MMRC
DISCUSSION PAPER SERIES

No. 362

Supply Chain Competitiveness and Robustness: A Lesson from the 2011 Tohoku Earthquake and Supply Chain "Virtual Dualization"

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September 2011

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Supply Chain Competitiveness and Robustness:

A lesson from the 2011 Tohoku Earthquake and supply chain "virtual dualization"

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Abstract: This paper argues that, even after the unprecedented earthquake in east Japan on 2011.3.11, the basic principle of designing industrial supply chains should achieve its competitiveness and robustness simultaneously, as opposed to psychological overreaction that emphasize the latter alone. After critically evaluating proposed changes on the damaged supply chains such as adding inventories, adopting standardized parts, duplicating equipment and tools, and evacuating facilities, the paper argues that, in the era of intensifying global competition, those proposals are appropriate only when it sustains supply chain competitiveness. As an alternative measure to make the chain more robust without significantly adding product cost, the paper proposes making the supply chain "virtual-dual" by enhancing portability of design information.

Key words: 2011 Tohoku Earthquake and Tsunami, supply chain disruption, robustness, design portability, virtual dualization of supply

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1. Supply chain disruption after a disaster and corresponding countermeasures

1.1 Supply chains that are strong both in regional disaster and global competition

The domestic and international supply networks of many industries were disrupted by the 2011 Tohoku Earthquake, causing much debate over approaches for improving the robustness of supply chains. This paper empirically and logically examines various methods for strengthening supply chain robustness in the event of a disaster. In particular, preliminary analysis will be conducted using examples mainly from the automobile industry, where the number of parts and necessary manufacturing processes make the supply network complex. This preliminary analysis will be conducted from the perspective of the "open manufacturing theory" (e.g., Fujimoto 2004), which interprets a supply chain as the "flow of design information to the customer."

The damage caused by the 2011 Tohoku Earthquake was beyond our imagination. Since the post-World War II devastation, there has never been any destruction on this scale and over such a large area. In addition, the series of problems at the Fukushima Daiichi Nuclear Power Plant, the expanding impact on overseas offices and foreign businesses due to the progress of globalization, and the complexity of disaster recovery work due to the digitalization of products have compounded the problems of restoration and reconstruction, making them more complex and uncertain, especially when compared to the Kobe Earthquake that occurred years ago.

In response to the Fukushima Daiichi Nuclear Power Plant accident, the mistakes committed in the early stage and the subsequent slow response can be blamed on the inability of the headquarters to respond to a disaster. However, the overall high resilience of the Japanese system on the ground can be seen in other areas, such as the relatively rapid repair and reopening of roads and bullet train service. In addition, the damaged automotive supply chain was up and running again for the most part within two weeks, displaying an extremely rapid recovery, especially in comparison to the size, extent, and complexity of the damage.

The problem lies in how these lessons can be applied to the planning of supply chains in the future. To begin with, let us consider that the 2011 Tohoku Earthquake is the first disaster to have affected a large region in a globally competing advanced country. However, for argument's sake, even if a supply chain's robustness to respond to a large disaster (the functional and structural stability of the system in the event of a sudden change in the environment) is enhanced in response to this most recent disaster, if it weakens the international competitiveness of concerned plants and companies, there is a great possibility that these plants, companies, and supply chains will be defeated by global competition, will decline, and disappear even before the next large disaster strikes. Now, at the beginning of the 21st century, companies and plants throughout the world have not forgotten the fact that they face global competition daily. Nobody knows when or where a disaster will strike (disaster someday), but competition occurs everyday without fail (competition everyday).

To state the conclusion first, as a result of this disaster, particularly with regard to supply chains of trade goods export industry, Japan's industries must improve the robustness of supply chains to deal with an unpredictable disaster only after considering the preservation and strengthening of their international competitiveness. It is true, however, that because of the impact of this huge disaster, we have tended to put "disaster mentality" before "competition logic," forgetting the latter and hence threatening the long-term existence of supply chains themselves.

On the basis of an awareness of the above problem, this paper will examine the supply chains of major Japanese export industries such as the automotive and electronics industries. The effects of the disaster on the supply chains, the characteristics of supply chain "weak links," as well as actual responses and the direction of future supply chain improvements will be closely examined. On the basis of the "broad manufacturing theory" of manufacturing business administration (Fujimoto 2004, Fujimoto & Manufacturing Management Research Center 2007, Fujimoto & Kuwashima eds. 2009), which states that "manufacturing refers to the control and improvement of flow of design information to the customer," it will be established that a single supply chain is "the flow of design information of a particular product through multiple suppliers to the end-point customer." Therefore, the reconstruction of a supply chain after a disaster is only a "resumption of the flow of design information."

1.2 Past examples of Toyota as a disaster victim

Here we will review the examples of automotive-industry supply-chain disruptions caused by a disaster.

First is the fire that occurred in the Nihonzaka Tunnel (outbound) on the Tokyo–Nagoya Expressway on July 11, 1979. The tunnel was closed to traffic for about one week and then was temporarily opened to one-way traffic. Complete restoration of the tunnel was finished 60 days later, on September 9. Since Toyota's assembly plants (not including consignment production plants) were concentrated around Toyota city at that time, the supply of parts from 65 companies east of the tunnel was severed, causing the temporary shutdown of the Motomachi and Takaoka plants. However, they resumed regular operations on the evening of the 12th. Resumption was relatively rapid because the suppliers' production lines were not damaged (regarding Toyota supply chain suspension, refer to Figure 13 in Shiomi 2011).

The Kobe Earthquake in the morning of January 17, 1995 caused the suspension of operations of Sumitomo Electric Industries' Itami Works (brake parts) and Fujitsu Ten's Kobe Plant (car audio), both of which are located in the Hanshin region. Because of this, 29 assembly plants of Toyota and their consignment production companies suspended operations on the 19th (Thursday) and 20th (Friday). However, normal operations were resumed on the 23rd (Monday) after the long weekend

(Shiomi 2011). At that time, Toyota engineers assisted in the restoration of the affected suppliers, thus resulting in rapid resumption. This method was also employed in later disasters.

Because of the fire at Aisin Seiki's Kariya No. 1 Plant on February 1, 1997, their brake parts production line was devastated. Since Toyota depended on this plant for the production of 80%–90% of its supply of brake components such as proportioning valves, operations at 22 of Toyota's 30 domestic assembly lines were suspended for three days. Normal operations were resumed on February 7 (reducing production by 70,000 vehicles). Long-term suspension of operations was unavoidable since the restoration of the Aisin production line would not occur until the end of April. However, companies that mainly dealt with Aisin as well as Toyota responded to requests for substitute production, allowing for full resumption of assembly plants within about one week—much sooner than expected (events are detailed in Nishiguchi & Beaudet 1999).

The Chuetsu Offshore Earthquake on July 16, 2007 caused the suspension of operations of all Toyota plants (including consignment production plants) for three days from the evening of the 19th since all of Japan's automobile manufacturers (12 companies) depended on the supply of piston rings and other parts (approx. 50% of the domestic share) from Riken's Kashiwazaki Plant in Niigata. Again at this time, Toyota dispatched about 500 people (about 650 including support from other companies) to the disaster site to assist in resuming production at the Riken Plant. Production resumed at the Kashiwazaki Plant on July 23, and Toyota resumed normal operations simultaneously at the beginning of the week on the 23rd (Monday) (all other domestic car manufacturers resumed by the 25th). Up to now, automobile manufacturers used to repeatedly conduct short-term, concentrated restoration support in times of a disaster.

As shown in the above examples, the various types of parts supply disruptions in the past can be categorized by whether the site of the disaster was a supply route or a supply base, whether the site of the disaster was singular or plural, whether the damage was light or severe, whether the dependency on the affected parts was high or low, whether the customization of the parts (part specialization) was high or low, etc. However, overall, stoppage of automotive manufacturers' assembly lines was held to one or a few days because of the concentrated restoration support and rapid procurement of substitute supply sources by Toyota and other automobile manufacturers. It can be said that the restoration of the supply chain was relatively rapid considering the seriousness of the damage done to it.

Of course, with every assembly line stoppage, there was no shortage of reporters and researchers ready to point out the limitations of Toyota's just-in-time system. However, if one considers the increase in costs involved in increasing inventory or the long-term dysfunction of lead-time extensions, using disasters as the only reason for demanding an increase in inventories lacks a rational foundation. In production control and logistics system theory, one should never plan an inventory system by attempting to include vague factors such as disasters or accidents, whose probability cannot be calculated. Incidentally though, Toyota's plants around Toyota city have long since stockpiled parts for the west of Seki-ga-hara, Japan, in winter as a countermeasure against heavy snows. Therefore, the inventory system is adjusted when it comes to predictable events. As long as an inventory system must be relied on, this is a natural approach for coping (Fujimoto 2001).

1.3 Differences from past examples: Effects of globalization and digitalization

Taking the Toyota Group as an example, we have examined supply chain disruption and restoration above. However, when comparing the circumstances of these recent supply chain disruptions to the damage done to the automotive and other industries' supply chains by the Tohoku Earthquake on March 11, 2011, and the number of affected suppliers and the large area they belong to, the number of damaged supply routes and the large area they cover, the extent of the devastation and lasting effects of the tsunami and nuclear power plant accident, etc., the scale is tremendous.

Hence, Japan's automobile makers' domestic assembly lines were in fact shut down for about one month. For example, Toyota at first predicted that the full recovery of production rates would take several months (recovery of production rates was considerably speeded up later).

In addition to the huge extent and large area of the damage, there are at least three following unique characteristics of the supply chain disruption caused by the 2011 Tohoku Earthquake (when compared with the Kobe Earthquake at the close of the 20^{th} century).

First is the "complication of hightech automobile electronic control systems." Starting in the 1970s with electronic fuel injection, gradually progressing from control of individually functioning parts to the vehicle as a whole, this progress has caused the automobile electronic control system to become a complex interlocking of multiple electronic control units (ECUs: individual semiconductor components and chips mounted on a circuit board and the embedded software that drives it).

The "box" that holds each ECU and the circuit board it is mounted on usually contains chips called microcontroller units along with other parts. These microcontroller units are accumulations of CPUs and memory on a single chip. A majority of these units are generic semiconductor products bought off the shelf by user companies such as automobile and parts manufacturers. Then, by embedding product-specific software, the user companies further enhance the ECU's product specificity (Tatsumoto, Fujimoto & Tomita 2009).

In this way, the automobile control systems have become complex and hierarchical. For example, as of 2011, luxury cars on the market in developed countries are controlled by tens of microcontroller units embedded with software formed of 10 million or more lines of code, making them extremely complex. Then, as a result of the 2011 Tohoku Earthquake, the affected plant that took the longest to recover and the one with the widest ranging effect was a microcontroller plant located in eastern Japan; this plant will be discussed in detail later.

Second is the "globalization of the supply chain." The Japanese automotive industry has been expanding the number of overseas bases since the end of the 20th century. Large mechanical parts and design components tend to be manufactured in the country of assembly—the country in which they are marketed—while manufactures of electronic parts such as the aforementioned microcontroller units and minute individual parts that utilize high performance materials are concentrated in Japan. These parts are then exported to assembly and functional component plants abroad. There are quite a large number of such parts. As a result, regardless of the tendency for increasing domestic production rates of parts for assembly plants in each country, the global supply network is still firmly rooted in Japan. Therefore, this disaster caused the suspension of operations at the overseas plants operated by Japanese companies. In most cases, since there was inventory in the pipeline between Japan and the overseas plants, stoppage of the foreign assembly lines was predicted to occur from May.

Furthermore, examining the case of Toyota's European assembly plants, although they tried to acquire functional parts from European companies as a stopgap measure, since those European companies purchased their individual functional parts from Japan, these European suppliers also had their functional parts supply lines severed. Interruption of the supply of microcontroller units from Japan had wide-reaching effects not only on Japanese manufacturers but also foreign assembly and parts companies.

Third is the "intensifying global competition." The competitive environment continues to be severe for Japan's domestic production bases because of challenges such as recession in the U.S. market caused by the 2008 subprime mortgage crisis, U.S. and European automotive manufacturers catching up with Japan because of assembly productivity and component quality, increasing competitiveness of the Korean automotive manufacturers, rapid growth of the automotive industry in China and other emerging nations, long-term stagnation of Japan's domestic automobile market, and the continual strengthening of the value of the yen. Because of these challenges, the only solution left with Japanese automotive development and manufacturing centers is to further improve productivity and design quality. In the midst of all this, the 2011 Tohoku Earthquake struck. However, as mentioned earlier, changes in the system in response to an earthquake cannot be implemented if they weaken international competitiveness. However, it is difficult to achieve the necessary strengthening of robustness in preparation for a disaster while at the same time maintaining the competitiveness of the domestic manufacturing system.

As compared to the time of the Kobe Earthquake, the situation surrounding the automotive industry has changed, which has made it more difficult for companies, factories, and supply lines to respond to an earthquake.

2. “Weak links” in the supply chain revealed by the 2011 Tohoku Earthquake

2.1 Semiconductor integrated circuits (microcontrollers and ASICs)

Next, we will discuss the three industries whose recovery was particularly slow after the earthquake and had a large impact on the operations of assembly companies. These industries include semiconductor integrated circuits (such as on-board microcontrollers) for controlling devices, functional chemicals such as synthetic rubber, and minute simple components that have been supported by material technology. Below is a brief overview of each industry.

First, semiconductor integrated circuits for controlling devices will be examined. In general, the control of certain devices (products) such as automobiles, home appliances, electronics, office equipment, and industrial machinery is uniformly possibly by any of the following measures: (1) a printed circuit board (PCB) with individual (discreet) semiconductors hardwired onto it, (2) a customer-product-specific integrated circuit (ASIC) that is mounted on a single silicon chip, or (3) a generic integrated circuit (microcontroller) with customer-product-specific software loaded into it (Tatsumoto, Fujimoto & Tomita 2009).

In most cases, a combination of these three is employed; however, recently, type (3) has been used in many cases for ECUs mounted on automobiles. For this type, the necessary semiconductor integrated circuit (chip) is a microcontroller. At present, nearly half of all Japanese manufacturers utilize microcontrollers (a total added value of approx. 100 trillion yen). However, there are numerous electronic devices that utilize type (2). The semiconductor integrated circuits for these devices are ASICs (for example, system on chip (SoC)), which have all the necessary design information for control of the specified product built right into them.

At any rate, a large plant that manufactured these types of semiconductors for microcontrollers and ASICs used for device control was located in the area struck by the earthquake. The factory was the Renesas Electronics Naka Plant in Hitachinaka city, Miyagi prefecture. Details can be found elsewhere, but basically this plant's manufacturing process was divided into two production lines: one for 200 mm wafers and the other for 300 mm wafers. The 200 mm wafer line produces microcontrollers for automobiles and other devices (type (3)), and the 300 mm wafer line produces customer-product-specific SoCs (one type of ASIC; type (2)) used for control of other devices. Production on both lines was delayed for about three months (initial predictions estimated that supply would be disrupted for one year, but ultimately supply was almost completely restored after three months). Because of this earthquake, the supply lines of many industries were affected by this one factory.

Onboard microcontrollers are application-specific devices for automobiles, but they themselves are not customer-product specific, but rather generic semiconductor products that user companies buy off the shelf. However, the microcontrollers produced at the Naka Plant are presumed to have been developed using design rules (functional design, process design, interpretation rules between process designs) (Source: Tatsumoto, Fujimoto & Tomita 2009) and in a development environment (development tools, planning library, simulation equipment, etc.) that was unique to that plant, and therefore, supplier-process specific (according to Hirofumi Tatsumoto, University of Hyogo). Therefore, by using these microcontrollers, when a user company develops customer-product-specific software to be loaded into them, that software then 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 the supply source to a different plant.

In general, the structural design of a part (a microcontroller, for example) is either customer-product specific (specific to the buyer) or supplier-process specific (specific to the seller). However, if a product is formed of both of these, its substitutability is reduced. In the case of the Naka Plant, it can be presumed that either the ASICs (SoCs) were more customer-product specific or the microcontrollers were more supplier-process specific. In either case, from the customer companies' viewpoint, the concerned parts (ASICs or microcontrollers) had low substitutability.

On the other hand, for these types of leading edge technologies, minute processing on a scale smaller than 0.1 μ is necessary. More than 100 steps are executed in these processes that utilize extremely expensive semiconductor manufacturing equipment. For some semiconductors, since the precision finishing process is capsulated within the plant, the process architecture is relatively modularized (DRAMs for example). However, the internal architecture is becoming more integral for advanced ASICs (SoCs) and microcontrollers (Suzuki & Yunogami 2008, Tatsumoto, Fujimoto & Tomita 2009). Consequently, there is an increasing affinity for Japan's planning and production sites, where teamwork among versatile workers is a prominent feature. Therefore, as will be mentioned later, Renesas Electronics holds 30% of the world market share for microcontrollers (40% when limited to those for automobiles), though there is much criticism regarding problems of profitability.

In addition, for semiconductor materials and manufacturing equipment, there are many integral architecture products; hence, Japanese companies are increasingly gaining a large world share in these areas. Customers include Japan’s automobile manufacturers and parts manufacturers such as Denso and Hitachi Automotive, GM, VW, and other foreign automobile manufacturers. (Some of the following information is from a discussion with the Development Bank of Japan (Fujimoto 2011).)

As shown above, what is unique about these onboard microcontrollers is that in addition to Japanese companies holding a relatively large share worldwide, they are also relatively poor in terms of substitutability. A major producer of these microcontrollers is Renesas Electronics’ Naka Plant.

Furthermore, not only is the substitutability of the design information difficult, but production processes are also advanced, complex, and rely on manufacturing equipment. In addition, unlike die cutting presses and milling equipment, the process of removing design information (the mask on which circuit design information is transcribed) from the equipment as well as other steps is very difficult in practice. This results in poor design information portability and leads to difficulties in switching to other suppliers. Thus, operations at a plant cannot resume until all the equipment that is damaged in a disaster is repaired, and since the process is complex, it takes time as well.

To make matters worse, this factory housed its new equipment in old buildings, which suffered serious damage in the 2011 Tohoku Earthquake. Therefore, as a result of holding a large market share, suffering heavy damage to its equipment, and the non-substitutability and non-portability of its microcontrollers, resumption of the factory’s production line was relatively slow in comparison to other parts and plants. The effect on customer companies’ supply chains was also very large.

Nevertheless, Japan’s automobile manufacturers, having grasped the seriousness of the situation, dealt with it in a manner similar to that with Riken after the Chuetsu Offshore Earthquake. All the automobile manufacturers that are members of the Japan Automobile Manufacturers Association deployed rebuilding assistance, and domestic and foreign semiconductor lithography manufacturers commuted continuously between their plants and Hitachinaka to speed up the recovery process. As a result, the complete recovery, which was initially predicted to take one year, was completed in three months at the end of May. From a business continuity plan (BCP) perspective, there were good developments as well. The design information (recipe) for about half of the products manufactured at the plant would be transferred to other cooperating plants (NEC plants, for example) to facilitate substitute production. Although it was feared that effects of the slow recovery of the Naka Plant would worsen because of the aforementioned uniqueness of the products such as onboard microcontrollers and ASICs, the recovery is expected to be achieved earlier than initially predicted because of the recovery assistance provided by user and supplier companies throughout Japan.

2.2 Functional chemicals

Another major component of automobiles that was a victim of the 2011 Tohoku Earthquake was functional chemicals. For example, rubber for tires and brakes (such as EPDM at JSR Corporation in Kashima, Ibaraki prefecture, kneaded rubber at Fujikura Rubber in Kodaka, Fukushima prefecture, and additives at Ouchi Shinko Chemical Industrial in Haramachi, Fukushima prefecture); paint pigments (such as Merck in Onahama, Fukushima prefecture); and condenser electrolytes (such as Nippon Chemi-Con in Takahagi, Ibaraki prefecture, and Tomiyama Pure Chemical Industries in Okuma, Fukushima prefecture).

What makes these chemical products special is that they are produced by processing industries that rely on manufacturing equipment. In addition, although some of these products can be supplied by other companies, the products themselves hold a very large share of the market (30%–100% domestic share for the abovementioned plants); hence, there are limits to what can be done. Most noticeable are plants around Kashima Harbor that were damaged by the tsunami and ones that lie within the evacuation zone surrounding the Fukushima Daiichi Nuclear Power Plant. Damage was not confined to the automobile industry but affected functional chemicals produced by Mitsubishi Chemical and Kaneka around Kashima Harbor as well.

Regarding the design information of chemicals, the equipment for manufacturing most of these products are not product specific, however, the recipe (processing knowhow) and some of the equipment are. Therefore, the key point in determining whether production can be transferred to another plant in a short time depends on whether the design information can be moved easily—i.e., its portability. For example, a disruption in the supply of materials for medical equipment could be avoided since the recipe for Kaneka's vinyl chloride production line damaged at Kashima could be transferred rapidly to the main plant in Takasago, Hyogo prefecture.

2.3 Microscopic parts and consumables

Third are the tiny simple components (such as screws and springs) that form some of the 30,000 parts that compose an automobile and the consumables used in parts of the manufacturing process. In general, automobile makers do not even notice these suppliers at the far end of the chain, but there were quite a lot of these small to medium sized businesses in Tohoku that suffered damage, especially suppliers for Toyota. For small suppliers like these, the problem does not lie in one of the product characteristics but in suppliers' visibility from the perspective of automobile makers. Hence, for example, regardless of how powerful Toyota's supplier recover assistance is, if the supplier is cannot be perceived, it will not be assisted.

The automobile supply chain is extremely complex; hence, it is difficult to fully comprehend the entire supply chain all the way up to the manufacturing of simple components. In addition, regarding regularly available parts, there is no need contractually as well as technically for automobile manufacturers to understand the process details of suppliers for second-tier manufacturers and beyond. In fact, it is a decentralized system where the first-tier suppliers handle the second tier, the second tier handles the third, and so on.

However, in dire emergencies such as this, where the disruption of the supply chain was caused by a disastrous earthquake, it is desirable to acquire an understanding of the supply chain in a relatively short period.

In previous disasters, automobile makers such as Toyota could provide effective recovery assistance by being able to understand instantly which plants were damaged. However this time, even a month after the earthquake, there is a possibility that the complete story of which suppliers suffered damage is still not understood. One month after the earthquake, people affiliated with Toyota reported that more than 100 parts manufacturers had been victims of the disaster, which means that the exact number is still unknown.

Of the suppliers that suffered damage from the 2011 Tohoku Earthquake, the suppliers of the following products are the ones who will recover relatively slowly and who were heavily damaged: products with poor substitutability, such as product-specific electronics like microcontrollers; functional chemicals; and microscopic parts, which have poor visibility. Now, the important concepts regarding the formation of a supply chain that is not only robust to a disaster but also maintains competitiveness will be examined.

3 Analysis of supply chain vulnerability and robustness

3.1 Open manufacturing concept from a planning flow perspective

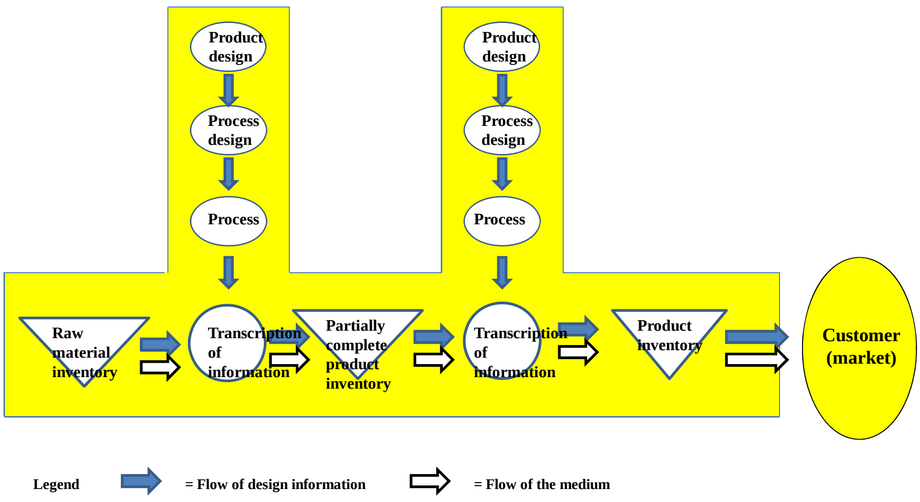
To begin with, returning to the basic concept of *Open Manufacturing Management* (Fujimoto & Manufacturing Management Research Center 2007), we will again explain a supply chain as a "flow of design information to the customer." It is first necessary to evaluate the entire subject of supply chain robustness required to deal with a regional disaster. That is, a supply chain's vulnerable points (weak links) must be specified.

Fujimoto & Manufacturing Management Research Center (2007) assert the necessity of obtaining an extensive understanding of manufacturing from a design concept perspective. As will be explained later, “open manufacturing” is identified as generic management skills that carry “good design” through “good flow” to the customer (Fujimoto 2004, Fujimoto & Manufacturing Management Research Center 2007). In other words, the key to manufacturing administration considers “manufacturing” in a broad sense. Broad “manufacturing” refers to building design information into a product (medium) and delivering that to the customer through “good flow,” all of which are based on “design.”

To broadly re-explain everything from design information to manufacturing, rather than describing “the making of things,” it is necessary to return to the basics of creation of man-made objects, which refers to “building design information into a product.” By taking this approach, manufacturing can be discussed in a broader sense, one which covers development, purchasing, and selling. Here “development” is the creation of product design information, “manufacture” is the transcription of that design information into a product, “procurement” is the purchasing of the product, and “marketing” is the transfer of design information to the customer through the product. This is the flow of design information, as is shown in Figure 1.

A supply chain that considers the “broad manufacturing theory” is not simply the flow of information, it is the entire flow of design information, including product design and process design. Therefore, in the case of a regional disaster, the entire flow of design information to the customer needs to be the subject of reconstruction.

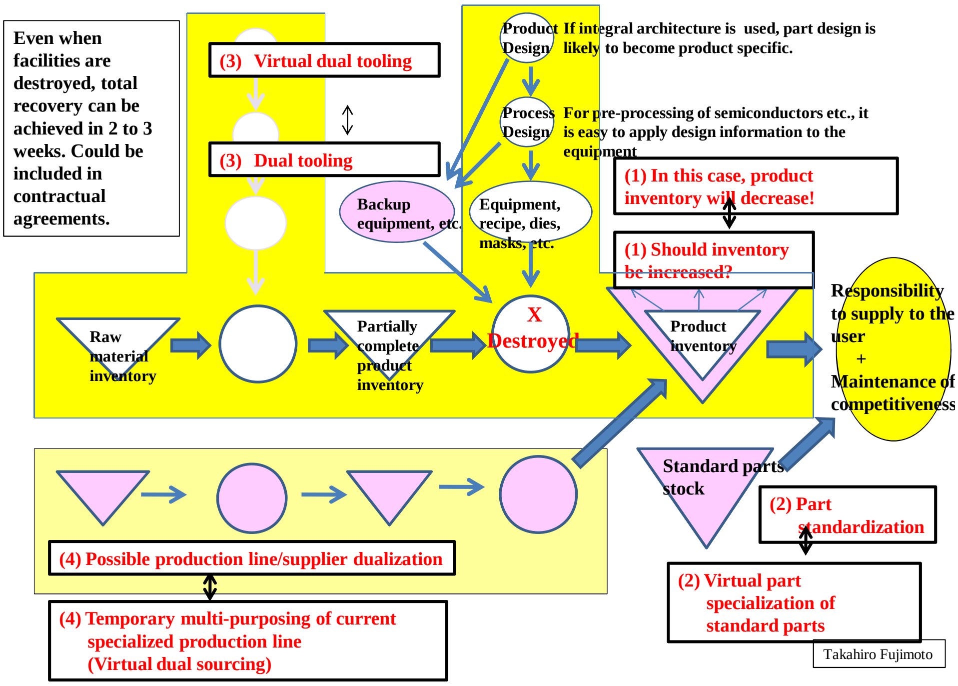
Figure 1: The supply chain as a "flow of design information"



When reconsidering disaster response measures from a "open manufacturing theory" perspective that starts from design theory, the purpose of the supply chain should be maintaining the "design information flow" for the product to arrive in the market. For example, when a certain production process is destroyed because of a disaster, the supply chain is severed at that point. In such a situation, the measures for maintaining the flow of design information to the customer can be divided into steps to be taken downstream from the information transcription point and those to be taken upstream from the transcription point.

For the former, in order to immediately restore the flow of already transcribed information (products or partially complete products) downstream from the point where the information flow was severed, the appropriate measure is to either increase the downstream inventory of products or partially complete products or to switch to standard or interchangeable parts that can maintain the same design information. For the latter, in order to immediately restore the design information (equipment, dies, tools, recipe, etc.) upstream from where the flow was severed, the appropriate measure is to create a “detour” for the design information. For example, dual tooling, which includes in-advance preparation of several copies of equipment and dies that contain the exact design information, and dual sourcing, which includes maintaining of multiple sets of the production line itself either within or outside the company. In short, by always maintaining an upstream stock of design information, it can be used in an emergency as a starting point for reconstructing or rearranging design information flow after the disaster. This can be considered as “virtual dual sourcing” (mentioned later) (Figure 2).

Figure 2: Response measures when a supply chain is damaged in a disaster



By combining these, the author believes that not only can a supply chain be built that is both competitive and robust, but it will also be able to respond to a disaster in this age of global competition. Exactly what measures need be taken should be determined after considering various factors such as the necessity of the concerned products, the target lead time until restoration, the size and growth of the domestic market, the severity of global competition, and value of inventory and equipment as well as the possibility of their becoming obsolete.

For example, in case of the necessary medical equipment whose supply must not be interrupted even for a single day, it is necessary to have suppliers maintain emergency stores. However, in the case of industries where ordered products have a long-term backlog or ones where the logistics industry already holds a large amount of products in inventory, it is highly possible that a recovery time of two to three weeks is within acceptable bounds. The first step that must be taken to establish a robust, totally optimum supply chain is for the involved parties to develop an agreement as to what is a socially and marketwise acceptable recovery time and then set that as their goal.

Next, the relationship between product and process specialization and supply chain vulnerability will be examined from the perspective of dependence, visibility, substitutability, and portability.

3.2 Dependence on suppliers

Extreme dependence upon a certain supplier's product can be a supply chain's "weak link," as has been clarified from previous examples (such as brake parts affected by the fire at Aisin and piston rings affected by the Chuetsu Offshore Earthquake).

Something that Toyota and other manufacturers realized anew from the 2011 Tohoku Earthquake is the "diamond structure" of a supply chain. In this structure, although the first- and second-tier parts (functional components) are decentralized amongst several suppliers, the third-tier parts (simple components) are centralized in one company that uses specialized process technology. Existence of such "irreplaceable suppliers" in and of itself is the foundation of Japan's industrial competitiveness. Forcibly decentralizing them is not a profitable measure since it can possibly reduce differentiation and volume efficiency.

The concentration of supply on a single company is the inevitable effect of technological strength and competitiveness. This in itself is certainly not faulty. In fact, forcibly decentralizing these suppliers carries a greater risk in terms of a competitive strategy. However, it is necessary for downstream assembly companies to remain continually aware that such deep dependence on a process or component can easily become a supply chain's "weak link," and they must intensively plan appropriate precautionary measures and restoration responses.

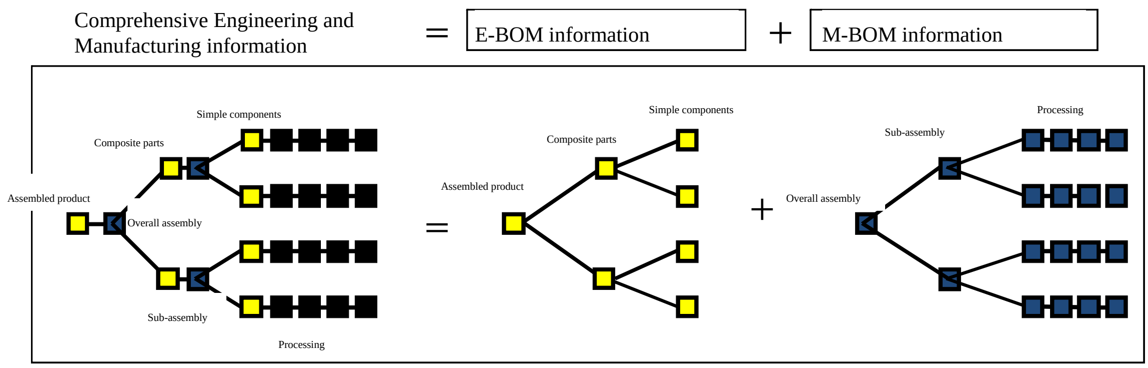
3.3 Supply chain visibility

The second point that became apparent from the 2011 Tohoku Earthquake is that downstream customer companies and assembled product manufacturers must constantly consider that the invisible points in a supply chain can become a serious bottleneck.

Critical processes can easily be overlooked, particularly in the case of complex products such as automobiles, since they are composed of many parts, and semiconductors, since they must go through many processes. For example, in case of consumables that do not remain in the final product, such as cleansers or catalysts used in the manufacturing process, there is a possibility that amongst them are materials for which restoration or substitution is difficult or on which a particular company heavily depends for supply.

In order for a certain final product manufacturer downstream in the design information flow to identify a "weak link" in advance, for example, in the case of automobiles, a breakdown of some 30,000 individual components or Engineering-Bill of Materials (E-BOM) is not enough. It is also necessary to have an understanding of the information in a Manufacturing-Bill of Materials (M-BOM), which contains data regarding facilities, equipment, consumables, and things that are necessary for the manufacture of each part at every level of the chain. Such a comprehensive image of the combination of manufacturing-level and engineering-level information, as shown in Figure 3, is necessary for assembly companies downstream in the flow of design information, so that the information can be rapidly comprehended when a crisis strikes.

Figure 3: Comprehensive chart of manufacturing-level and engineering-level information



However, the traditional supplier system for Japan’s automotive industry is a layered system where first-tier manufacturers manage the second-tier parts manufacturers and the second-tier manufacturers manage the third-tier manufacturers. For such a complex supply chain, this type of system is effective in its own way. Maintaining this system’s strengths, while at the same time allowing for transparency of supply chain information, in an emergency is difficult and will be dealt with later.

3.4 Design information substitutability

Third, such products are defined as having high non-substitutability and are therefore items with a relatively high supply risk. As mentioned above, these products utilize a specific design for a particular customer’s product only (customer-product specific), particularly when it relies on the supplier’s design resources, or those whose supplier-specific processing is based on the supplier’s unique development or manufacturing process (supplier-process specific). In a crisis, such products would be difficult for the purchaser to replace by switching to standardized parts or by switching suppliers.

A prominent characteristic of much of Japan's manufacturing industry is the teamwork of its versatile workers. Several authors assert that "comparative advantage in design" has been easy to achieve in Japan's manufacturing industry because of the "integral architecture" of products (Fujimoto 2003, Fujimoto 2004). These are products that have achieved an optimum design through reciprocal coordination between a complex combination of product function and product structure. Therefore, the component parts of such products tend to be product-specific custom components. One source of Japan's manufacturing competitiveness is the development of a system of close alliances and collaborative problem solving between assembled products and parts manufacturers following World War II, which was caused by the efficient and rapid development of the abovementioned custom components (Nishiguchi 1994, Asanuma 1997, Takeishi 2003).

A dilemma has, therefore, been created for these industrially competitive Japanese products. Since they consist of so many components that are "irreplaceable, specially designed parts," in the event of a disaster, they create vulnerabilities in the supply chain. As mentioned previously in the microcontroller example, added to this is the uniqueness of supplier-side processes, which in many cases, is the source of the suppliers' competitiveness. The dilemma that has thus been created is a relatively strong trend of non-substitutability of parts for products that Japan is famous for.

Of course, there have been cases where supply chain disruption has been anticipated and a practice of ordering parts of the same design from multiple suppliers (multiple supplier ordering) has been implemented. However, this usually occurs when the "blueprint lending method" is employed—when the assembly company that is making the purchase has conducted detailed product design. On the other hand, when the "approved blueprint method" is employed—when the parts company that is selling the parts is responsible for the detailed design—or when the selling and purchasing companies collaboratively design the parts, ordering of parts is usually concentrated to a single company because of issues of design ownership rights (Fujimoto 1997, Fujimoto, Nishiguchi

& Itoh 1998). For effective mass production, it is also desirable from a cost competitiveness perspective to concentrate orders from a single company.

As a result of this concentration of ordering from a single company, since the parts are not standardized, when a crisis hits, there are naturally no supply companies that can provide substitute parts. How to assure the ability to recover from this type of crisis becomes an issue for downstream companies to tackle.

3.5 Design information portability

Finally, the problem of whether the design information used at a certain manufacturing plant for producing products can be removed from that plant and transferred to another plant in the time of a crisis.

In general, for products manufactured mechanically, the die from a destroyed press can be removed and transplanted to another press, or the drilling tools can be collected from a damaged machining plant and moved to another plant along with blueprints and numerical data. Thus, design information (dies and tools in this case) is relatively portable.

In the case of chemical plants, when operations are suspended because of an accident or a disaster, often the design information—the recipe (operating procedures)—is moved to another plant, and the equipment and the recipe undergo a “recipe amalgamation,” where they are adjusted to match each other.

However, in the case of advanced production lines such as those for manufacturing semiconductors, the removal of the product-specific circuit design information (mask and recipe) from the equipment for emergency evacuation to other equipment is a technically difficult process. In these cases where processes that have non-portable design information are destroyed, resumption of production of the concerned products is impossible until all the equipment and the entire production line have recovered. This means that processes in equipment manufacturing industries that depend on manufacturing facilities and have design information that is not easily portable can easily become the "weak link" in a supply chain. The aforementioned microcontroller plant that was damaged in the 2011 Tohoku Earthquake is a typical example.

Therefore, in order to analyze and evaluate a supply chain's vulnerabilities in advance, an evaluation must be made regarding the purchaser's dependency, visibility from the purchaser's perspective, substitutability of design information, and portability of design for each product's components and processes. A prior indication of where a supply chain's "weak links" might lie in time of a disaster is desirable.

However, actually conducting an accurate beforehand evaluation of an extremely complex supply line is difficult and will be examined later.

4 Post-disaster measures and their weaknesses

4.1 Considering post-disaster measures beforehand

After conducting a detailed analysis of a supply chain's vulnerabilities and robustness, the person responsible for the supply chain should (1) consider preventative measures before an actual disaster strikes and implement them into the supply chain design and (2) determine procedures to be taken in response to a disaster and incorporate them as rules before the next disaster strikes. In addition, they must (3) carry out responses after the next disaster for the cases that were not anticipated in (1) and (2) above. That is, in preparation for the next big disaster, the three following measures are necessary: (1) prior determination of precautionary measures, (2) prior determination of post-disaster measures, and (3) post-disaster determination of post-disaster measures. As described later in this paper, (2) careful prior determination of post-disaster measures is considered to be particularly important.

Bearing the above in mind, a few of the proposals for changes in the supply chain caused by this earthquake and which are currently being debated will be evaluated. In particular, these proposals are the aforementioned adding of inventories, switching to standardized parts, dual sourcing, transfer of production to other domestic or foreign plants, and others. First, the disadvantages of such measures will be discussed.

4.2 Should inventories be increased?

As a measure in response to supply chain disruption, it would first necessitate an increase in inventories of raw materials, goods in progress, and final products. One of the basics of the inventory theory is the stockpiling of an appropriate safety inventory or buffer inventory at a proper location (e.g., Fujimoto 2001). This inventory is for under-supply or over-demand risks whose occurrence can be calculated, such as a sudden increase in orders, traffic congestion, or snowstorms.

This indicates that Toyota's manufacturing method, which uses a just-in-time ideology, does not advocate complete elimination of all inventory. In fact, without a certain amount of inventory, this elemental ideology can never be achieved. Therefore, for all manufacturing systems, based on their functional requirements and constraints, an appropriate level of inventory in the right place is presumed in order to maintain competitiveness and uphold supply responsibility. However, the main thrust of the just-in-time ideology is that there is too much wasted inventory in the industry—inventory that exceeds this functional amount.

Considering the intensification of global competition in the 21st century, the author believes that only those Japanese plants that stick to this Japanese-made supply chain ideology will survive.

If this is true, then the following principle should apply to the adding of inventories. First, the adding of inventories that, from a productivity, lead time, and quality standpoint, has the negative effect of reducing plant and product competitiveness. In principle, this should not be applied only for the purpose of preparing for a disaster. It is also inventory theory common sense. In general, an inventory system that takes into account risks whose probability can be calculated should be planned. However, it would be a burden on the daily competitiveness to stockpile extra inventory in preparation for a disaster whose probability cannot be calculated and which will only occur once every few decades or centuries.

Without a doubt, when observing the unbelievable spectacle of the 2011 Tohoku Earthquake, we are inclined to think that "first, it is most important to prepare for the next earthquake." However, considering the intensity of global competition, it should be assumed that actually doing so would considerably increase the probability that the plants and companies themselves would decline and disappear even before the next disaster struck. Although big disasters usually strike when they have been forgotten, industrialists must not forget that industrial competition occurs everyday.

Of course, depending on the products such as foodstuffs, fuel, water, medical supplies, medical equipment, and other daily necessities, the responsibility on the companies that supply these products is very heavy. For some of these products, this disaster caused a sort of hording panic. However, for many of these items, the government, industries, and households already had a certain amount of emergency and distribution inventory, so all that is necessary now is a reassessment of whether the current emergency stores are enough.

Moreover, with regard to distribution inventory, for example in the case of Japan's home appliance industry, because of the recession and stagnant spending, they are already carrying a huge inventory of many of their products. Instead, the lack of supply from this disaster should be thought of as a chance for clearing out excessive inventories.

In any case, the adding of inventories that would lengthen production and supply lead times must be avoided at all costs. The first priority is a further strengthening of the ability to rebuild the supply chain (the flow of design information). This is the conclusion derived from the "broad manufacturing theory." With every disaster that strikes, some domestic and foreign media outlets repeat their conclusion that "the weakness of the just-in-time theory has been exposed. Increase your inventories." It is nothing but a simplistic and inappropriate proposal that is out of sync with the overall optimized production ideology and the basic inventory theory.

4.3 Should a switch be made to standardized parts?

This earthquake has again revealed that irreplaceable product-specific materials such as microcontrollers, functional chemicals, and some high-performance components are the cause of vulnerabilities in a supply chain. Despite this reality, many believe that "Japanese companies and plants should use parts that have an easily replaceable supply source and that are more standardized in case of a disaster."

It is true that when Japanese companies that are rich in adaptability plan products, this adaptability tends to get overused, and they are likely to produce optimum designs that are above and beyond the functional requirements and constraints called for by the market. Based on reflection upon this, since the 1990s, there have been numerous demands to declare that customized designs should not be relied on, and more parts that are standardized or interchangeable within a company should be used as long as they do not reduce the quality of design and product performance (Fujimoto & Takeishi 1994). In the increasingly intensive global competition that has overtaken since the beginning of the 21st century, the necessity for such product design simplification and streamlining is increasing.

However, such discussion and the discussion about "preparing for the next disaster by increasing the use of standardized parts" are deceptively similar. The basic logic behind this and the previously mentioned argument behind adding of inventories are the same. That is, in order for domestic companies and plants to survive global competition, the standardization and interchangeability of parts and materials as a part of design streamlining is a proper corporate activity.

However, the architecture of products that have market staying power will ultimately be determined by the market and society and not by companies or designers (Fujimoto 2009). Therefore, deciding to use standardized parts solely for the reason of "preparing for a disaster" is a deviation from creating a product architecture that meets the customers' functional requirements and social and technological constraints and will result in reduction in design quality and competitiveness. Making design changes for that reason is the same as removing industrial competitiveness right from under your own feet, and must be avoided at all costs.

4.4 Should supply chains be dualized?

This earthquake brought about many hardships such as destruction of buildings and equipment in the earthquake itself, washing away of entire factories by the tsunami, inaccessibility of factories because of the nuclear accident, and preparations for rolling and unplanned blackouts. These tribulations caused comprehensive, regional, and devastating supply chain disruptions and an increase in disruption risk. Because of this, the natural reaction has been to demand "maintaining duplicate equipment" (dual tooling) as well as "constructing copies of entire production lines in western Japan or overseas" and "increasing the number of suppliers of specialized products" (dual sourcing).

Regarding this, an awareness of the present condition of "global competition in an earthquake" is necessary. It is true that having multiple copies of substitutable equipment and production lines that contain the same design information is an extremely effective approach for improving supply chain robustness since if one suffers supply disruption, the other can immediately provide support.

Therefore, according to the previously mentioned analytical framework, implementing this type of "multiplicity of design information flows," especially where there is high dependency or low substitutability or portability of a product or process in the supply chain, is highly effective under certain conditions. Those conditions are that this can only be achieved by affecting cost, quality, lead time, and other aspects such that the industrial competitiveness of the plants is reduced.

In other words, dualizing (double tracking) the supply chain in order to prepare for the next disaster, thus aversely affecting costs and quality, is not an effective measure. To repeat, nobody knows when the next big disaster will strike, but global competition occurs everyday without fail.

For example, in response to a certain product's production line being a victim of the 2011 Tohoku Earthquake, the creation of another production line for the same product in west Japan or overseas seems economical and logical. However, it depends on certain conditions: for example, what if a production line that supplies automotive parts mainly domestically is damaged in a disaster? The product is for the domestic market and no growth is anticipated for its production or marketing. Therefore, increasing the productive capacity by dualizing the production line, equipment, and dies for manufacturing the product, particularly for a large, capital intensive line of minimum efficient scale, would immediately lead to a reduction in productivity and increase in fixed per-product costs. Cost competitiveness in emerging nations is intense; hence, this type of "dualizing supply chains without increasing production" regardless of how much this disaster experience tells us we should do so, is a certain way to reduce the competitiveness of domestic manufacturing plants. The above reasoning also applies to dualizing suppliers of foreign products.

However, under the following conditions, dualization of a domestic production line or supplier could be justified. First, if the worldwide demand for the concerned product is growing and the increase in production capacity created by dualizing production lines would be absorbed by that growth. Second, if production innovation makes it possible to considerably decrease the size of the production line's minimum efficient scale. Third, if the technology or proprietary nature of the concerned product is such that there is overwhelming non-price competitiveness and confidence that this competitiveness would not erode if the increase in fixed costs incurred by dualizing is added to the product price. Fourth and finally, in addition to the above, if for some reason, the concerned product is so necessary for society that, even after considering product inventory, there is an intensive responsibility to supply it. Therefore, it is necessary that same-day restoration of production capacity be possible in the event of a big disaster.

In any case, unless such conditions are present, if a production line is destroyed, transferring the critical design information to another product's existing production line—"virtual dualization"—should be considered as an alternative measure rather than actual dualization of the production line. "Virtual dualization" will be explained in detail later.

4.5 Should plants be transferred outside the area affected by the disaster?

Finally is the choice to transfer entire production lines affected by the 2011 Tohoku Earthquake to west Japan or abroad. Especially if the production facilities are located within the area made inaccessible because of the nuclear power plant accident, there is no other choice but to temporarily or permanently move the plant. Due to increased short- and mid-term blackout risks and energy use limitations in east Japan, there may also be companies that voluntarily suspend operations or construct additional power generation facilities, as well as consider moving their plants outside of east Japan. Such industries include processing industries that must be under continuous operation and the medical supplies industry.

However, regarding plant transfer, the assertion of this paper—"priority of competitiveness standards over disaster response measures"—can be applied as it is. That is, if a certain production line that was damaged was already being considered for transfer overseas in the interest of maintaining competitiveness over a long term, there is no problem in speeding up that process. In general, considering the intensiveness of global competition, the decision to move production facilities outside of Japan is not rare these days. From a macro perspective, when it comes to trade goods, there are always relatively superior and inferior goods. Hence, when an industry is judged to have lost its competitive edge, taking the leap and moving production overseas actually invigorates domestic plants and industries. There is in fact proof of such occurrences (Amano 2005). In any case, competitive strategies must take precedence when making such decisions.

In addition, as for moving within Japan is considered, if the plant that was damaged in the disaster used equipment that was already paid for and was being considered for rebuilding for reasons not involving the disaster, such as being technologically obsolete, then moving the plant to west Japan is a possible option.

However, the author would like to repeat that to abandon judgment on the basis of competitive strategies and to consider moving a plant outside the Tohoku region just because of an earthquake is, in most cases, motivated by temporary psychological influences, and is not logically acceptable in the long term. That is, a company must sensibly consider which possibility is more likely: another earthquake occurring in the disaster-struck Tohoku region or a "devastating damage" such as war damage, civil strife, or confiscation occurring in the foreign country to which the plant is moved. There are risks everywhere in the world.

Predominately for large manufacturers of trade goods, there are two ways of long-term thinking that must be combined when selecting domestic and foreign plant sites for global expansion: the "build where the goods are sold" logic of building in the market location and the "build where we are strong" logic of building where there is a competitive edge (Fujimoto, Amano & Shintaku 2007). What must also be taken into long-term consideration for determining competitive edge is "comparative advantage criterion" based on each country's wages and exchange rates, as well as “absolute advantage criterion” based on comparison of factors such as productivity and quality at domestic and foreign plants (e.g., Takemori 1995). This is necessary because global business is constantly affected by long-term changes in wages, productivity, exchange rates, and environmental and organizational learning. Domestic plants have “absolute advantage” since they surpass foreign plants in material productivity and manufacturing power but are comparatively inferior in terms of per-item production costs because of the current exchange rates and relative wages. However, in order to maintain total global optimization’s comparative superiority over a long term, keeping plants inside Japan is logical from a long-term total optimization perspective (Fujimoto & Shiozawa 2010). In fact, they should be maintained for various purposes such as to be a mother plant (that is a “fighting mother plant” that competes in the market itself) that supports the improvement of productivity at overseas plants, or a development plant that assists in creating easy-to-build designs or as a plant just for the domestic market whose main weapon is short lead time (Yamaguchi 2006).

These same things are true for the idea of moving to west Japan. If an existing production line in east Japan was aging before the disaster, since production conditions have grown worse in east Japan, there is nothing wrong with moving the line to west Japan when looked at from a competitiveness perspective. Though moving to west Japan just because of this big earthquake in east Japan may be understandable psychologically, it lacks logical persuasiveness. Japan is a land of earthquakes, so naturally, the next one could strike in either east or west Japan.

Before the earthquake, companies in the automotive industry such as Toyota had been moving automobile assembly plants to facilities in Tohoku (such as Toyota Motor Tohoku, Kanto Auto Works, and Central Motor). In general, for automobile plants in the Tohoku region, there are still problems with the supply chain such as a lack of prominent parts plants and decentralization of ports, but the area is attractive because of the superior tenacity of the labor. However, these advantages and disadvantages to manufacturing that were there before the quake will basically remain unchanged afterward.

In fact, whether moving overseas or to west Japan, if before the 2011 Tohoku Earthquake, there was no reason to prevent such a carefully considered decision to move, then there is every reason now to accelerate that move. However, if the only incentive for moving out of Tohoku is the big earthquake, it is based on a psychological reason rather than a rational one and is not considered an advantageous business move from a long-term perspective. The author believes that with regard to choosing where to place a plant after the earthquake, competitive considerations must take precedence over disaster prevention measures.

5 Improving robustness without sacrificing competitiveness

5.1 Disaster prevention measures based on the major premise of global competition

As stated previously, Japanese companies must reassess their present supply chains by aiming to improve the robustness of their supply chains considering what happened in the 2011 Tohoku Earthquake. In order to do this, they must first identify vulnerabilities by re-examining supply source dependence and visibility as well as design information substitutability and portability and then focus on making those points more robust. In addition, a free and unbiased decision must be made regarding the advisability of measures being considered in response to this earthquake on the basis of the conditions of each measure. These measures include (1) adding inventories, (2) switching to standardized parts, (3) supply chain dualization, and (4) moving plants outside of Tohoku and east Japan. The author believes that there are no unconditionally correct or incorrect measures.

However, at the very least, what should be considered for each of these measures is what was stated at the beginning—that they need to be examined with an awareness that this earthquake was "the first disaster to affect a large region in an advanced country that is competing globally." In other words, we must consider that changing a production system solely in response to the earthquake while sacrificing the ability to respond to the daily developments of global competition will result in deterioration of competitiveness and endanger the very existence of such companies and plants even before the next big disaster strikes. Although the impetus has been to create supply chain countermeasures in the event of an earthquake, post-earthquake supply chain construction should aim to maintain competitiveness while strengthening visibility and robustness.

In other words, even if a target period is set for recovery of a damaged supply chain or for finding a substitute supply in the event of a disaster that affects a large area and a consensus is achieved throughout the supply chain regarding this target, the main purpose of building a supply chain's capabilities is to maintain long-term international competitiveness and also to strengthen it. Many opinions after this earthquake have been so overwhelmed by the dreadfulness of this tremendous disaster that they have tended to close their eyes to the reality of global competition. However, the author believes that the perspective that we should hold is one that achieves a balanced pursuit of both supply chain robustness in response to a disaster and supply chain competitiveness that can survive global competition.

5.2 How should a target period for supply chain recovery be set?

Again, speaking from the perspective of open manufacturing management, when a supply chain is disrupted in a big disaster, the flow of design information to the customer must be maintained. The target recovery period depends on the severity of the damage and the necessity of the goods. However, considering the fact that for most consumer goods, there is enough in distribution inventories and household emergency stores to last for a short while, whether they are trade goods or not, after a large disaster, there will probably be no demand for same-day recovery of the production line.

As an example, a Toyota representative said at first that the number of suppliers in the Tohoku region that suffered damage due to this earthquake was over 100 (the total number of suppliers in Tohoku is several hundred), most of which were second-tier and lower suppliers. However, most of those recovered within two weeks, and in mid-May, two months later, all but a handful of companies had resumed production in some form or the other. Besides, except in the case of plants that operate 24 × 7, if the production stoppage was for two to three weeks, the annual production can be recovered with overtime and working on holidays for six months. Therefore, for the domestic automotive industry, the target period for supply chain recovery should be determined by comprehensively considering the necessity and ability of recovery and must be considered in detail for each industry type and product. In the case of the domestic automotive industry, one way of thinking is to set it at two to three weeks on the basis of an overall assessment. However, since this was not achieved after this disaster, this issue will be examined later.

In other words, in the event of a disaster that affects a large area, the goal of same-day or next-day supply chain recovery, in most cases, is highly unrealistic and is also not necessary. Hence, no matter how much inventories and production lines are maintained in multiplicity on the basis of the unreasonable idea of "same-day recovery of parts supply even in a big disaster," in the event of a real disaster, even if the supply of the concerned part is possible the same day, if the supply of other parts that form the customer's product has been disrupted, then the product ends up not being able to be produced. In short, when considering the entire supply chain, it is meaningless to set a goal of "same-day supply of our part only." Instead, what is more important is to set a more realistic goal of "work together to recover production of all necessary components for the product in two weeks" and gaining a consensus for this throughout the supply chain.

As mentioned above, since there is no need to set a goal of same-day recovery for a production line in the event of a large disaster, even in the case of this large-scale, regional disaster, there is no need to hastily decide to forcibly increase inventories or spend huge sums of money to dualize production lines and dies. First, considering that the present production lines are to be maintained, the "weak links" should be identified by taking the time to closely investigate whether all supply chains for all products can recover within, for example, two to three weeks.

Then, these "weak links" should be focused on, and with the aforementioned two- to three-week period as a goal, measures that will reinforce supply chain robustness without spending a lot of money and without increasing waste should be considered. Such measures would be those mentioned above: inventory augmentation, standardization of parts, dualization of production lines, production equipment and suppliers, and relocation of production centers. In addition to these is "supply chain virtual dualization," which will be discussed later. Each of these measures should be considered flexibly, taking into account individual conditions.

Of course, regardless of whether there was an earthquake, companies would engage in competitive advantage by improving production or the inventory system, adopting interchangeability or standardization of parts, or relocating production centers; however, such efforts should be implemented in advance. The author is merely asserting that these measures should not be implemented as a psychological overreaction to this earthquake.

In fact, for countermeasures in the event of a giant regional disaster, the two following policies should always be considered: (1) competitiveness of plants and products should not be reduced in the face of global competition and (2) aiming for supply chain robustness and visibility when establishing an overall supply chain recovery period of, for example, two to three weeks.

5.3 Improvement in supply chain visibility

First, in the case of this disaster in Toyota, it took an excessively long time to comprehend the extent of damage caused to second tier and lower suppliers in Tohoku (about one month). Considering this issue, supply chain visibility should be improved so that even in the case of a severe disaster as this one, a complete understanding of the situation across the entire supply chain, including all tiers of suppliers, should be achieved in two to three days, at least for the main products. If the affected suppliers cannot be identified, then no matter how superb Toyota's recovery assistance capabilities are, they cannot be implemented to the greatest effect.

Of course, there is no need in normal times for Toyota to have an understanding of equipment and production conditions throughout the supply line on a daily basis. In fact, this type of stratified management that Toyota employs is considered to be the source of their supply system's efficiency. Discarding this and taking up strict information control measures would not be beneficial. In addition, in terms of procurement contracts, it would be inappropriate for Toyota to ordinarily maintain inside information about second-tier and lower suppliers with whom they have no direct contractual agreement.

However, things are different in situations such as this where the supply chain was severed in a big disaster. Hence, for final product manufacturers who have the responsibility to supply goods to the market, in order to rapidly acquire an understanding of the extent of damage caused to a supply chain in the event of a big disaster, measures such as including a special clause in procurement contracts must be implemented to maintain supply chain visibility in a crisis.

5.4 Ensuring design information portability

As mentioned before, in the 2011 Tohoku Earthquake, the breakdown in the supply chains that had the greatest effect on several industries occurred at a microcontroller plant in Tochigi—Renesas Electronics' plant in Hitachinaka. Since a characteristic of the microcontroller manufacturing process (especially preprocessing) is the necessity for detailed precision work at a micron and smaller scale, hightech, expensive equipment are considerably used. We are, therefore, reminded of the extreme complexity and length of the processes utilizing this equipment.

Furthermore, because of the above, product-specific design information such as masks that contain circuit design information and recipes that hold process design information were actually “stuck” to the damaged facilities. We noticed that it was extremely difficult to transfer the design information to plants that escaped damage and adjust it to those plants. That is, the design information was not sufficiently portable.

Examining the past cases, there are examples where a substitute supply source is sent product-specific design information and generic machine tools (machining centers) and versatile workers (skilled machinists at machine plants) are utilized to rapidly establish a substitute production line after a disaster. One such example is the Aisin fire (Nishiguchi & Beaudet 1999), where the machining tools that held the design information were recovered from the ashes and sent along with blueprints of the parts and used at a substitute supplier. Similarly, in this big earthquake, there were many cases of design information (such as recipes) undergoing emergency transfer to another plant and the design information being adjusted to that production line (such as “recipe amalgamation”).

In general, for mechanical products, it is possible to relatively rapidly establish a substitute production line by moving equipment that contains the product design information such as dies, tools, and jigs from a damaged facility to a generic production line and going through the process of adjusting it to the substitute facility. That is, the portability of the design information is secured to a certain degree.

Compared to this, for processed products produced mostly by process industries, adjusting the recipe to each individual piece of equipment is difficult. It is particularly difficult for functional chemicals for which product functionality must be achieved with pinpoint accuracy (Fujimoto &

Kuwashima 2009). Even so, for the various chemical plants around Kashima Harbor and Fukushima Daiichi Nuclear Power Plant that were affected by this disaster, a substitute supply source was prepared by transferring the recipe to a different plant and then adjusting it to that plant's equipment (recipe amalgamation). For example, in the case of Kaneka's damaged Kashima production plant, which produced vinyl chloride for medical equipment, the recipe was transferred to the vinyl chloride facility at the company's Takasago Plant in west Japan, therefore allowing a substitute supply source to be opened in a relatively short period.

However, the process industry basically intensively employs hightech equipment for the production of onboard microcontrollers. Since the production of semiconductors utilizes ultra-minute processing, the design information is stuck to the equipment, eliminating its portability. In addition, as a general rule, production of electronic goods is process specific, therefore weakening substitutability. As a result of these characteristics, of all the parts of the supply chain that were damaged in this disaster, this industry was one "weak link" that affected other industries the most.

Ultimately, the recovery time for the plant in Hitachinaka, which was originally predicted to take from several months to a year, was considerably decreased to around three months (as of end of May, 2011). This is because of the restoration effort by the affected company itself, Renesas Electronics, as well as restoration assistance provided by users such as many domestic automakers like Toyota, and the top-speed construction of semiconductor manufacturing equipment provided by domestic companies.

In the meantime, substitute supply production lines were also established for nearly half the products by transferring the design information to other semiconductor plants and making adjustments to them (recipe amalgamation). That is, a certain degree of portability of microcontroller design information was achieved.

However, everything achieved by this "All Japan" effort still does not change the fact that the disruption of the microcontroller supply had overall the greatest impact. Of course, explanations such as the technical one of “microcontrollers require such types of processes” and “earthquake damage of such scale was never expected” are acceptable to a certain degree. Although when considering maintaining international competitiveness in the future, it will be necessary to work toward drastically increasing design information portability for advanced semiconductor processes such as those for microcontrollers by producing innovations for all types of products and processes. If this is not done, then it is quite possible that orders for microcontrollers from quake-prone Japan will sharply decrease.

On the other hand, in order to achieve differentiation in design quality for hightech products such as automatic control devices, product-specific circuit design is necessary, which therefore makes generic replacements for microcontrollers technically difficult as well as strategically undesirable. Consequently, the author believes that in order to correct the microcontroller “supply chain vulnerability,” rather than improving microcontroller substitutability, effort should be concentrated on improving its portability.

5.5 Supply chain “virtual dualization”

As shown above, if the portability of critical design information can be secured to a certain degree, then even without regularly maintaining dual production lines, equipment, or suppliers, the responsibility to provide supply can be fulfilled during a crisis, at least temporarily, if the design information undergoes “emergency evacuation” to another production line. Thus, a substitute supply of products utilizing the same design information can be rapidly achieved. This shall be called supply chain “virtual (in actuality) dualization.”

In general, if there is only one production line to meet worldwide demand for a certain product, then sustaining dual copies of production lines and equipment will produce extra fixed costs. If such additional costs are to be avoided in order to win against global competition, then “virtual dualization” of the supply chain is one possible effective disaster countermeasure. In order to maintain both competitiveness and robustness, while avoiding regular maintenance of actual dual “flows” at all costs, a cost-effective method would be able to rapidly start up a second production line in a crisis. In other words, the situation would be one where “there is actually only one production line, but in a crisis, it is the same as having two.” This is referred to as “virtual dualization.”

The substitute production line where the design information will be transferred to can be one’s own company’s plant, a related company’s plant, or a substitute supplier’s plant. In any case, if the target period for restarting supply after a massive disaster is two to three weeks, then all that is important is securing at least a temporary substitute design information flow. Later, after examining such points as the competition environment and the status of repayment regarding the equipment, a decision can be made as to whether to rebuild the damaged production line or turn the substitute line into the main production line, or even specially build an entirely new production line.

In general, if design information is dualized, the cost of regular maintenance of dual lines of design information decreases as the design information moves higher up in the supply chain. For example, in the case of a semiconductor manufacturing process, since the manufacturing of production equipment is expensive, regularly maintaining their dual lines would certainly not be beneficial, even from the perspective of maintaining operation rates. In this situation, if a backup of the mask that contains circuit design information used on the current line is made, then in a disaster where the ability to conduct semiconductor lithography is destroyed, the backup mask and recipe can immediately be brought to a predesignated substitute production line and adjustments can be started right away.

Even in this case, there may be differences between the destroyed line and the substituted one, such as the model of lithography equipment (the device that transcribes the design information) or the size of the wafer (the medium on which the design information is transcribed). In this instance, although the circuit design information that is to be transcribed onto the chip is the same, the design information regarding the wafer to be transcribed onto is not the same at the second production line. It is, therefore, necessary to conduct design board “disaster drills” at regular intervals, especially for critical processes that are highly vulnerable. An example of such a disaster drill would be having the disaster backup plants designate one another and prepare the necessary design information on the basis of those same processes being carried out at the substitute plant and then confirming whether it is possible to make adjustments to the equipment within the prescribed period.

Moving further up the design information flow, if the circuit design information necessary for creating the mask can be dualized, and not the mask itself, then it will lead to even further reductions in cost. In general, the further up the flow the production resources are, the cheaper it tends to be to duplicate the product design information. In other words, the cost is cheaper as you move up the flow, such that dualization of separate equipment costs less than the total production line dualization, mask dualization costs less than equipment dualization, and duplication of circuit design information costs less than mask dualization.

In addition, if a substitute flow is to be established by transferring design information from the present production line to a backup line in two to three weeks, for example, the lead time necessary for translating and transcribing the design information (the production and adjustments of the mask by going from circuit diagrams to process design) can be calculated. Using this calculation, a careful examination can be made in advance as to at what stage along the flow would dualization of design information be the most efficient. This at least should be performed for critical processes. There is, therefore, a tradeoff between the lead time necessary for translating and transcribing design information and the additional costs for maintaining dual production resources.

As another example, a certain large company had concentrated its plants in a specific region of east Japan that was struck by a big earthquake and aftershocks, so it considered a plan to build a new production line in west Japan. However, since the domestic market was already saturated and growth in emerging nations' markets could be absorbed by overseas plants, the new production line plan would not be effective. In this situation, by either establishing a relationship with another company's plant in west Japan that can maintain operation rates through an established demand or by purchasing a "west Japan plant with an established market," rapid mutual transfer of design information can be achieved between that plant and the company's current plant. In this way, virtual dualization of the supply chain can actually be achieved without reducing operation rates.

5.6 Backup production line designation, backup stipulations, and "disaster drills"

In order to ensure the practicality of the aforementioned "supply chain virtual dualization," it is necessary to implement some adjustments in procurement contracts and plant organizational routines.

For example, backup stipulations should be added in each procurement contract that supports a complex supply chain, especially for the parts and processes identified as critical in the aforementioned vulnerability analysis. Such stipulations include (1) predesignation of a "backup production line" to be used as a substitute in the event that the production line is damaged in a big disaster, (2) designation of processes for establishing the backup production line within a set time period (two to three weeks for example), and (3) requirement of periodic "design information disaster drills" to assure that actual establishment of the backup production line can be carried out. As a further stipulation, (4) in an emergency, the supplier must ascertain the state of the damage caused to the points that the company is in charge of upstream in the supply chain within a short period and then report that to downstream companies.

By applying the above adjustments to critical points in the supply chain, design information portability and visibility can be assured, enabling “supply chain virtual dualization,” which secures an alternative route for design information within a set time period. Depending on needs, by utilizing this measure in combination with traditional measures such as adding inventories, using standardized parts, actual dualization, and transfer of production centers, both competitiveness and robustness can be achieved for the entire supply chain. This is one possible solution asserted by this study.

6 Conclusion

This paper examined the conditions of the disruption of Japan’s supply chain caused by the 2011 Tohoku Earthquake as well as previous cases of supply disruption, especially with regard to the complex automotive industry and the effects it suffered. From this, we derived a simple analytical framework for assessing supply chain vulnerabilities by examining dependency, visibility, substitutability, and portability.

Next, regarding this supply chain problem, the measures that would strengthen the supply chain in the event of a big disaster were analyzed, and their advantages, disadvantages, and establishment conditions were examined. The measures that were examined were adding inventories, using standardized parts, dualization of production lines, equipment and suppliers, and transfer of production centers. However, most of these were determined to be countermeasures to be used to deal with today’s global competition.

The important point here is maintaining an awareness that this is “the first disaster to have affected a large region in a globally competing advanced country.” Although we do not know when or where the next big disaster will strike, businesses continue to face pressure from global competition.

The industrialists that manage supply chains have been so overwhelmed by the awfulness and complexity of the damage that a psychological response has taken precedence over a logical one. Therefore, the author believes that supply chains should not be altered to achieve robustness that is so biased toward disaster preparedness that competitiveness declines. What is most necessary is the establishment of both competitiveness and robustness.

In fact, since such a tremendous disaster over such a large area was not anticipated, Japan’s supply chains may have leaned too much toward being competitive. However, considering the strong yen and recession, which Japan’s trade goods industry has had to face recently while earnestly working to strengthen supply chain robustness in preparation for a disaster, domestic plant and product competitiveness would decrease. This would cause inferiority in the face of daily global competition and thus threaten to cause decline and disappearance even before the next big disaster struck. In short, pursuit of robustness without the perspective of strengthening competitiveness is not advantageous in the long term.

Therefore, this paper proposes a new approach, “supply chain virtual dualization,” which assures rapid recovery after a disaster strikes (for example, a goal of two to three weeks until total recovery) at a relatively low cost. Regularly maintaining excessive inventories or duplicating supply routes out of fear of supply disruption would be disadvantageous in terms of cost and lead time and therefore should not be implemented. If a particular product or part can be supplied well enough by a single production line, there is no need for forcibly creating a second one. Rather, by assuring the portability of design information through development of an approach for rapidly transferring critical design information to another production line and then preparing for and practicing it in normal times, the ability to reconstruct the production line can be improved.

In this way, each company can improve the reconstruction capabilities of their supply chains. It may even become unnecessary for a company that is earnestly working to strengthen robustness to select a measure that is competitively unreasonable, such as adding inventories, using standardized parts, maintaining dual supply routes, or transferring to a plant that is contrary to competitive strategies. Of course, when necessary, implementation of measures such as inventory system innovations, use of standardized or interchangeable parts, dualization of production lines or suppliers, or transferring of a plant overseas or to west Japan is unavoidable. However, the decision to execute such measures must be based on the reality of global competition. They should not be implemented solely as disaster countermeasures. The author believes that this is the measure we should take as precautions against a huge disaster in this era of global competition.

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