condenser electrolytes at Nippon Chemi-Con in the city of Takahagi, Ibaraki Prefecture, and Tomiyama Pure Chemical Industries in the city of Okuma, Fukushima Prefecture. It is important to note that functional chemicals are also relatively integral products, in which Japanese genba have achieved architecture-based comparative advantages with high market shares (30%–100% domestic share for the abovementioned plants that are all located in the Tohoku region).

In case of disasters, the basic nature of chemical products and processes makes their recoveries somewhat industry-specific. First, as chemicals are produced by means of capital-intensive processes with large equipment, such as reactors, tanks and pipes, the safe and rapid repair of said equipment is crucial. When explosive and toxic materials are involved, safety is by far the most important concern throughout the recovery period. Second, removal of in-process residuals inside the tanks and pipes often becomes the first critical task to complete, particularly if they are toxic or explosive. Third, if substitutive production is required, it may prove difficult to transfer the "recipe"—or product-specific design information which controls the chemical process—from the damaged plant to substitutive production sites and to adjust it to the new facilities (recipe adjustment). This is particularly true for high-performance functional chemicals, requiring complex and integral recipes, which are extremely product-specific and process-specific.

It is therefore vital for chemical plant managers to accurately and quickly assess recovery lead times for all items, compare them with inventories and demand, and decide between on-the-spot recovery and substitutive production, with product-by-product transfer of recipes. This is a daunting challenge in the middle of post-disaster confusion.

As for substitutive production, the key is whether recipes can be effectively transferred from the damaged plant and adjusted to another plant. Ideally, recipes should be easily portable and active communication should be maintained between potentially substitutable plants as well as the plants and the headquarters prior to disasters.

During the 2011 Earthquake, the most notably affected chemical plants were those around Kashima Harbor, Ibaraki prefecture, which were damaged by the tsunami, and those within the evacuation zone surrounding the Fukushima Daiichi Nuclear Power Plant.

One of the remarkable cases of effective recovery in this area (although not related to automobile parts) was that of Kaneka's vinyl chloride production line damaged at the company's Kashima Plant. It manufactured materials for infusion solution bags, which are in high demand at times of wide-area disasters, and supply shortages could be avoided by rapidly transferring its recipes to the main plant in the city of Takasago, Hyogo prefecture, in Western Japan. Let us briefly look at what they did after the 2011 Earthquake:

- *March 11, 2011*: The earthquake, tsunami and soil liquefaction damaged the tanks, pipes and material handling facilities of Kaneka's Kashima Plant. Fortunately, its main processing equipment did not suffer major damage, as it was set up high above ground.
- *March 12*: The Plant Manager, Masahiro Kozai, returned from the company's Osaka headquarters to Kashima, and after first verifying the safety of the plant's employees, he read the damage reports, inspected the damaged areas in person, and checked secondary disaster prevention. Kozai judged that restoration would be difficult if carried out solely by the plant employees, so he immediately reported to the headquarters and divisions the extent of the damage and requested water and food from the rescue team dispatched by the headquarters. Kozai continued to have daily contacts with the Kashima Plant managers from then on.
- *March 13*: Trucks from Osaka reached the Kashima Plant carrying rescue goods, which were quickly distributed to the employees and their families.
- *March 14*: Kaneka's vice president arrived at the Kashima Plant and inspected the damaged area. Details of equipment failures were checked and, after discussing the best way to do so, the removal of potentially dangerous residuals between the reactors and tanks was initiated.

Engineers and maintenance staff from the Takasago Plant in Western Japan, Kaneka's main plant, reached Kashima to help in the restoration.

- *March 31*: Equipment repair and removal of the residuals were completed.
- *April 2*: Substitutive production of vinyl chloride for medical use (infusion solution bags) started at the Takasago Plant, after the recipes were moved from Kashima and adjusted to the existing equipment. This decision to opt for substitutive production was made by Kozai after he received a joint report from Kaneka's engineering and marketing divisions that, because of the sharp increase in rescue-related demand for medical products due to the earthquake, the resumption of Kashima's own production for this particular item would not occur in time for inventory replenishment.
- *April 5:* The Kashima Plant resumed operations at 50% utilization ratio, using the remaining raw materials (new supplies of raw materials were not available at this time).

This is a typical example of what we may call "virtual dual sourcing" in response to major disasters, but the meaning of the measures taken in such a case will be discussed later in this book (see Chapters 2, 3, 6, and 10).

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 8th or 9th 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, which will be discussed later in this book.

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. In the following chapters of this book, a framework for analyzing supply chain disruptions caused by disasters and effective recovery strategies will be presented in detail.

3. SOME PRACTICAL AND THEORETICAL ISSUES

Finally, let us discuss some of the practical and theoretical issues that may be derived from the cases described above of how firms and genba respond to difficult situations of disasters and disruptions. Three issues are discussed here: whether we should add buffers or build capabilities in preparation for the next major disasters; whether we should focus on quick, on-the-spot recovery of production or shifting quickly to substitutive production; and whether we should utilize *kaizen* capabilities or set up separate emergency teams in response to disasters.

3.1. Buffers or Capabilities?

First, let us consider whether we should add buffers or build capabilities in preparation for the next major disasters. A quick answer is that we will need both buffers and capabilities, but this book gives priority to the latter, i.e., capability building. That is, firms and sites should first build capabilities to simultaneously cope with disasters and competition and then determine the appropriate level of buffers, given their capabilities.

Buffers and slack have been recognized as effective measures for organizations dealing with environmental uncertainty (Cyert and March 1963, Thompson 1967). For instance, Thompson (1967) called an organization's central value-creating process its "technical core" and argued that this core pursues stability and efficiency and, when facing environmental uncertainty, an organization tries to insulate its technical core by setting up boundary spanning units as buffers between the stable core and the fluctuating environment.

Note that disasters, such as big earthquakes and fires, are the ultimate form of environmental uncertainty, so buffers are needed to alleviate shocks to organizations. Typical examples of such buffers and slack against disasters are inventories of products and materials, as well as duplication of production lines manufacturing the same product.

However, we should also observe that, given the level of environmental uncertainty, the level of buffers is affected by the available organizational capabilities of the technical core to deal with environmental uncertainties. The Toyota Production System, for example, emphasizes continuously improving manufacturing capabilities (kaizen). The level of work-in-process inventories in its kanban or just-in-time systems, in turn, depends on the level of a genba's manufacturing capabilities, as efforts are made to continually decrease the inventory levels.

In this book, we share the capability-first perspective inherent in the Toyota Production System. Our focus is on the capability building efforts of firms and factories to effectively respond to damage caused by disasters before and after they actually happen, and to maintain or improve competitiveness at the same time. We do not deny the essential functions of buffers in times of disasters, but we reject the idea of depending solely on buffers as preparatory measures against disasters.

Note also that large-scale disasters are almost completely unpredictable, in that we cannot assign probability to such events. It is, therefore, impossible to make rational estimates of optimal buffer levels against them. There are uncertainties in competitive environments too, but they are not as unpredictable as large disasters. So, for example, Toyota sets its target inventory levels from the standpoint of competitiveness, given predicted levels of uncertainty in normal market-production conditions. Toyota may add to its inventories when supply chain disruptions are predictable to some extent, as in the case of heavy snows in specified areas stopping supply chains in winter, but this method would not be applicable to something almost entirely unpredictable like big earthquakes.

To sum up, one way for firms and factories to simultaneously deal with disasters and competition is to focus on improving competitive capabilities first, set inventory levels according to the competitive capabilities achieved, and then try to improve supply chain recovery capabilities accordingly. If, for instance, today's competitive environments and capabilities call for two weeks' inventories for a particular product, then said two weeks will become a target for the capability building efforts of recovering supply chains in times of disaster.

3.2. Recovery or Substitution?

Given that capability building is the key to enhancing the anti-disaster robustness of firms and genba, the second question is whether, in preparation for future disasters, they should strive to build capabilities for (i) quick on-the-spot recoveries of production sites or for (ii) quick shifts to substitutive production. Our straightforward answer is both (i) and (ii). The main reason for this is that, as shown in the 4 cases below, both (i) and (ii) can be a rational choice for the damaged suppliers, depending on the situation, and no one knows which case will present itself when the next large disaster strikes.

From the clients' point of view, supply chain recovery for a given product can be achieved either by restarting the damaged production line itself or by commencing substitutive production elsewhere. It is irrelevant to them which option the supplier chooses, as long as their requirements regarding quantity, quality and delivery are met. So, if the supplier has accurate estimates of lead times for both on-the-spot recovery and substitution and is able to make rational judgments, the supply stoppage will be avoided or minimized.

Case 1: Suppose that, when the disaster happens, the client has 30 days worth of inventory on hand ($T_{inv} = 30$) and all other inventories are damaged. Let us assume that the supplier's estimated lead time is 20 days for on-the-spot recovery ($T_{rec} = 20$) and 10 days for substitutive production ($T_{sub} = 10$). Let us also assume that the damaged production line has cost advantages vis-à-vis the substitutive line in normal times (which is why this line was chosen) and that delivery is by far the main priority during the emergency. For the sake of simplicity, recovery costs and substitution costs are assumed to be equal ($C_{rec} = C_{sub}$).

In this case, the rational supplier would choose on-the-spot recovery, despite the fact that substitutive production can start earlier, because supply shortage can be avoided anyway. In more general terms, if $T_{inv} > T_{rec}$, then the supplier's choice would be on-the-spot recovery, even when substitution lead times are shorter ($T_{rec} > T_{sub}$).

Case 2: Suppose that the client has 20 days of inventory on hand ($T_{inv} = 20$), and that the estimated lead times are 30 days for on-the-spot recovery ($T_{rec} = 30$) and 10 days for substitutive production ($T_{sub} = 10$), respectively. Hence, the times are as follows: $T_{sub} < T_{inv} < T_{rec}$. In this case, supply shortages affecting the client can be avoided only if the supplier chooses substitutive production ($T_{inv} < T_{rec}$; $T_{inv} > T_{sub}$). When the damaged production line is ready to reopen (T_{rec}), however, production will be moved back to its original place, so substitutive production will last for 20 days in this case (T_{rec} - T_{sub} =30- 10 = 20).

Case 3: Now, suppose that the client has only 10 days of this product's inventory on hand ($T_{inv} = 10$) and that the estimated lead time for on-the-spot recovery is 20 days ($T_{rec} = 20$), while it is 30 days for substitutive production ($T_{sub} = 30$). In this case, the supply chain cannot be restarted in time ($T_{inv} < T_{rec} < T_{sub}$), and there is a supply stoppage period of 10 days ($T_{rec} – T_{inv} = 20 – 10 = 10$). It is obvious that a rational supplier should choose on-the-spot recovery, since it makes for faster reopening of the supply chain ($T_{rec} < T_{sub}$), thereby reducing the supply stoppage period to 10 days.

Case 4: If, as before, the client's inventory is enough only for 10 days ($T_{inv} = 10$) but lead times are 30 days for on-the-spot recovery ($T_{rec} = 30$) and 20 days for substitutive production ($T_{sub} = 20$), then the supplier will rationally chose temporary substitutive production, because the supply chain can reopen faster ($T_{inv} < T_{sub} < T_{rec}$) and delivery is the top priority in this case. If production restarts on the original line as soon as its recovery is completed, this will result in the client using its inventory for 10 days ($T_{inv} = 10$), followed by 10 days of supply stoppage ($T_{sub} – T_{inv} = 20 – 10 = 10$), 10 days of temporary substitutive production ($T_{rec} - T_{sub} = 30 – 20 = 10$), and production on the original line after that.

Note that, in some situations under case 4, restarting the damaged line may take a very long time, so that the period of substitutive production will be considerably extended. Large-scale fires and chronic flooding are such examples (Nishiguchi and Beaudet 1998, Chapter 5, Chapter 7). In extreme cases, the supplier may forego on-the-spot recovery and permanently move production to new or substitutive lines if the former takes too long or is too difficult (Chapter 6). After the 2011 Tohoku Earthquake, for example, the plants that happened to be located within the evacuation zone of the Fukushima Daiichi Nuclear Power Plant had no choice but to close down.

To sum up, assuming that the manufacturing of a particular product goes back to its original factory, the above cases represent the four basic recovery patterns:

Case 1: If $T_{rec} < T_{inv}$, then choose on-the-spot recovery (no supply shortage).
Case 2: If $T_{sub} < T_{inv} < T_{rec}$, then choose substitutive production (no supply shortage).
Case 3: If $T_{inv} < T_{rec} < T_{sub}$, then choose on-the-spot recovery (supply shortage occurs).
Case 4: If $T_{inv} < T_{sub} < T_{rec}$, then choose substitutive production (supply shortage occurs).

With the above assumptions, these four cover all of the logically possible patterns. Clearly, we do not know which case will come to pass when the next major disaster strikes, and this is the reason why firms and genba should build capabilities for both (i) quick and effective on-the-spot recovery and (ii) quick and effective substitutive production. As the cases in this book will show, all of the four patterns have actually occurred in real cataclysmic situations, such as earthquakes, floods and fires.

Cases 1 and 3 (on-the-spot recovery) and cases 2 and 4 (substitutive production) are illustrated graphically in Figures 1 and 2, respectively.

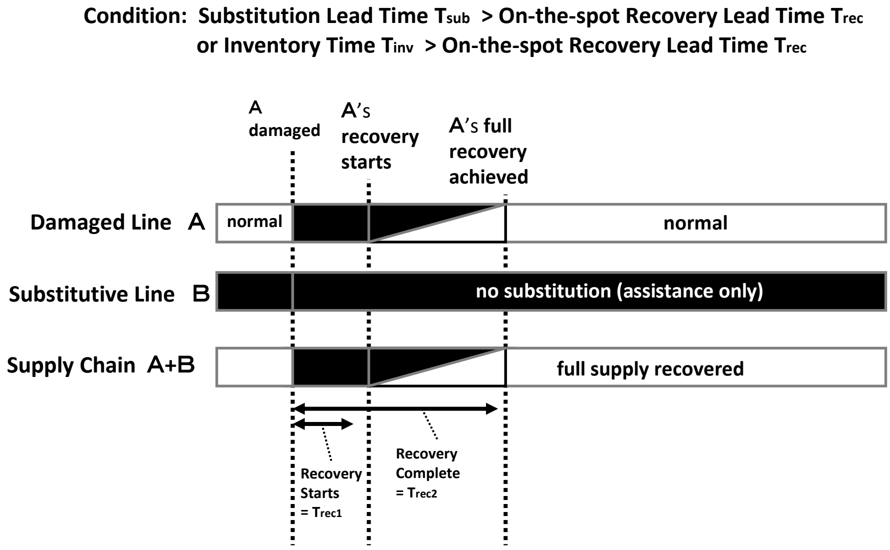

Figure 1. Simple Model of On-the-spot Recovery.

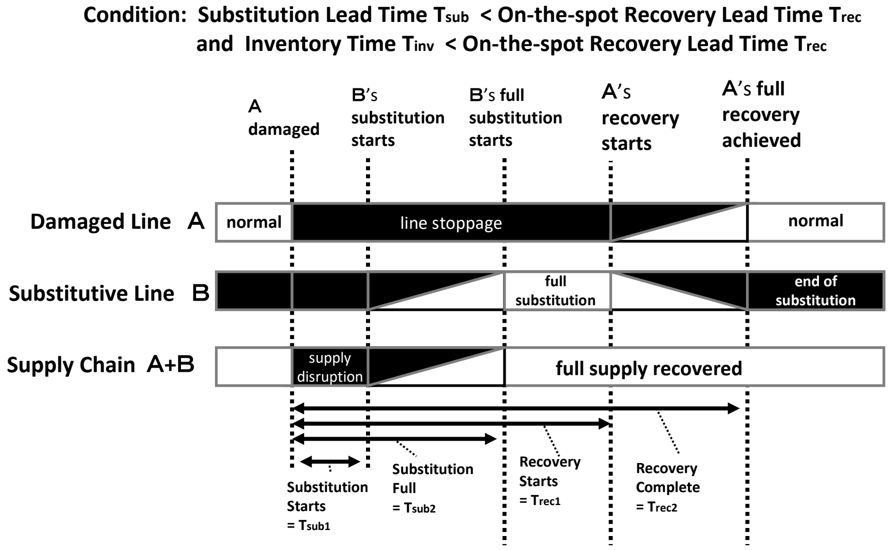

Figure 2. Simple Model of Substitutive Production.

3.3. Kaizen or Top Down?

The third question concerns organizational design and leadership in response to big disasters. One opinion is that a large-scale disaster can cause an unprecedented crisis across the whole company, requiring special organizational units and strong top-down leadership. Others believe that recovering from a disaster is a process of problem finding and problem solving, so experts in kaizen, Toyota Production System (TPS), Total Quality Control (TQC) and so on can be effective leaders in helping the recovery activities, particularly at the genba of small and medium manufacturing enterprises.

Thus, some may argue that dealing with big events like rescue, recovery and restoration following large-scale disasters requires extensive organizational design, with company-wide emergency taskforces led by the top management. On the contrary, others claim that what the damaged firms need are people who can observe, analyze, decide and physically initiate actions at the actual genba, and these are usually kaizen experts rather than corporate staff.

These contrasting views may be related to another matter of debate, that is, whether or not organizations which are good at many small changes, such as incremental innovations and kaizen, are able to handle infrequent big changes, such as radical innovations and recovery from unprecedented disasters (Abernathy and Utterback 1978). Organizational ambidexterity—or the organizational ability to pursue both incremental and discontinuous innovations at the same time (Tushman and O'Reilly 1996)—is closely related to this issue. We take these arguments from innovation management and apply them to anti-disaster management.

The case studies in this book confirm the coexistence in some organizations (e.g., Toyota, Kaneka, Honda) of: (i) strong leadership of executive or upper-middle managers (e.g., vice presidents, plant managers and project leaders) in emergency teams involving multiple factories or firms and (ii) quick analyses and actions carried out by shop floor managers and kaizen experts. Hence, we may call these organizations ambidextrous in managing situations of disaster. The next question then is whether (i) groups working on big changes and (ii) groups focusing on many small changes coexisted separately within the same firm, or whether (i) and (ii) coexisted as a continuum sharing the same philosophy and routines. Our case studies on Toyota tend to support the latter hypothesis. We will see if this is the case mainly in the last part of this book (Chapters 8 and 9).

3.4. Summary

This chapter introduced the motivations, purpose and background of the present book on industries and disasters. The ways in which firms and factories responded to the supply chain disruptions caused by the 2011 Great East Japan Earthquake were described and discussed as a preliminary analysis. The concepts of genba, capability building, competitiveness, disaster-robustness, architecture, as well as the design-flow-oriented approach to manufacturing, or "monozukuri," were presented as the book's analytical framework. The cases of microprocessors, functional chemicals and automobile piece parts were illustrated as preliminary case studies. Then, some key criteria were derived from them, most notably, concentration, substitutability, portability and visibility, which may make recovering from disasters more difficult. Finally, some practical issues were outlined: buffers versus capability, recovery versus substitution, and kaizen versus big changes. All of the above will be elaborated and discussed further in the following chapters.

In brief, this volume is about the simultaneous pursuit by modern firms of disaster robustness and global competitiveness. Indeed, one of the most important lessons which the Japanese industrialists learned from the 2011 Tohoku Earthquake and the subsequent recovery period is that they must strengthen their supply chain's robustness against major disasters but they must also not forget that, at the beginning of the 21st century, firms in industrialized, high-cost countries like Japan face severe cost competition.

Against this background, the present book discusses the ways in which today's manufacturing firms deal with disruptions in their supply chains caused by disasters, such as earthquakes, floods and fires, and how they balance robustness against such disasters with competitiveness vis-à-vis their rivals. In Chapter 6 and the concluding chapter, we will discuss the potential and effectiveness of an approach called "virtual dual sourcing," which attempts to cope with big disasters without losing competitiveness before and after the actual occurrence of supply chain disruptions.

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