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Implications of the Tohoku Earthquake for Toyota's coordination mechanism: Supply chain disruption of automotive semiconductors

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Abstract
The 2011 Tohoku Earthquake damaged severely and extensively a large geographical area and caused devastating disruptions to the industrial supply chains in Japan. This paper focuses on a case of supply disruption of the automotive microcontroller units, which were produced by Renesas Electronics and supplied to Toyota via its first tier vendors like Denso. The first purpose of this paper is to describe, from a supply chain management view point, what happened and what actions these companies took, and to understand why it took three months for Toyota to recover to its pre-earthquake production level. Since many things happened, we apply a framework of SCM hierarchy to analyze the issues from the perspective of execution, design, strategy and sustainability. The second purpose is to identify based on this case analysis what functions are missing in the supply chain coordination mechanism of Toyota Production System, where the coordination is propagating from Toyota to upstream suppliers through the close interaction between the successive layers of its multi-layered supplier network. This case analysis implies that direct control functions need to be added to alleviate the disruption risk and secure the supply of key parts and materials. The third purpose of this paper is to show by presenting a detailed case analysis that the underlying characteristics of supply chain structure and infrastructure should be linked with the resilience tactics adopted.

Keywords: Supply chain management, Disruption risk management, Automotive electronics, Toyota Production System

1. Introduction

The 2011 off the Pacific Coast of Tohoku Earthquake occurred at 14:46 JST on March 11, 2011. The unique characteristics of this earthquake were the strong ground motion over the large areas and its severe Tsunami damage along the 670 km Tohoku Pacific Coastline. The magnitude of earthquake was 9.0 (Mw), and the maximum peak ground acceleration measured was 2,933 gal, which is equal to 2.99 times gravity. The earthquake may have ruptured the fault zone with a length of 500 km and a width of 200 km. The peak ground acceleration of greater than 1,305 gal was measured over 10 sites covering the prefectures of Miyagi, Ibaragi, Tochigi and Fukushima (NIED, 2011).

This earthquake caused the severe damages in large-scale inland and coastal areas, which cover one half of Tohoku region and the north and east Kanto region. The transportation networks of roads, gas stations, railways, and ports were severed, and other lifelines were destroyed. Fifteen nuclear reactors in the regions were damaged, aggravated by the meltdown of Fukushima Daiichi. The residential areas and fishing industry in several coastal areas were wiped away by Tsunami.

In terms of industrial supply chains, the damages were also extensive and unprecedented. In the coastal area, petrochemical complexes were severely damaged, and specialty chemical such as hydrogen peroxide, which was used for semiconductor manufacturing, became short in supply. In in-land areas along Tohoku bullet-train line and highways, many high-tech component plants were damaged. The products affected were display components such as glass substrate, synthetic resins panel, LCD stepper, indium tin oxide target, anisotropic conductive film, nitrogen trifluoride gas, and resin treatment solvent; electronics components such as semiconductors in general, aluminum electrolytic capacitor, chemicals for capacitors, barium carbonate, copper foil; lithium-ion battery and hard disk drives (Nikkei Electronics, 13/6/2011).

Of the many disrupted supply chains, this paper focuses on the supply disruption of the automotive microcontroller units, which were manufactured by Renesas Electronics and supplied to Toyota via its primal vendors like Denso. This paper summarizes what happened and what actions were taken by these companies. This part is based on Matsuo (2012). Toyota Production System has been well-studied in the literature for its efficiency and effectiveness, taught in classroom, and practiced extensively in the manufacturing industries. Such a well-studied and famed production system did not function over three months because of the disruption. This paper investigates why it happened and discusses the implications for the supply chain coordination mechanism of Toyota Production System.

The purpose of this paper is three-fold. The first purpose is to archive this rare case of supply chain disruption with sufficient details. This is to provide an important reference point for further research on supply chain disruption management. The second purpose is to present a concrete recommendation on the modification of Toyota's supply chain coordination mechanism based on thorough analysis of the disruption case. The third purpose is to contribute to the literature on supply chain disruption management. We present an important case implying that a structural and infrastructural design such as the supply chain coordination mechanism has a large effect on how mitigation and contingency tactics can be effective on managing disruptions, and thus the linkage has to be thoroughly considered to enhance supply chain resilience without sacrificing its competitiveness.

We organize this paper as follows. In Section 2, we review the literature on the supply chain disruption management with the purpose of positioning the objectives and contributions of this paper. In Section 3, we contrast two types of supply chain structure and infrastructure. This is to show that the supply chain structure and infrastructure affect the measures for enhancing resilience. We introduce a framework to describe the supply chain coordination mechanism of Toyota Production System. This framework is intended to be neither new nor comprehensive. But it is stylized to pinpoint why the coordination mechanism of Toyota Production System led to failure in this disruption case, and to discuss what modification is necessary. In Section 4, we describe the case of supply chain disruption of automotive microcontroller units. In Section 5, we list the lessons learned from this incidence and the issues that should be addressed. In Section 6, we discuss what additional coordination functions should be added to the coordination mechanism of Toyota Production System. Section 7 discusses the implications for the supply chain disruption management research. Section 8 concludes this paper.

2. Literature on supply chain disruption management and Toyota cases

2.1. Management of supply chain disruptions

Supply chain risk management has been studied extensively in the literature. The reader is referred to Brindley (2004), Sheffi (2005), Tang (2006), Tang & Musa (2011) and Sodhi & Tang (2012) both for holistic treatments of this subject and for comprehensive lists of the past literature. The further literature review and discussions on the sources of risk can be found in Rao & Glodsby (2009) and Thun & Hoenig (2011). Ponomarov & Holcomb (2009) provide a literature review integrating the ecological, psychological, economical and organizational perspectives on supply chain resilience.

Kleindorfer & Saad (2005) state that there are two broad categories of risk affecting supply chain: risks arising from the problems of coordinating supply and demand, and risks arising from disruptions to normal activities. In this paper, we address the latter category, disruption risks, particularly of a catastrophic event which has a low probability of occurrence and a high consequence (Knemeyer et al., 2009). Based on a catastrophic case of supply chain disruption, we investigate how to enhance supply chain resilience. As in Christopher & Peck (2004), our working definition of resilience is the ability of a system to return to its original state after being disturbed.

Kleindorfer & Saad (2005) identify three main tasks of disruption risk management: specifying the sources of risk and vulnerability, risk assessment, and risk mitigation. Tomlin (2006) categorizes tactics for managing disruption risks into three: financial mitigation, operational mitigation and operational contingency. Mitigation is exercised in advance of a disruption while operational contingencies are those in which a firm takes an action only in the event a disruption occurs. Sodhi & Tang (2012) summarize the supply chain risk management as a process of identifying, assessing, mitigating, and responding to risks. In this paper, we use the terminology of mitigation tactics to imply activities done in advance of a disruption and contingency tactics to imply activities done after and in response to the disruption.

As mitigation tactics, Sheffi & Rice (2005) point out that companies usually build in redundancy or build in flexibility. Building in redundancy entails adding inventory or adding capacity (Chopra & Sodhi, 2004), and building in flexibility entails adding suppliers (Sheffi & Rice, 2005) or ensuring multiple-sourcing (Tomlin, 2006). As contingency tactics, Tomilin (2006) uses the examples of rerouting supply flows and managing demand, and Sodhi & Tang (2012) emphasize the importance of quick detection time, design time and deployment time for response.

Since most research look at how various firms deal with disruptions and tries to extract the commonly effective measures, the underlying characteristics of supply chain structure and infrastructure is often failed to be linked with the disruption management tactics and its consequence. One of a few exceptions is Christopher & Peck (2004). They claim that enhancing resilience requires supply chain reengineering, supply chain collaboration, agility, and creating a supply chain risk management culture. Craighead et al. (2007) explore conceptually why one supply chain disruption is more severe than another, and the factors such as supply chain density, supply chain complexity, node criticality, recovery capability, and warning capability are identified as potential differentiators. Although the research direction is important, it is difficult to collect an enough number of meaningful incidents to substantiate the importance of such linkages because serious disruption incidences do not occur frequently. Rather in this paper, we present an extreme disruption case of an important automotive supply chain, which convincingly shows that the relationships between the nature of supply chain structure and infrastructure and the effects of resilience tactics must be considered to effectively manage disruption risks.

2.2. Literature on disruption cases of Toyota Production System

It is well known that Toyota's operations are characterized by just-in-time inventory management and a long-term supplier relationship among others. As discussed in the literature of disruption risk mitigation, redundant inventory and multiple or even redundant suppliers are recommended. Sheffi & Rice (2005) caution, however, that digressing from just-in-time to just-in-case inventory management is proven to be detrimental to product quality and to lean operations in general.

To contrast contingency tactics with mitigation tactics, the case of a fire at Aisin Seiki's Kariya First plant in 1997 is insightful. Aisin Seiki is one of the first tier suppliers of Toyota. The plant produced 80 to 90% of several brake component parts for Toyota. As a consequence of the disruption, 22 of Toyota's 30 assembly lines were suspended for three days and normal operations were resumed in six days with some reduction of production volume (Fujimoto, 2011). In a sense, the severe consequence of disruption was caused by just-in-time and single-sourcing nature of operations. That is, in this case, usual mitigation tactics such as adding inventory and having multiple sourcing discussed above had not been taken by Toyota. However, although the line was severely damaged, the production of particular component parts was quickly and effectively substituted by other suppliers of Toyota (Nishiguchi & Beaudet, 1998). This quick recovery capability can be attributed to Toyota' long-term and collaborative supplier network. After everything is normalized, Toyota decided to stay with a single supplier for this case since the cost of having multiple suppliers for the parts in question was deemed too high to be competitive and, as a Toyota official commented, "We relearned that our system works" (Sheffi & Rice, 2005). That is, Toyota confirmed that contingency tactics are superior to mitigation tactics in this sort of case because Toyota's collaborative supplier network has a capability to quickly recover from disruptions.

A similar disruption event occurred in 2007. Riken's Kashiwasaki Plant in Niigata prefecture was hit by the Chuetsu-Oki Earthquake. Riken Corp. was a first-tier supplier of automobile engine components with its 50 to 60 per cent domestic market share of the highly specialized and customized piston rings (Wiegel, 2010). This disruption causes the suspension of operations of all Toyota plants for three days (Fujimoto, 2011). In this case, too, Toyota's collaborative supplier network worked well for recovering from the disruption. Wiegel (2010) concludes that the Japanese automotive supply chain is capable of responding to and recovering from disruptions; it, however, lacks the event readiness. Again, Toyota confirmed in this incidence the superiority of contingency tactics over mitigation tactics.

Considering the case of 2011 Tohoku Earthquake along with other disruption cases, Fujimoto (2011) argues that adding inventories, adopting standardized parts, duplicating equipment and tools are appropriate only when it sustains supply chain competitiveness. Rather, he proposes supply chain virtual dualization by enhancing portability of design information. That is, his recommendation is to enhance contingency capability through design portability rather than to enhance mitigation capability.

Kleindorfer & Saad (2005) propose ten principles, derived from the industrial risk management and supply chain literatures. Relevant principles of the ten are those of avoiding extra leanness, adding redundancy, and modularizing process and product design. These principles are well-accepted measures for enhancing resilience in the literature. Our point is that they may not be appropriate within the context of Toyota or Japanese automobile supply chains because of the difference in supply chain structure and infrastructure. An added point to explore in this paper is that the analysis of this Tohoku Earthquake disruption case implies the necessity of modifying Toyota's supply chain coordination mechanism.

3. The supply chain coordination mechanism of Toyota Production System

In this section, we introduce two models of supply chain structure and infrastructure. We construct them by summarizing the relevant elements from the existing literature. One is a stylized version of the supply chain coordination mechanism of Toyota Production System. The other is a de facto counterpart, which might correspond to a stereotypical supply chain coordination model. These models are to pinpoint why the coordination mechanism of Toyota Production System failed in the Tohoku Earthquake case, and to discuss what modification is necessary.

Fujimoto (1999) states that an assembly product such as an automobile can be decomposed into subassembly modules, components, and piece parts, and the entire production processes can be partitioned into an assembly firm, first-tier suppliers, second-tier suppliers and so on. Takeishi & Fujimoto (2001) contend that the hierarchies in product, production, and inter-firm systems make up one complex system where the three systems are related to each other.

Ulrich (1995) introduces the basic concepts of product architecture and compares integral architecture with modular architecture in terms of their implications for product change, product variety, product performance and component standardization. The design of an automobile is categorized as integral architecture. However, various types of modularization are incorporated in the automobile industry with respect to product architecture, production and supply chain (Takeishi & Fujimoto, 2001). Takeishi & Fujimoto (2001) point out that European and U.S. automobile assemblers tend to use large subassemblies and outsource the production of such subassemblies. On the other hand, Japanese counterparts apply integral architecture to greater extent, limiting the use of such large subassemblies. van Hoek & Weken (1998) discuss the impact of modularity particularly on supply chain management. Fixson (2005) provides a comprehensive review of the literature discussing the effects of product architecture on product, process and supply chain.

Figure 1 represents the coordination mechanism of Toyota Production System. Takeishi & Fujimoto (2001) point out that Japanese automakers have traditionally built highly integrated assembly lines, as epitomized by the famous Toyota's lines, for maximum efficiency. The assembler and its vendors of customized components collaborate from the product's design stage on, and this closed and close supplier relationship is attributed to the high quality of product and the competitive cost due to the removal of wasteful general specifications. The use of customized components also provides an opportunity for the suppliers to improve both the component design and its production processes. The closed network also facilitates the collaborative efforts of its members to substitute the production capability affected by disruptive incidents as well as to restore the affected factory by itself. This is a risk management feature of the coordination mechanism.

To coordinate the entire supply chain, Toyota structures its supplier network in a pyramidal shape of multiple layers with Toyota on its pinnacle. Toyota interacts directly and closely with the first-layer suppliers, and they supply key sub-assembled components to Toyota. Since such key components are customized, only a few pre-selected vendors are in its first layer for each subassembly. Making multiple vendors competing for a higher share of assembler's orders is interpreted from a perspective of the game theory as an incentive mechanism for improvement activities (McMillan, 1992). Such closed and close relationships can make the just-in-time inventory management feasible, which requires tight coordination between the concerned buyer and seller. Although the membership of qualified suppliers is closed, Toyota in principle avoids single sourcing. This is to alleviate the high risk of supply disruption associated with single sourcing as well as to maintain improvement incentives.

The multi-layered structure makes such a coordination mechanism between the first-layer suppliers and Toyota to cascade through the entire supply chain network. Such coordination mechanism of Toyota Production System leads to high performance in quality, cost and delivery (QCD), and it also includes features of supply chain disruption risk management.

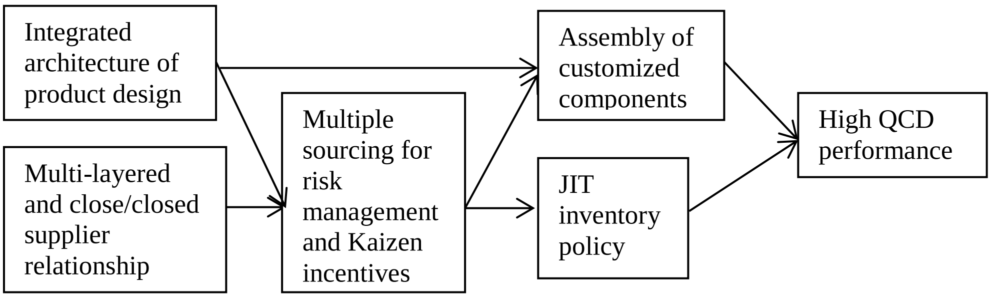

Figure 1 - Coordination mechanism of Toyota Production System

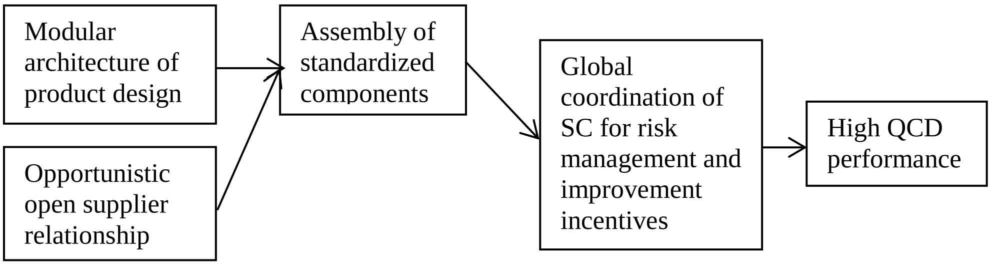

Figure 2 - Coordination mechanism of a modularized manufacturing system

Figure 2 represents a manufacturing system of a product based on modular architecture, which is derived to highlight the elements contrasting with those in Figure 1. Ulrich & Eppinger (2000) summarize the advantages of modular architecture based on the component standardization. The advantages are the ease of component production out-sourcing and the low components costs associated with the economy of scale in production. In addition, it is simpler and faster to reuse standard components in product development, and it is cost efficient to provide spare parts in an extended period.

Since the assembler of a product with modular architecture uses standard components, the participation of component vendors in the race of winning an order from the assembler is open for a relatively large qualified vendor pool. This enables the assembler to select the vendors that meet the requirements for quality and delivery due dates with the minimum cost. This gives in turn a proper incentive for improvement to the qualified vendors. In terms of risk management, a new supplier can easily substitute for the disrupted one. With such an opportunistic coordinating mechanism of supply chain, the modularized system can achieve high performance in QCD.

Note that the logic leading to high QCD performance of the two models depicted in Figures 1 and 2 is different. Toyota Production System is developed based on the premise that its coordination mechanism in Figure 1 is superior to that of the modularized manufacturing system in Figure 2, particularly in its incentive mechanism to improve production capability over time.

4. Severance of the automotive microcontroller supply chain of Toyota

4.1. The data and information sources used in this research

The case description in this paper is based on the relevant information that has appeared extensively in public sources. For instance, the Nikkei Telecom 21 database, which includes all the articles appeared in Nikkei's four newspapers, lists 1732 articles with a word "supply chain" included during one year period after the earthquake as compared with 180 during one year before the earthquake. Of the 1732 articles, 584 also include the word "severed."

The author served as an advisor of Renesas Technology, which was merged with NEC Electronics in April 2010 to form Renesas Electronics, and also as an advisor of its premerger company of the semiconductor group of Hitachi, together from April 2000 to March 2010. Therefore, the author has the basic knowledge on the semiconductor manufacturing and its supply chain concerned. In addition, the author conducted an interview with an Executive Director and a Corporate Communication Director of Renesas Electronics on July 6, 2011 and obtained its press releases (Renesas, 2011a, b) to cross-check the relevant information.

4.2. What happened to Toyota?

Table 1 lists chronologically the events related to Toyota after the earthquake. For two weeks after the earthquake, the entire Toyota plants in Japan stopped completely. Thereafter, Toyota resumed its production of popular hybrid cars. Most of Toyota assembly plants in Japan locate in Nagoya and Kyushu regions, and were not damaged by the earthquake.

Table 1 - Time series of events related to Toyota after the earthquake

3/11	Earthquake
3/14-26	Closed all the domestic plants
3/15	Reduced production at foreign plants
3/28	Resumed production of 3 hybrids at Tsutsumi plant and Fukuoka plant
4/11	Resumed production at Sagamihara plant
4/18	Resumed production at all 17 domestic plants at 50% utilization rate, and would increase production in July. Would keep 40% utilization rate overseas, and increase it in August.
4/22	Announced that it would normalize production in Nov-Dec.
5/11	Announced that it would recover to the pre-earthquake production level in June both domestically and overseas.
6/6	Resumed two-shift operations at domestic plants
6/11	Announced that the worldwide annual sales by 3/2012 would be 7.39 million.

(Source: The author created based on the articles appeared in Nikkei from 11/3/2011-30/6/2011)

The problems were lack of parts, or not even knowing which parts would be missing when it resumed production. It is reported that it took a week for Toyota to list 500 parts sourced from 200 locations which would be difficult to secure and recover to the normal production level. Although it grasped the availability of parts up to the second tier suppliers, Toyota did not keep track of the suppliers of third tiers or further down in general. Not only Toyota, but also most of Japanese major assembling companies during the first week or two after the earthquake worked frantically to list missing parts in their entire supply chains. This is a period when one-of-a-kind-product companies like Fujikura Rubber, Ltd., which had 1,333 employees in 2010 and produced rubber parts that were used in some of Toyota's cars, became well-known to the public (Nikkei, 6/4/2011). The number of missing parts remained at 150 items in April 2011 and at 30 items in May 2011 (Nikkei, 20/5/2011).

After gaining a reasonable prospect for securing sufficient supply of parts, Toyota announced on May 11, 2011 that it would recover to the pre-earthquake production level in June both domestically and overseas, and announced on June 11, 2011 that its worldwide annual sales by March 2012 would be 7.39 million (which is 1% increase in annual sales). Table 2 shows the percentage changes of cars produced domestically in Japan from the previous year for representative automobile producers in Japan. It shows clearly that Toyota took at least three months to recover from the earthquake disruptions and Nissan two months. Honda took four months to reasonably recover the production level, but again was disrupted by the major flood occurred in Thailand from October to November 2011.

Table 2 - The percentage changes of cars produced domestically from the previous year

Year 2011	Toyota	Nissan	Mazuda	Honda	Daihatsu	Mitsu-bishi	Hino	Japan Total
March	-62.7%	-52.4%	-53.6%	-62.9%	-57.3%	-25.7%	-47.3%	-57.3%
April	-78.4%	-48.7%	-49.7%	-81.0%	-62.6%	-31.7%	-34.7%	-60.1%
May	-54.4%	0.8%	-11.8%	-53.4%	-14.8%	7.7%	-6.9%	-30.9%
June	-15.9%	1.9%	-2.3%	-50.6%	-2.2%	8.1%	24.9%	-13.9%
July	-12.5%	15.3%	-5.0%	-18.5%	-4.9%	-20.1%	22.1%	-8.9%
August	11.9%	-2.5%	5.6%	-17.2%	9.1%	-19.2%	37.1%	1.8%
September	1.2%	-6.7%	-3.0%	-21.2%	-10.2%	-18.7%	21.4%	-4.5%
October	33.5%	32.9%	-0.8%	18.3%	18.8%	-17.9%	47.3%	20.3%
November	5.1%	25.1%	1.6%	-37.8%	22.2%	-11.9%	37.7%	4.5%
December	16.7%	24.6%	-8.1%	10.8%	35.9%	-2.4%	27.7%	13.4%

(Source: The author created based on the data compiled by Japan Automobile Manufacturers Association, Inc.)

Fujimoto (2011) pointed out three weak links in Toyota's supply chain, which became apparent immediately after this earthquake. They are: semiconductor integrated circuits such as microcontroller units and ASICs, functional chemicals such as rubber for tires and brakes and condenser electrolytes, and microscopic parts and consumables such as screw, spring and expendable for processing. In this paper, we explore the issue associated with the shortage of microcontroller units.

4.3. What happened to automotive semiconductors?

4.3.1. Automotive microcontroller unit and its supply chain

Automotive electronics now accounts for 15% of the total cost for a regular car and 47% for a hybrid car, and consists of the systems for controlling power train, body and safety as well as various multi-media functions (METI, 2010). Microcontroller units (MCUs) are the core of such automotive electronic control mechanism, and each MCU consists of CPU, memory and peripheral functional units. About 50 MCUs or more are used in one car for various functions. They are Application Specific Standard Products (ASSPs), which are in catalogues for off-the-shelf sales. Such MCUs are programmable by embedded software, and require user specific programming. The number of lines in embedded software coding per car now is about 5 to 10 million (METI, 2010).

Toyota purchases the automotive electronic control systems from its first tier suppliers. For instance, Toyota procures fuel injection control systems from Denso and other Toyota Keiretsu suppliers. These companies develop embedded software coding for the MCUs purchased from semiconductor companies. Several tiers of suppliers may exist in between the first tier suppliers and the semiconductor companies in Japan.

In 1992, Toyota depended on Denso in this category by 74.0%, but it reduced its dependency to 43.6% in 2007 (Tokuda, 2008). However, after the earthquake, it turned out that all the first tier suppliers purchased the same MCUs from a single semiconductor company, Renesas Electronics, and to make the matter worse, from a single factory of Naka plant, which was severely damaged by the earthquake.

Honda also was in the same situation. Honda bought electronics systems from its first tier suppliers of Denso, Kehin, and Hitachi Automotive Systems, and these three suppliers procured the same MCUs from the Naka plant (Nikkei Sangyo Newspaper, 21/7/2011). That is, although an assembler purchases from multiple sources to alleviate the disruption risk, these first-tier sources end up with sharing a single source in their upstream supply chains. This cinched nature of supply chain may explain the difference of recovery time of 2 months for Nissan vs. 3 months for Toyota and 4 months for Honda as shown in Table 2.

4.3.2. What happened to Renesas Electronics?

Renesas Electronics was formed in April 2010 by the merger between Renesas Technology (then the 9th in the world-wide semiconductor sales) and NEC Electronics (then the 14th in the world-wide semiconductor sales), where Renesas Technology was formed in 2003 by the merger between the semiconductor divisions of Hitachi and Mitsubishi Electric. Initially, Renesas Electronics was owned 34% by NEC Corporation, 31% Hitachi, 20% Mitsubishi, and 1.5% Japan Trustee Service Bank, and 14% was traded in Tokyo Stock Exchange. In 2010, its world-wide share of semiconductor was 3.9%, that of MCU was 27.3%, and that of automotive MCU was 44.0% (See Table 3). All the companies listed in Table 3 are the integrated device manufacturers (IDMs), which both design and manufacture semiconductor products. In contrast, the manufactures that do only design products are called fabless while those that do not design but manufacture are called foundries. Note that the foundries do not produce automobile MCUs.

Table 3 - World-wide share of automobile MCUs

44%	Renesas Electronics (Naka Plant: 20%)
22%	Freescale
9%	Infineon Technologies
7%	Texas Instruments
6%	Fujitsu Semiconductor
3%	ST Microelectronics
3%	Microchip Technology
2%	Toshiba
4%	Others

(Source: HIS iSuppli)

Renesas Electronics had 12 back-end sites and 10 front-end sites in Japan. Figure 3 shows the front-end sites, and five shaded sites were damaged by the earthquake. Kofu, Takasaki, Naka, and Tsugaru sites are former Hitachi plants. Saijo and Kochi sites are former Mitsubishi Electric plants. Kumamoto, Shiga, Tsuruoka, and Ube sites are former NEC Electronics plants. All the fabs have been set up differently in terms of wafer size (125, 150, 200 and 300 mm), basic process (CMOS, BiCMOS, Bipolar, and

GaAs), minimum geometry (800~40 nm), and product (IC Insights, 2012). Particularly, the fabs with different company origins have developed and accumulated over time different production know-how and process technology, and thus it is not trivial to produce a product even with the same wafer size, basic technology, and line width, which is produced in a different fab with the different original company.

Tsuruoka and Tsugaru plants accounted for 20% of the entire capacity of Renesas Electronics at the time of earthquake, and resumed its production in the end of March 2011. Kofu and Takasaki plants accounted for 15% of the capacity, and resumed its production in early April 2011. The most severely damaged was the Naka plant, which accounted for 15% of the entire capacity. The Naka plant consists of two fabs: N2 Building for 200 mm wafer and 90~130 nm geometry, and N3 Building for 300 mm wafer and 40 nm up geometry. N2 Building produces automotive MCUs, and its world-wide share was 20% at the time of earthquake. N3 Building produces SOC chips for mobile phones (Renesas, 2011a, b).

Figure 3 - Ten front-end sites of Renesas Electronics

N2 and N3 Buildings of Naka Plant were severely damaged by the earthquake. The infrastructure of fab was destroyed to the extent that the wall and ceiling collapsed and people could enter the supposed-to-be-dust-particle-free clean rooms with street shoes on. Hundreds of precision machines were completely or partially destroyed. Renesas (2011b) reports that Renesas Electronics expected as of March 21, 2011 to take six months to start mass production (i.e., on September 1, 2011), which means eight months to resume shipping the products considering two-month production lead-time.

A maximum of over 2,500 persons per day were sent to support the plant recovery by the other organizations in the industries of automotive, electronics, semiconductor equipment and construction among others. The efforts continued 24 hours a day, 7 days a week with an effective project management of paralleling multiple streams of tasks and expediting each task. With such a united work of many stakeholders concerned, the recovery time to starting mass production was shortened from six months to three months, which means that the fabs could resume partial production on June 1, 2011, and started to ship some amount from August 1, 2011.

In June 2011, Renesas Electronics sourced 10% of the pre-earthquake capacity of Naka plant from other Renesas factories and outside foundries and expected to recover to the pre-earthquake capacity at the end of September 2011 by combining the outputs of Naka plant and outside sources. Renesas expected that, by October 2011, 50% of pre-earthquake capacity would come from the second sources. The products produced in N2 building would be second sourced from Saijo factory and Tsugaru factory internally and from GlobalFoundries externally. The products of N3 Building would be second sourced internally from Saijo factory and Tsugaru factory, and externally from TSMC. (Renesas, 2011b)

4.3.3. Why were the automotive MCUs single-sourced?

It is difficult to imagine that anybody in Toyota did not recognize the effective single sourcing situation of the automotive MCUs although Renesas could be a fourth or fifth tier supplier of Toyota. Toyota relied on Denso or other automotive electronics systems vendors, but did not rely on them completely. This was because Toyota had recognized the automotive electronics vital and even internalized some of the production (Tokuda, 2008). At least, it is reasonable to assume that Denso recognized the risk of single sourcing of parts from Renesas. If Denso recognizes so, then why is this risk left unaddressed? There are conceivably two reasons.

Table 4 - QCD requirements for automotive semiconductors

			Automotive	Consumer
Quality	Environment	T_j Vibration Static electricity Humidity	-40~175(200)℃ 50 G 15~25 kV (ECU) 95%	0~125℃ 5 G 2 kV (HBM) 40~80%
	Field	Defects Durability	~1 ppm 20 years	~200 ppm 10 years
Cost			Low	Low
Delivery		Supply Sample	10 years ~ 3 years in advance	1.5~2 years 1 year in advance

(Source: "Recent conversion to electronics and part reliability in automobiles (in Japanese)," presented by Noriyuki Iwanori, Division of Device Development, Denso Corporation at the 15th OEG Seminar on 13/7/2010)

The first reason is that Toyota and Denso demand a very high quality level and potentially the minimum price from their vendors. For many automotive component and part suppliers at least in Japan, Toyota and Denso are the primal and leading customers. Table 4 shows the QCD requirements for automotive semiconductors as compared with those for consumer semiconductors, presented by the then Director of the Division of Device Development, Denso Corporation. An automobile is used on average over 10 years under severe environmental and operational conditions. The field failures of component are potentially fatal to the users of automotive, and might expose Toyota to costly product liability lawsuits. This should be contrasted with the field failures of mobile phones, for which the consumer may demand only money back or replacement.

The defect occurrence is required to be less than 1 ppm. Renesas' outgoing quality level can be less than 1 ppm for automotive MCUs, and Denso might be able to screen out the rare defective MCUs in their production and testing processes to achieve virtually zero outgoing defects from Denso. Before the merger of April 2010, NEC Electronics and Renesas Technology were likely the rare companies that could satisfy such high quality requirements.

The second reason for the single sourcing is a non-transferable nature of embedded software encoded in the automotive MCUs. There have been efforts for standardizing embedded software and coding in the industries using MCUs (Tokuda, 2008). However, the company-specific coding is necessary to the extent that a buyer of MCUs cannot expend the cost and efforts to develop two different software programs to replicate the same functions.

In relation to the embedded software, another problem is an analog nature of some MCUs functions. For instance, what control the MCU in a fuel injection system should make in response to a circumstance can be programmed in a discrete fashion. However, the speed of sensing the circumstance, determining a control signal, and converting it to a mechanical motion depends on the specific MCU and the total electronics system. Two MCUs made by two different companies can be programmed to replicate the same set of controls, but the respective response times can be significantly different. If the timing is different, very subtle and complex adjustments of the relevant parameter values are necessary to ensure safety and reliability in driving.

The buyers of automotive MCUs customarily certify the manufacturing process lines (Nikkei, 5/12/2011). This means that Renesas cannot easily change the equipment and recipe once the lines are certified. This line certification may be done to ensure the very high quality level and the same response time profile discussed above. However, it is pointed out that the line certification might have prolonged the recovery time after the earthquake (Yunokami, 2011).

4.3.4. Second sourcing practice

Considering the time and cost required for Denso to source two MCUs that play the same functions for an electronics system, Renesas should have prepared the second production site for the key MCUs which were made in Naka plant and were difficult to be substituted. IDMs like Renesas are sometimes required by its clients to secure the second source that produces the same semiconductor device. This is to ensure the resilience to disruptions as well as to increase flexibility in capacity in response to difficult-to-predict demand upsurge.

In 2009, IDMs sourced from foundries as follows: Renesas by 10 to 20%, Texas Instruments by 55%, Freescale Semiconductor by 23%, and STMicroelectronics by 20%. In 2009, foundries shipped to IDMs by 20% of its total sales for TSMC and 21% for UMC (IC Insights, 2011). That is, this second sourcing practices are common for IDMs. In fact, the author conducted a research project with a researcher of Renesas Technology on the IDM's second sourcing contract issues with foundries from 2008 to 2010. For some of the research outcomes, the reader is referred to Wu et al. (2011) and Wu et al. (2013).

4.4. What actions did Renesas plan to take afterwards?

It is reported that Renesas set the target of production recovery time at one month, instead of the actual three months, for the next possible earthquake with the same magnitude of intensity. Renesas plans to increase the resistance to earthquakes of the building infrastructure and equipment. (Nikkei, 13/3/2012). In the meantime, Renesas urged the customers to hold 3.5 to 4.5 months of semiconductor chip inventory (Nikkei, 5/12/2011). If the recovery time becomes one month, Renesas thinks that the ordinary amount of downstream inventory should ensure non-disruptive operations. Renesas also assures their customers that they will make efforts to secure the second source either internally or externally.

To achieve the cost necessary to implement these plans, Renesas needs to reduce the number of SKUs, which is now 100,000. This number is high as compared with 40,000 for the non-Japanese IDMs with the similar size like Texas Instruments (Nikkei, 10/3/2010). The product variety proliferates unusually because Renesas still keeps the product lines originating from the three original companies, and their automotive or consumer product clients demand often new semiconductor parts that are fine tuned for their new products. To justify the costs associated with the increasing amount of downstream inventory and the second sourcing, standardizing and streamlining product lines are necessary.

5. What did we learn and what issues should be addressed?

In this section, we analyze what we learned in the supply chain disruption case and what issues we should address. To do so, we use a framework of SCM hierarchy, which represents four layers of perspective. They are execution, design, strategy and sustainability. The reader is referred to Matsuo (2008, 2012) for the SCM hierarchy.

5.1. Execution Perspective

Immediately after the earthquake, many manufacturing companies in Japan realized that the availability of parts, materials and chemicals for processing was not sure for the time being, and it was difficult to obtain the necessary information. Many manufacturing companies realized after the earthquake that their supply chains included sole sourcing bottlenecks somewhere upstream. Some bottlenecks were well-known to companies like Renesas, but many damaged suppliers were not-so-well-known small-scale niche manufacturing companies with advanced technological know-how and a high market share.

Because of the multi-layered structure of supplier network in Japan, the assemblers were not sure of when the damaged factories would be able to resume its production. They did not have sufficient information to deal with the supply chain disruption occurred in a highly upstream entity of supply chain. Is the concerned part substitutable by another part, or can the production of the part be done in another factories? How much part inventory is available upstream and how much final product inventory is available downstream?

This lack of information on hidden key upstream suppliers was more or less faced by many manufacturing companies in Japan. From an execution perspective, a manufacturing company should have a database on the supply sources in its entire upstream supply chain. By this, we mean the information on the suppliers of not only the first tier but also of the tiers further upstream.

5.2. Design Perspective

As described in Section 4.4, Renesas at some point set the target of production recovery time at one month to deal with the same magnitude of earthquake. Let us assume that this one month recovery time means to take one month to resume production and take another two-month production lead-time to reach the pre-earthquake production level. If this recovery schedule is feasible and no second sourcing is used, how much inventory should Renesas' downstream supply chain should hold including Renesas' own final product inventory? For the simplicity of argument, assuming that Denso purchases directly from Renesas, how much inventory should each party of Toyota, Denso and Renesas hold as their assets to optimally share the disruption risk?

Renesas selected GlobalFoundries as its second source after the earthquake. The reason why GlobalFoundries was selected is that it had taken over an old fab of Hitachi, and some of Renesas’ engineers knew that it could be an alternative production site.

To produce the automotive MCUs that require extremely high quality, a substantial fixed cost of investment and process changes are necessary for the fab that currently manufactures other products. A modified fab can continue to produce the devices for non-automotive products, but the devices produced may be over-specification in terms of quality and require extra cost per chip. If the line cannot be used for non-automotive products competitively, then what kind of second sourcing contract should be used to share the return and risk under the normal time? What kind of provision should be added to deal with a large disruption in case it happens again? If the second sourcing option is added, how much inventory should each party of Toyota, Denso and Renesas hold?

To produce a new semiconductor device, it takes a fixed cost and time in process engineering and takes significant production ramp-up time to realize efficient mass-production (McIvor et al., 1997). Therefore, to make the second sourcing option economically viable, a certain level of production volume for each device is necessary to achieve the economy of scale. As discussed in Section 4.4, Renesas has a variety of 100,000 devices, and they need to standardize the products to achieve the scale large enough to justify the second sourcing option. How many products within one category of automotive MCU should they develop? To reduce the number of offerings without decreasing the total volume, the products with more general functions should be developed. Since they are not customized so much, unnecessary functions are included for general purposes. However, the total cost of such standardized products may be lower than customized products, considering the needs of second sourcing and high downstream inventory requirements.

5.3. Strategy Perspective

The automotive MCUs are produced by IDMs as in Table 3. The only company in the list that recorded positive profits for both 2009 and 2010 fiscal years is Texas Instruments, which was competitive in analog and mixed-signal products. Renesas lost US$2,869 million, US$1,483 million, and US$1,351 million in the fiscal years ending in March of 2009, 2010 and 2011, respectively (IC Insights, 2012). Renesas supplies critical and high quality MCUs to profitable Japanese automotive manufacturers. Renesas will not be able to survive with this poor fiscal performance, and Japanese automotive companies would be in trouble without the continual supply of high quality MCUs of Renesas. Then, what should be done here?

As far as the automotive semiconductors are concerned, Renesas is a vendor far upstream in the supply chain for Toyota and Denso. Renesas is located in the supply chain far from the final customer, and does not have any dominant platform that can make it possible to control the price of its downstream market. The company is on the verge of reorganization. What should Renesas, Denso and Toyota do to secure the flow of these high quality MCUs in ordinary time as well as in a disrupted period?

5.4. Sustainability Perspective

To produce high quality and durable automobiles with long lasting supply of spare parts is a sustainable business model. Extremely high performance required for semiconductors may be a foundation of such a model. Efficient consumption of energy and low contamination is also desired and will likely be required by the governments of many societies. Therefore, the more advancement of automotive electronics systems will likely be demanded.

As discussed in the execution perspective in Section 5.1, many manufacturing companies in Japan have created the comprehensive database of their entire supply chains. Therefore, they now know what materials and chemicals their both direct and indirect suppliers use. In the conventional Toyota's supply chain management, Toyota's suppliers have much discretion on what materials and chemicals they use and how they use them. This delegation of developing and improving the production procedures is part of the coordination mechanism discussed in Section 3.

Considering the societal needs for not using toxic or non-earth-friendly materials, Toyota might need to enforce certain rules for their suppliers' use of materials. Such standardization of materials and procedures are a direct and central control mechanism and may affect negatively the Kaizen activities of its vendors. An extensive database on sourcing can make it possible to monitor and control vendors' material use. How to balance the standardization of parts/materials with the delegation of improvement activities should be an issue to be addressed further.

6. Implications for the supply chain coordination mechanism of Toyota Production System

In this section, we discuss the implications of the disruption case described in Sections 4 for the supply chain coordination mechanism of Toyota Production System formalized in Section 3. The discussion is based on the lessons learned and issues raised in Section 5.

Are the automotive MCUs the unique parts that do not warrant further consideration within the framework of coordination mechanism of Toyota Production System? That is, is this just a special case to be put aside? As mentioned in Section 4.3.1, automotive electronics accounts for 15% of total cost for a regular car and 47% for a hybrid car. Therefore, the components with semiconductor devices have become increasingly important for automobile manufactures, and the coordination mechanism of Toyota Production System should cover the parts such as automobile MCUs as well as other automobile electronics parts.

As described in Section 4.3.1, the automotive MCUs are Application Specific Standard Products (ASSPs), which are in catalogues for off-the-shelf sales. In that sense, it is a standard product. However, it does not possess any characteristics of a standard product. That is, it cannot be produced easily in any fab other than a specific fab. Different automobile companies seem to be using different MCUs. In addition, the products are customized by sub-assemblers further as a form of extensive embedded-software programming. As discussed in Section 4.3.3, the high quality and durability requirements for the automobile MCUs restrict the number of qualified fabs to the minimum although the automotive MCUs do not have to be produced in a fab with the most recent technology generation. This is evidenced by the fact that the automotive MCUs at Naka plant are produced in Building N2, which utilizes the older technology than Building N3. Also, note that the automobile companies need the semiconductor products as spare parts for many years to come beyond the automobile’s average product life of over 10 years. This means that the producers of the automotive MCUs need to keep several technology generations of fab facilities operational.

As discussed in Section 3, Toyota’s supply chain coordination mechanism is founded on integral architecture. The use of customized components is critical in optimizing the overall product design, and also serves as an incentive to the vendors to continually improve the component designs and their production methods. However, in spite of such advantages, the potential weakness is in its risk management.

In the disruption cases such as Aisin Seiki’s Kariya First plant in 1997 and Riken’s Kashiwasaki Plant in 2007 mentioned in Section 2.2, the substitution of production was completed by other member suppliers of Toyota’s supplier network within a period of one week. In that sense, the coordination mechanism in Figure 1 worked well for disruption risk management purpose. In the case discussed in this paper, the devastated Naka plant was restored by a large group of the stakeholders broadly defined. Such concerted efforts reduced the recovery time of the plant from six months to three months. This was said to be a miraculous achievement under the worst circumstance and was made possible by the close/closed multi-layer supplier network. However, Renesas failed to secure alternative production sources in a timely fashion. If the automobile MCUs had possessed more characteristics of standard products, then the production substitution could have been easier and faster. The case clearly indicates that the coordination mechanism in Figure 1 can have both merits and demerits with respect to risk management against severe supply chain disruption.

Granted that the automotive MCUs are important parts and that they cannot be addressed well by the framework in Figure 1, we need to discuss how the coordination mechanism should be modified for managing the automotive MCUs. There are two focal points. One is the risk management against production disruption, and the other is to secure the supply of high quality and durable computer chips. Our proposed modification is the coordination mechanism described in Figure 4. The revised coordination mechanism of Toyota Production System is simply adding a box of direct control of key parts/materials in Figure 1. The intent is to indicate the necessity of direct control mechanism of key parts/materials in addition to the coordination mechanism cascading from Toyota through the layers of supply network.

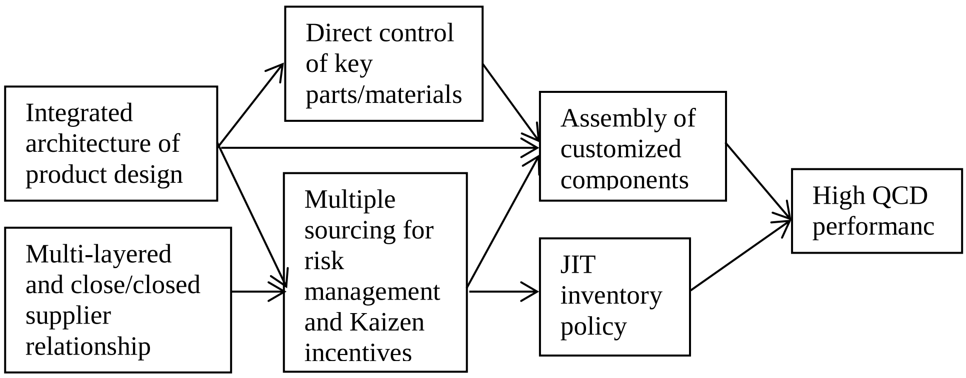

Figure 4 - Revised coordination mechanism of Toyota Production System

The direct coordination mechanism of key parts/materials in Figure 4 is the management control exercised by the final assembler to the entire supply chain and should address the following:

- **a)** Monitoring the information on all the suppliers of key parts/materials across the entire supply chain
- **b)** Managing the inventory of key parts/materials across the entire supply chain
- **c)** Ensuring the continuing supply of key parts/materials
- **d)** Increasing the standardization of key parts/materials and their production methods

The discussion in Section 5.1 indicates that (a) monitoring the information on all the suppliers across the entire supply chain in upstream and downstream is necessary to react to the severance of upstream supply chain. Toyota is reported to have developed by the summer of 2011 the database for keeping track of parts and materials for their purchasing components and to have the ability to estimate the effect of production disruption at any domestic factory. However, the database did not cover the suppliers in Thailand when the major and extensive flood occurred in Thailand from October to November in 2011 (Nikkei, 01/11/2011). As a result, Toyota again suffered from the potential shortage of around 100 parts, and could not produce worldwide as it originally had planned.

The function of (b) managing the inventory of key parts/materials across the entire supply chain can be realized with a central and direct control, instead of applying the existing cascading coordination. As discussed in Section 4.3.4 and Section 5.2, if Renesas could form horizontal capacity alliance with foundries well, then the continual supply of the key parts could be secured without the proposed modification of coordination mechanism. However, the idiosyncratic requirements for producing high quality devices and maintaining spare parts in an extended period make ad hoc alliance with foundries not sustainable. If a foundry can specialize in the manufacturing of automotive MCUs as the second source for other IDMs listed in Table 3, the economy of scale may be achieved. Then, the coordination mechanism in Figure 1 can be maintained without any change for addressing the risk management for severe disruptions.

If the horizontal alliance cannot be effectively formed by Renesas, then an optimal amount of inventory of automotive MCUs must be kept in the entities in the supply chain in between Renesas and Toyota as discussed in Section 5.2. Decentralized control of such supply chain inventory is difficult to realize. For instance, an incentive scheme to hold the optimal total channel inventory across Renesas, Denso and Toyota is difficult to develop. Hence, this should be a type of problem that Toyota should directly manage over the entire supply chain.

In 2012, Toyota faced the problem of (c) ensuring the continuing supply of key automotive MCUs even in a normal time because the financial situation of Renesas was extremely dire. Renesas Electronics announced on December 10, 2012 that it would issue shares through third-party allotment of 150 billion yen to The Innovation Network Corporation of Japan (INCJ) and eight manufacturers including Toyota, Nissan, and Denso (Nikkei, 11/12/2012). The ratios of new share holdings are INCJ (69.16%), Japan Trustee Service Bank (8.12%), Hitachi (7.66%), Mitsubishi Electric (6.27%), Toyota (2.50%), Nissan (1.50%), Denso (0.50%), Keihin (0.50%), and so on. Toyota needs to exercise more proactive and direct management control in order to secure the source of extremely high quality chips.

The central control function of (d) increasing the standardization of key parts/materials and their production methods does not fit well with the coordination mechanism in Figure 1. The standardization of parts may be against the tenet of the coordination mechanism in Figure 1. The efforts, delegated to the component vendors, to improve the component designs and production methods are regarded as vital for the high QCD performance. However, what this case analysis is leading to is that some standardization is necessary related to the electronics parts and some other key parts/materials. That is, Toyota needs to directly coordinate the entire supply chain to increase the commonality of key parts and materials as well as the standardization of part production methods.

In this section, we have argued for the incorporation of direct control into the coordination mechanism of Toyota's supply chain management, especially for key parts/materials such as MCUs. Note that directly managing inventory across the entire supply chain is not a customary procedure for Toyota as we have discussed so far. It must be done such a way as not to be conflicting with the conventional cascading coordination mechanism. For instance, just applying the central control to automotive MCUs may not be much in conflict with the current coordination mechanism. The implementation issue is how and how far the direct control of parts/materials should be exercised so that the merits of the coordination mechanism in Figure 1 are kept intact.

7. Implications for the supply chain disruption management research

As discussed in Section 2.1, Kleindorfer & Saad (2005) put forth ten principles, derived from the industrial risk management and supply chain literatures in general. The principles relevant in the context of this paper are avoiding extra leanness, adding redundancy, and modularizing process and product design. That is, the general disruption management research emphasizes the effectiveness of mitigation tactics, assuming the coordination mechanism depicted in Figure 2.

On the other hand, the disruption management research of Toyota Production System values its contingency capability for restoring to the normal production level after a disruption (Nishiguchi & Beaudet, 1998; Sheffi & Rice, 2005; Fujimoto, 2011). As discussed in the previous sections, this capability is based on its coordination mechanism depicted in Figure 1. It is important to be aware that the two streams of disruption management research assume different types of supply chain structure and infrastructure.

Should manufacturing companies use just-in-time inventory management system under some exposure to disruption risks? It depends on the supply chain structure and infrastructure. If the company's supply chain structure and infrastructure are as depicted in Figure 2, a usual course of measures discussed in the literature should be applied. That is, a sensible way of modularizing product and process, strategic redundancy of resources, and flexibility should be thought out to alleviate the negative effect of having redundancy under normal circumstances. With Toyota's collaborative recovery capability based on the coordinating mechanism depicted in Figure 1, the contingency capability has been recognized as sufficient for disruption risk management purposes, and sticking to just-in-time in ordinary time has been the choice superior to having just-in-case inventory (Nishiguchi & Beaudet, 1998; Sheffi & Rice, 2005; Fujimoto, 2011).

As discussed in Section 6, the 2011 Tohoku Earthquake is an important case to cast doubt on the extent of this contingency capability of Toyota Production System. The discussions in this paper have led to the incorporation of direct control mechanism of key parts/materials like automotive MCUs into Toyota's coordination mechanism as depicted in Figure 4. The contribution of this paper to the practice is the derivation of this implication.

The contribution of this paper to the literature on supply chain disruption management is as follows. In order to consider how to balance between resilience and competitiveness, we need to have a clear framework that represents the relevant supply chain structure and infrastructure, and evaluate both the positives and negatives of resilience tactics based on it. By going through the details of this case with respect to disruption phases, nature and dynamics of supply chain, and the product and process technologies, we sorted out the complex linkages between the resilient tactics and its potential outcomes. In so doing, we showed the importance of considering the linkages in supply chain disruption management. To demonstrate the importance of considering the linkages is a contribution of this paper to the general literature on supply chain disruption management. We point out that the linkages have not been addressed well in the existing literature as discussed in Section 2.

8. Conclusions and Discussions

The 2011 Tohoku Earthquake was a disaster affecting the lives of many people in a large geographical region. The supply chains severed were numerous and affected in many dimensions for a long period of time. It is probably not feasible to satisfactorily hedge this magnitude and extent of calamity. Therefore, in this paper, we tried to learn what this incidence revealed, with a wish of identifying what we can do to better cope with it. We investigated a case of the automotive MCU supply chain linking Renesas Electronics with Denso and Toyota. Toyota Production System is famed for its efficiency and effectiveness and has been well-studied in the literature. We focused on its coordination mechanism of supply chain and tried to understand why Toyota's production was significantly affected for a long period of three months due to the earthquake disruption.

Based on the argument that integral architecture and customized components are the tenet of Toyota Production System, we summarized the standard interpretation of Toyota's coordination mechanism of supply chain. The coordination is between the successive layers of its supply network. It achieves the high QCD performance through its cascading control mechanism.

The case analysis in this paper leads to the necessity of direct control mechanism for key parts and materials across the entire supply chain. The required functions are monitoring all the suppliers in the entire supply network, managing the total supply chain inventory, securing the sustainability of key part/material suppliers, and standardizing key parts/materials and production methods. These functions are not in the conventional framework of supply chain coordination mechanism of Toyota Production System. However, it has become increasingly important to incorporate direct control to execute these functions, at least for electronics components.

The detailed case analysis in this paper presents a reference point for further research on the supply chain disruption management. The single important incident discussed in this paper demonstrates that the supply chain structure and infrastructure should be tightly linked with the resilience tactics to be taken. Since such linkages are not addressed well in the literature, further research in this respect is necessary.

The research presented in this paper is relevant to the disruption management for supply chains that adopt the close/closed supplier relationships in the sectors other than the automobile manufacturing. The close/closed supplier relationships are often used in manufacturing of the products that require high quality and unique technology components such as machine tools, gas turbines and airplane engines. For the key components in these industries, a few qualified vendors exist and they work with their buyers from its design stage on. For such a situation, the results of this paper can be relevant.

In Section 3, the coordination mechanism of Toyota Production System is constructed by summarizing the relevant elements from the existing literature. As stated in Section 4, the case description in this paper is based on the information and data that has appeared in the publicly available sources, and has been cross-checked against the Renesas Electronics' press release documents. The development and arguments in this paper are not based on the interviews with personnel from either Renesas Electronics or Toyota. Therefore, they do not reflect the views of eithr of the companies on the issues. The results of the analysis in this paper have not been endorsed by the companies, and the author is solely responsible for them.

Since the information used in this paper is quoted and cross-checked carefully, the author believes that the case facts presented are reproducible and accurate. However, the information and data used are more from the view point of semiconductor manufacturing. Although the author claims that this side of view is increasingly important, the relative lack of Toyota's side of view is a limitation of this paper. Since this paper proposes the modification of Toyota's coordination mechanism, the incorporation of potential responses by Toyota's personnel responsible for disruption management would be of great complementary value. However, the author leaves such exploration as a further research topic. Since this paper touches on the essential logic of

Toyota Production System and strategic issues, the author expects that the responses from Toyota should be interpreted carefully and may elicit a diverse range of responses from a large organization such as Toyota. For instance, part standardization and direct control of key parts should also be considered in the context of cost competition and globalization. That is, the potential responses should be analyzed from a broader and diverse perspective beyond disruption management.

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